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Endovascular Treatment of Small Intracranial Aneurysms: Three Alternatives to Coil Occlusion

Abstract

Introduction: Small intracranial aneurysms with a fundus diameter of 2 – 3 mm may rupture and are therefore potential targets for an endovascular approach in treatment. Currently available coil technology is less than optimal for the treatment of aneurysms within this size range. Even the smallest coils are sometimes too large. If such a minute coil can be introduced into a small aneurysm, the hemodynamic effect and the induced thrombosis are frequently inadequate to occlude the aneurysm sufficiently from the parent artery circulation. **Methods:** Three technical alternatives for the endovascular treatment of small intracranial aneurysms not suitable for coil occlusion are illustrated with the following three case descriptions. **Results:** Stent grafts are usable for the intracranial internal carotid artery and for the V4 segment. The stiffness of the stent and the high expansion pressures are the two major drawbacks. Coaxial deployment of two or more self-expanding porous stents can result in sufficient redirection of the blood flow to induce aneurysmal thrombosis. Deployment of multiple stents, however, may require several treatment sessions in order to allow for the integration of the stents into the vessel wall from session to session. A regular microcatheter can block aneurysmal inflow in aneurysms with a very narrow neck. This allows the occlusion of the aneurysm with an appropriate amount of highly concentrated, rapidly polymerizing glue. Polymer emboli may result from excessive or rapid glue injection. **Conclusion:** The available coil technology has inherent limitations in the treatment of very small intracranial aneurysms. Liquid embolic agents and stent-based extrasacular treatment strategies may provide solutions for these challenging lesions.

Key words

Aneurysm · endovascular · embolization · coil · stent · stent graft · neuroform · histoacryl · NBCA

Introduction

The success of endovascular coil occlusion is currently limited in treating very small and giant aneurysms. Most difficulties observed in the treatment of giant aneurysms are related to recurrent aneurysm perfusion, due to coil compaction and/or coil migration into the intra-aneurysmal thrombus. Both issues are well addressed by meticulous follow-up examinations and eventual retreatments.

In aneurysms with a fundus diameter of 2 – 3 mm, the initial endovascular treatment may be more dangerous and less efficient than in midsize aneurysms. The currently available microcatheters and microguidewires allow for precise catheterization of small aneurysms and are therefore less of a risk factor. Existent coil technology, however, has not been adapted to the specific requirements of small aneurysms. With our experience, it is commonly found that even the smallest and softest available coils are sometimes too large and/or too stiff for this specific pur-

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Bibliography
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pose. If the attempt to introduce such a coil into an aneurysm is successful, the isolation of the aneurysm and subsequent thrombosis are frequently incomplete, and rupture or rerupture may result.

Based on an institutional experience of more than 2,700 intracranial aneurysms treated by coil occlusion, it is the purpose of this paper to present alternative endovascular treatment strategies. These alternatives might be contemplated in case of failure or anticipated difficulty of conventional coil occlusion.

Illustrative Cases

Case 1 (stent graft)

This 47-year-old male presented with severe headache and was diagnosed as having a subarachnoid hemorrhage on July 7, 2004. Cerebral angiography revealed an aneurysm of the left internal carotid artery at the origin of the superior hypophyseal artery with a diameter of both the fundus and neck of 2 mm. On July 10, 2004 an attempt at surgical clipping of this aneurysm was undertaken with an anterior pterional approach and failed because the aneurysm was not sufficiently visible and reachable. The patient was referred to us for endovascular treatment. On July 17, 2004 the procedure was carried out under general anesthesia. Injection of the left ICA via a 6F guiding catheter confirmed size and location of the aneurysm as previously known (Fig. **1a**). Under controlled heparinization, all possible efforts to catheterize the aneurysm with sufficient stability failed. We therefore decided to seal the aneurysm with a stent graft. For this purpose, a Choice PT extra support microguidewire (Boston Scientific) was introduced into the left middle cerebral artery through an Echelon_14 microcatheter (MTI). In order to prevent vasospasm during the insertion of the stent graft, 2 mg glycerol trinitrate were slowly injected into the ICA via the guiding catheter. A 3.5 mm/12 mm stent graft (Abbott) was introduced without difficulty until reaching the level of the aneurysm orifice. At this point of the procedure, 500 mg Aspisol (intravenously) and 300 mg Clopidogrel (gastric tube) were given. The stent graft was deployed by primary balloon inflation with 10 atm in the selected position. The stent graft was also found to be covering the origin of the ophthalmic artery. In order to both preserve the patency of the ophthalmic artery and to completely cover the aneurysm, the deflated balloon was slightly advanced more distally and reinflated in the distal half of the stent graft with 16 atm. Subsequent angiography confirmed the obliteration of the aneurysm with normal opacification of the ophthalmic artery present (Fig. **1b**). The procedure was tolerated well and the patient was discharged home 19 days later without any demonstrated neurological deficit. Follow-up angiography 6 months later confirmed the obliteration of the aneurysm. In the meantime, the ophthalmic artery had thrombosed. Ophthalmologic examination confirmed normal visual acuity of the left eye.

Case 2 (stent-in-stent)

This 28-year-old female experienced a subarachnoid hemorrhage on September 1, 2001. Angiography showed an aneurysm of the right ICA at the origin of the posterior communicating artery (Fig. **2a**). She underwent an operation for this aneurysm on September 5, 2001. Postoperative angiography, however, revealed an aneurysm remnant with a diameter of 2 mm adjacent to the applied clip (Fig. **2b**). Neither coil occlusion nor stent graft deployment was considered promising. The aneurysm appeared too small to accept a coil. The vasculature in this young lady was quite irritable and we feared a risk of severe vasospasm or dissection related to the attempt of introducing a stent graft. After routine premedication with a loading dose of 500 mg ASA and 300 mg Clopidogrel, the first endovascular procedure was carried out on July 9, 2004. Under controlled heparinization an X-celerator_10 guidewire was introduced into the right MCA. Via this wire a Neuroform2 Treo stent (3.5 mm/20 mm) was inserted and deployed over the residual aneurysm. The filling of the aneurysm appeared unchanged on immediate DSA (Fig. **2b**). Follow-up angiography on September 11, 2004 revealed a slightly reduced size of the aneurysm remnant. A second Neuroform2 Treo stent (4.5 mm/15mm) was deployed within the first stent on September 11, 2004. This second procedure was carried out in essentially the same way as the first treatment. Eight weeks after the first treatment session, the previously inserted stent appeared completely integrated into the vessel wall. The struts of this first stent did not interfere with the insertion of the microguidewire or the Neuroform2 stent catheter. Aneurysm filling was insignificantly reduced immediately after the second stent deployment (Fig. **2c**). Both procedures were tolerated well without neurological sequelae. The patient has been kept on 100 mg ASA orally since the last procedure, while the intake of Clopidogrel was discontinued in November 2004. Angiographic follow-up on December 8, 2004 showed the complete thrombosis of the aneurysm without any evidence of angiographically visible intimal hyperplasia within the stent (Fig. **2d**).

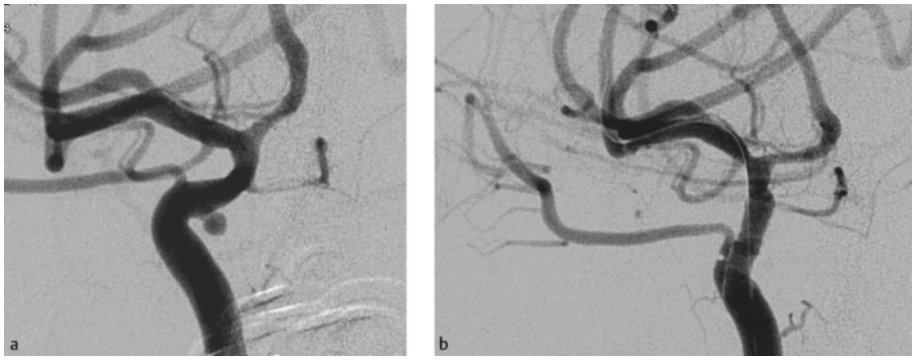

Fig. **1** Ruptured small aneurysm of the left ICA/superior hypophyseal artery (**a**). Attempts at surgery and coil occlusion both failed to occlude the aneurysm. Treatment was finally accomplished by deploying a stent graft into the left ICA, sealing the aneurysm neck and leaving the origin of the ophthalmic artery patent (**b**). A comparison of **a** and **b** reveals a significant straightening of the ICA and a displacement of the ACA and MCA, related to the stiffness of the implanted stent graft.

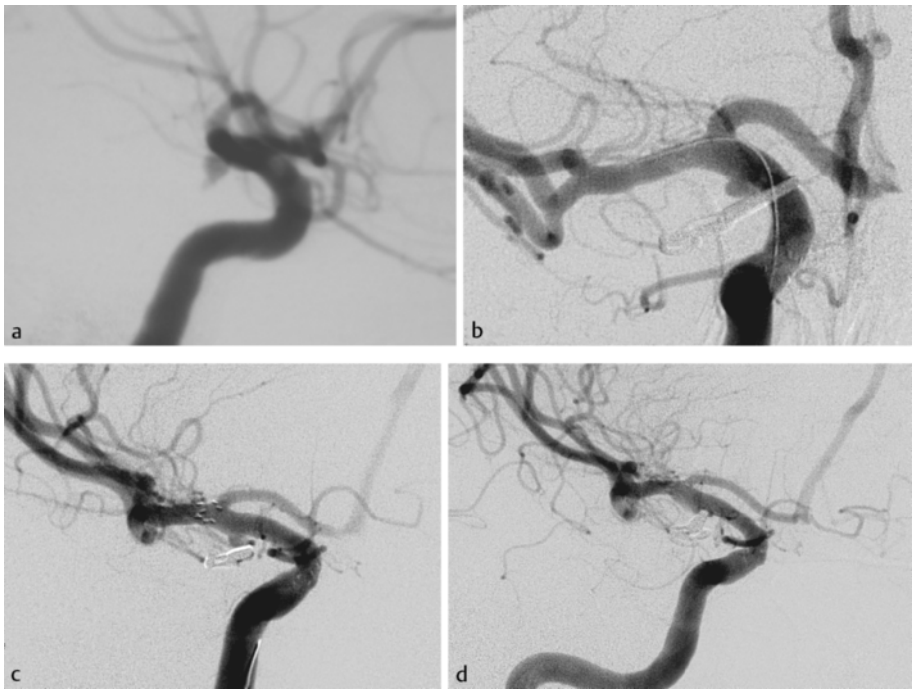

Fig. **2** Ruptured aneurysm of the right ICA at the origin of the posterior communicating artery, preoperative angiogram (**a**). Postoperative angiography showed an aneurysm remnant after partial clipping. Deployment of a first (**b**) and a second Neuroform stent (**c**) did not immediately change the filling of the aneurysm. Angiography 3 months after deployment of the second stent revealed complete thrombosis of the aneurysm (**d**).

Case 3 (intrasaccular polymer glue injection)

This 39-year-old female experienced a subarachnoid hemorrhage on April 22, 2003. Angiography revealed a large, ruptured aneurysm of the left ICA at the origin of the posterior communicating artery, a small left paraophthalmic aneurysm and an even smaller aneurysm of the left ICA at the origin of the superior hypophyseal artery. The large aneurysm was occluded with coils at another institution on April 23, 2003 and required retreatment due to coil packing on November 13, 2003. Further angiographic follow-up on June 8, 2004 showed a significant reperfusion. On July 21, 2004 a Neuroform2 stent (4.5 mm/20 mm) was deployed into the distal segment of the left ICA, followed by coil occlusion of the PcomA aneurysm on October 20, 2004. During this treatment session an attempt at catheterizing the paraophthalmic aneurysm had failed. After a completely frank discussion of all possible options for the untreated paraophthalmic aneurysm, the patient opted for another endovascular attempt. At this time, a heat-shaped Echelon_14 microcatheter was inserted without difficulty into the aneurysm using a SilverSpeed_14 guidewire. Stabilization of the microcatheter was substantially facilitated by the Neuroform2 stent, which bridged both aneurysms. Injection of the ICA with the microcatheter in the paraophthalmic aneurysm showed no opacification of the aneurysmal sac (Fig. **3b**). The attempt to introduce a small coil (2 mm/15 mm mini com-

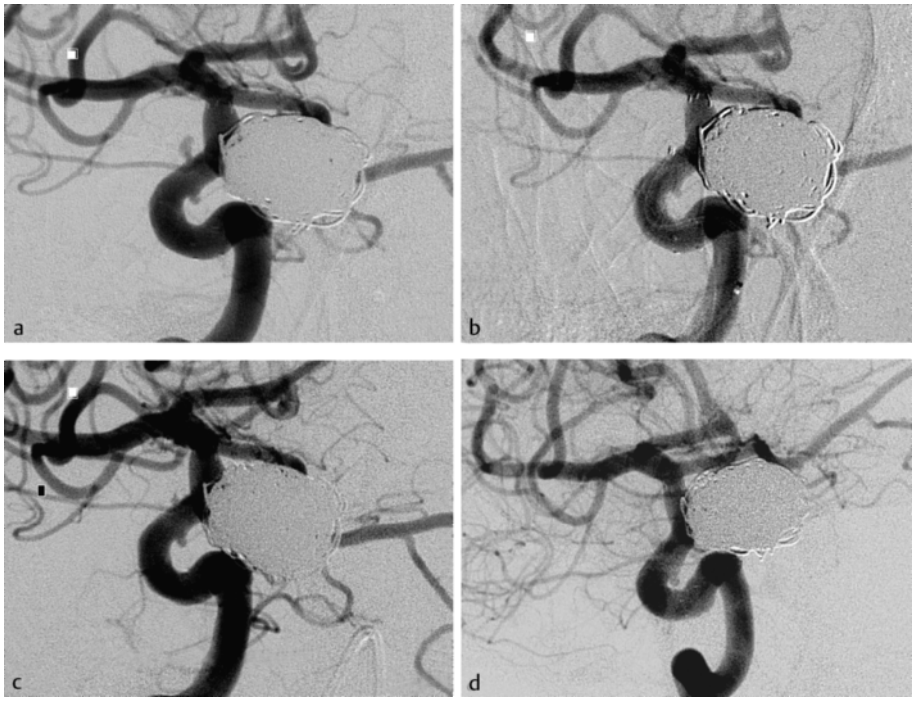

Fig. **3** Small unruptured paraophthalmic aneurysm of the right internal carotid artery, with a small aneurysm of the superior hypophyseal artery and a previously ruptured, large aneurysm at the origin of the posterior communicating artery, which had been coil treated (**a**). Flow in and out the paraophthalmic aneurysm was interrupted after a microcatheter had been introduced into the aneurysm orifice (**b**). Injection of a small amount of polymer glue obliterated the aneurysm fundus, leaving an aneurysm neck remnant behind (**c**). Angiography 7 months later showed complete occlusion of the paraophthalmic aneurysm (**d**).

plex, Cordis; NXT 2 mm/10 mm soft, MTI) failed. It became evident that the space provided by the aneurysm sac was too small to allow a circular configuration of the coil loops. After gentle flushing of the microcatheter with a 40% glucose solution, < 0.1 ml of a homogeneous Histoacryl (Braun Aesculap)/Lipiodol (Guerbet) solution of equal parts was injected into the hub of the microcatheter. The liquid embolic agent was very gently advanced within the microcatheter by slow injection of 40% glucose solution. Under non-pulsed fluoroscopy the distal end of the microcatheter was observed. The injection was terminated as soon as the radiopaque Histoacryl/Lipiodol column appeared in the field of view. Then the continued propagation of the glue column was decelerated by applying negative pressure to the syringe. A small volume of Histoacryl/Lipiodol detached slowly from the distal tip of the microcatheter and stayed within the aneurysm. After two seconds the microcatheter was abruptly withdrawn. The Histoacryl/Lipiodol remained unchanged within the aneurysm. Immediate angiography showed a minor neck remnant (Fig. **3c**). Follow-up angiography 7 months after the final treatment confirmed the complete obliteration of the paraophthalmic aneurysm and showed the small aneurysm of the superior hypophyseal artery essentially unchanged (Fig. **3d**). With respect to the size and the unfortunate angle between ICA and aneurysm, no further attempt at endovascular treatment was undertaken until now. Treatment with a new hemodynamically active device, which will soon be available, was discussed with the patient as a future option.

Discussion

The treatment of a very small aneurysm is clearly indicated if an intracranial hemorrhage can be attributed to it. A previous hemorrhage from another aneurysm also justifies treatment. In the case of a small unruptured aneurysm, we explain the indication criteria to the patient [1]. Our final recommendation, however, also takes individual aspects such as patient age, medical condition, and extent of atherosclerotic changes of extra- and intracranial vessels and aneurysm geometry into account. The dilemma of recommending conservative or proactive treatment to a patient with an unruptured intracranial aneurysm can hardly be solved on the basis of statistic numbers [2]. The microsurgical and endovascular treatment risks vary in relation to many individual factors. The risk of future rupture is even more difficult to anticipate. The wall of unruptured aneurysms with identical angiographic appearance may at surgery be found to be very thin and fragile or thick and robust. One might assume that this is a more predictive feature for rupture than any other.

The three methods of endovascular aneurysm treatment described above clearly constitute “off-label-use” for all involved products. All patients were informed and had agreed in advance to the potential use of medical products which are not certified for this specific purpose. Apart from that, German law provides the option of using medical products “off-label” for the sake of the patient, if the physician in charge is convinced that there is no feasible alternative at hand (“Heilversuch”).

Covered stents or stent grafts are intuitively an exquisite concept for the treatment of intracranial side wall aneurysms [3]. Vessels originating adjacent to the target aneurysm, however, are a concern. Currently the only available device suitable for intracranial vessels is the Jomed StentGraft (Abbott), which is premounted on a balloon. This stent is very stiff and rigid and the recommended expansion pressure of 16 atm requires precise sizing. In general, this stent is certainly a last resort and not a first choice of neurovascular aneurysm treatment.

The self-expanding nitinol stent Neuroform (Boston Scientific) was originally developed as an adjunctive device to allow coil occlusion of wide-necked aneurysms. This stent is very flexible and deployment is atraumatic [4]. Experimental data have revealed that a single porous stent will significantly reduce flow into an underlying aneurysm [5,6]. The hemodynamic effect of the coaxial deployment of two Neuroform stents will vary depending on the resultant overlapping effect of the stent struts. This can hardly be influenced by the operator. Intimal hyperplasia has been reported after the deployment of Neuroform stents [7,8]. In our patient a certain degree of intimal hyperplasia, not apparent angiographically, may have contributed to the complete occlusion of the aneurysm. The major drawback of the treatment strategy described in this patient is the unpredictable efficacy. It may last several weeks if not months from the first treatment until the occlusion of the target aneurysm.

Several liquid embolic agents have been proposed for the endovascular treatment of intracranial aneurysms, including n-BCA [9], cellulose acetate polymer (CAP) [10–12], and ethylene vinyl alcohol copolymer dissolved in dimethyl sulfoxide (Onyx®, MTI) [13]. Only Onyx® had been developed as a commercial product. The use of liquid embolic agents has been justified by the search for a more complete and lasting aneurysm occlusion. Despite good initial results, aneurysms filled with Onyx may show reperfusion [14,15]. These procedures turned out to be substantially more demanding than conventional coil occlusion. Escape of the embolic agent out of the aneurysm sac into the parent artery is one of the major risks. The currently available n-BCA polymer glues Histoacryl® (Braun/Aesculap) and Glubran2® (GEM) are far from ideal for the use in aneurysm treatment. Apparent advantages are their low viscosity, high radiopacity and short polymerization time on contact with blood. Radiopacity and modification of polymerization is, for both substances, achieved by adding Lipiodol® (Guerbet). The resulting delay in polymerization is, however, variable and to a certain degree unpredictable. There would certainly be a space in the neuroendovascular product assortment for optimized polymer glue. Adding an inert radiopaque compound to the liquid embolic agent and modifying the polymerization time by an independently added agent might be one of several possible solutions [16]. Prevention of the escape of the embolic agent from the aneurysm sac can be achieved in different ways. Balloon sealing was established for the use of Onyx. In our case the microcatheter isolated the aneurysm from the parent artery. Alternative methods might be considered under certain circumstances. Transient circulatory “arrest” for 10–15 sec can be achieved by the intravenous injection of adenosine [17]. A significant reduction of blood circulation within the aneurysmal sac is caused by the insertion of even a small number of coils [18]. Coil occlusion, stent deployment and polymer injection are therefore potentially synergistic methods.

In summary, very small intracranial aneurysms remain a challenge for endovascular treatment and the three methods of treatment described in this paper are rather preliminary efforts than final solutions.

References

[1] Johnson SC, Higashida RT, Barrow DL, Caplan LR, Dion JE, Hademenos G, Hopkins LN, Molyneux A, Rosenwasser RH, Vinuela F, Wilson CB. Committee on Cerebrovascular Imaging of the American Heart Association Council on Cardiovascular Radiology: Recommendations for the endovascular treatment of intracranial aneurysms: A statement for healthcare professionals from the Committee on Cerebrovascular Imaging of the American Heart Association Council on Cardiovascular Radiology. Stroke 2002; 33: 2536 – 2544

[2] Wiebers DO, Whisnant JP, Huston J, Meissner I, Brown RD, Piepgras DG, Forbes GS, Thielen K, Nichols D, O'Fallon WM, Peacock J, Jaeger L, Kassell NF, Kongable-Beckman GL, Torner JC. Unruptured intracranial aneurysms: natural history, clinical outcome, and risks of surgical and endovascular treatment. Lancet 2003; 362: 103 – 110

[3] Felber S, Henkes H, Weber W, Miloslavski E, Brew S, Kühne D. Treatment of extra- and intracranial aneurysms and arterio-venous fistulas using stent grafts. Neurosurgery 2004; 55: 631 – 639

[4] Henkes H, Bose A, Felber S, Miloslavski E, Berg-Dammer E, Kühne D. Endovascular coil occlusion of intracranial aneurysms assisted by a novel self-expandable nitinol microstent (Neuroform). Interv Neuroradiol 2002; 8: 107 – 119

[5] Lieber BB, Stancampiano AP, Wakhloo AK. Alteration of hemodynamics in aneurysm models by stenting: influence of stent porosity. Ann Biomed Eng 1997; 25: 460 – 469

[6] Rhee K, Han MH, Cha SH. Changes of flow characteristics by stenting in aneurysm models: influence of aneurysm geometry and stent porosity. Ann Biomed Eng 2002; 30: 894 – 904

[7] Fiorella D, Albuquerque FC, Deshmukh VR, McDougall CG. In-stent stenosis as a delayed complication of neuroform stent-supported coil embolization of an incidental carotid terminus aneurysm. AJNR Am J Neuroradiol 2004; 25: 1764 – 1767

[8] Lopes D, Sani S. Histological postmortem study of an internal carotid artery aneurysm treated with the Neuroform stent. Neurosurgery 2005; 56: 416

[9] Teng MM, Chen CC, Lirng JF, Chen SS, Lee LS, Chang T. n-Butyl 2-cyanoacrylate for embolization of carotid aneurysm. Neuroradiology 1994; 36: 144 – 147

[10] Macdonald RL, Mojtahedi S, Johns L, Kowalczuk A. Randomized comparison of Guglielmi detachable coils and cellulose acetate polymer for treatment of aneurysm in dogs. Stroke 1998; 29: 478 – 485

[11] Szikora I, Guterman LR, Standard SC, Wakhloo AK, Hopkins LN. Endovascular treatment of experimental aneurysms with liquid polymers: the protective potential of stents. Neurosurgery 1996; 38: 339 – 347

[12] Yang X, Wu Z, Li Y, Sun Y, Yin K. Comparison of cellulose acetate polymer and electrolytic detachable coils for treatment of canine aneurysmal models. Chin Med Sci J 2002; 17: 47 – 51

[13] Molyneux AJ, Cekirge S, Saatci I, Gal G. Cerebral Aneurysm Multicenter European Onyx (CAMEO) trial: results of a prospective observational study in 20 European centers. AJNR Am J Neuroradiol 2004; 25: 39 – 51

[14] Magoufis GL, Vrachliotis TG, Stringaris KA. Covered stents to treat partial recanalization of Onyx-occluded giant intracavernous carotid aneurysm. J Endovasc Ther 2004; 11: 742 – 746

[15] Saatci I, Cekirge HS, Ciceri EF, Mawad ME, Pamuk AG, Besim A. CT and MR imaging findings and their implications in the follow-up of patients with intracranial aneurysms treated with endosaccular occlusion with Onyx. AJNR Am J Neuroradiol 2003; 24: 567 – 578

[16] Gounis MJ, Lieber BB, Wakhloo AK, Siekmann R, Hopkins LN. Effect of glacial acetic acid and ethiodized oil concentration on embolization with n-butyl 2-cyanoacrylate: an in vivo investigation. AJNR Am J Neuroradiol 2002; 23: 938 – 944

[17] Hashimoto T, Young WL, Aagaard BD, Joshi S, Ostapkovich ND, Pile-Spellman J. Adenosine-induced ventricular asystole to induce transient profound systemic hypotension in patients undergoing endovascular therapy. Dose-response characteristics. Anesthesiology 2000; 93: 998 – 1001

[18] Sorteberg A, Sorteberg W, Rappe A, Strother CM. Effect of Guglielmi detachable coils on intraaneurysmal flow: experimental study in canines. AJNR Am J Neuroradiol 2002; 23: 288 – 294

Treatment of Recurrent Previously Coiled Anterior Circulation Aneurysm with Minimally Invasive Keyhole Craniotomy: Report of Two Cases

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Abstract

The use of minimally invasive techniques has not yet been reported for the treatment of recurrent aneurysms after coil embolization. A 47-year-old man with a long history of headaches had an anterior communicating aneurysm that had previously been coil embolized. Three-year follow-up angiography showed a significant recurrence. A 50-year-old woman with subarachnoid hemorrhage and acute visual loss underwent coil embolization of a large ophthalmic artery aneurysm, which recurred 3 months later. In both cases, a keyhole fronto-orbital one-piece craniotomy was performed. In the first patient, the aneurysm was clip ligated. The coil mass, which had eroded through the dome, was excised. In the second patient, the anterior clinoid was removed and the aneurysm was clip ligated. Postoperative angiography showed no residual aneurysm and no evidence of branch or parent vessel compromise in either patient. Both patients had an uncomplicated postoperative course. Recurrent previously coiled aneurysms are technically challenging to treat. A minimal fronto-orbital craniotomy provides a sufficiently capacious working space for successful treatment of some recurrent aneurysms of the anterior circulation.

Key words

Aneurysm · coil embolization · keyhole craniotomy · subarachnoid hemorrhage

Introduction

The minimally invasive fronto-orbital keyhole approach has been used to clip both ruptured and unruptured aneurysms [1,2]. However, it has not yet been applied to the treatment of a previously coiled recurrent aneurysm. We report the first two cases of previously coiled, recurrent aneurysms treated with the minimally invasive fronto-orbital craniotomy.

Case Report

Presentation

Evaluation of a 47-year-old man with a long history of headaches revealed an anterior communicating artery aneurysm. This aneurysm was coil embolized at an outside institution. Three-year follow-up angiography showed a complex recurrent aneurysm (Fig. **1**). During this 3-year interval, the patient reported that headaches had recurred, but he exhibited no neurological deficits at presentation. Because of the complexity of the recurrent aneurysm, it was not considered amenable to endovascular treatment. The patient elected craniotomy and clipping of the lesion.

A 50-year-old woman with a history of subarachnoid hemorrhage and acute visual loss in the left eye had a large ophthalmic artery aneurysm that had been coil embolized (Fig. **2**) 3 months earlier. With a significant aneurysmal recurrence at its base, the arterial anatomy made stent-supported coil embolization infeasible.

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Bibliography
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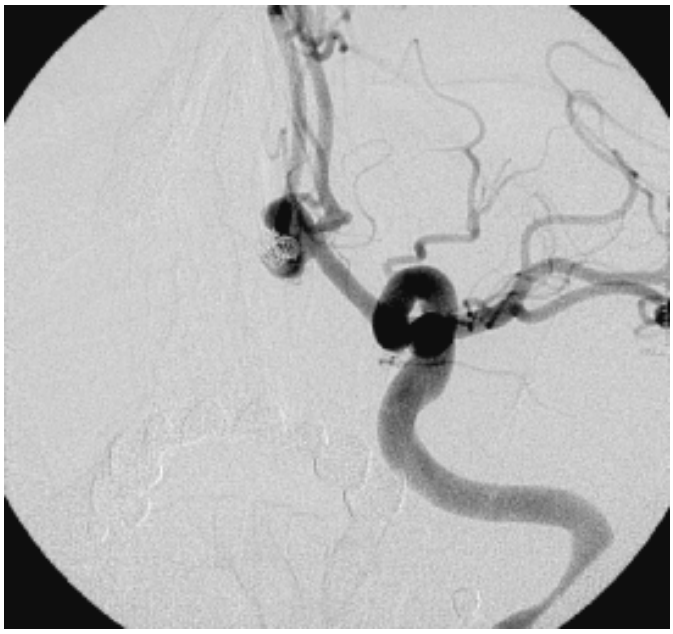

Fig. **1** Submentovertex view shows a bilobed recurrent aneurysm involving the anterior communicating artery.

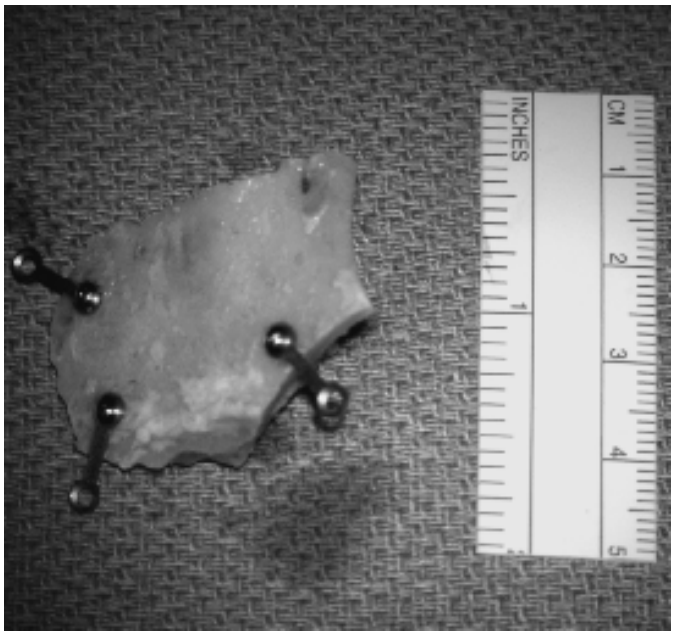

Fig. **3** The craniotomy flap is approximately 3 × 3 cm.

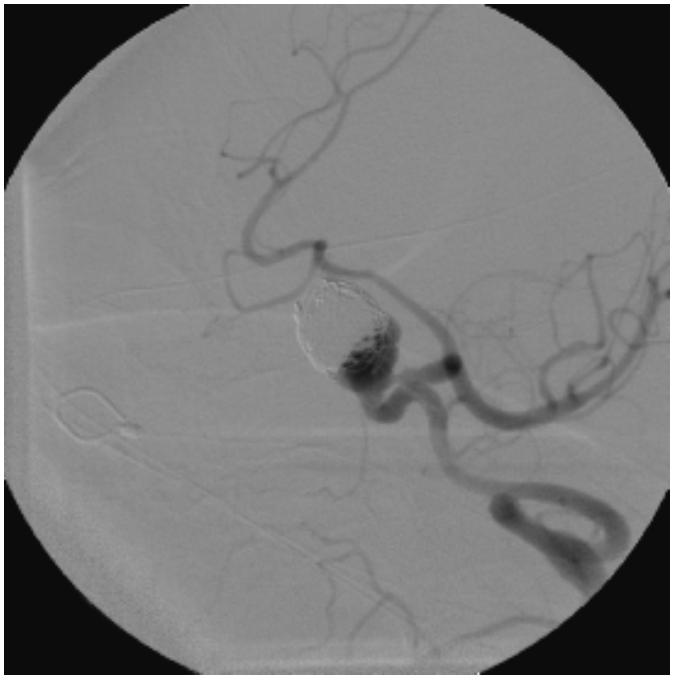

Fig. **2** Working-angle angiographic projection shows a significant recurrence at the base of a previously coiled aneurysm.

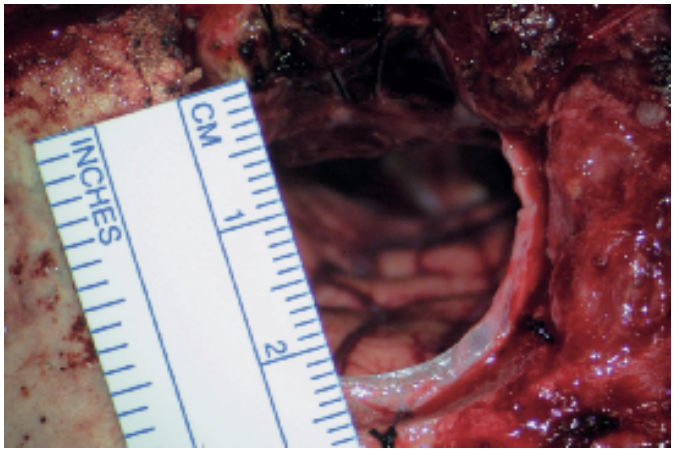

Fig. **4** The fronto-orbital window is demonstrated. The temporalis muscle is minimally manipulated.

Operative details

The patients were placed supine on the operating table. The head was fixated so that the malar eminence was at the apex of the surgical field and turned 30 degrees to expose the frontotemporal region. The incision extended from 1 cm anterior to the tragus of the ear to just beyond midline and immediately behind the hairline. At the first glimpse of the fat pad, the temporalis fascia was incised. A subfascial dissection was performed to expose the supraorbital ridge. A burr hole was drilled at the lateral aspect of the frontal bone 1 cm above and lateral to the keyhole. A 3 × 3 cm frontal craniotomy was elevated (Fig. **3**). The orbital bar was removed as a one-piece flap by using an osteotome. The dura was opened in a curvilinear fashion (Fig. **4**).

In the first patient, with the use of the operative microscope, the ipsilateral and contralateral A1 were identified. The aneurysm was immediately obvious, and there was evidence of coil extrusion outside its dome (Fig. **5**). The A2 segments of both anterior cerebral arteries, the orbitofrontal artery, and the artery of Heubner were identified. An 11-mm, straight titanium clip was used to ligate the aneurysm (Fig. **6**). The coil mass was excised with curved microscissors and sent for histological analysis. In the second patient, the medial Sylvian fissure was opened, and the anterior clinoid was removed. The aneurysm was clip ligated with an 11-mm titanium straight clip and a 3-mm miniclip. The coils were not removed because the patient had already lost vision in her left eye. At no point was a brain retractor necessary.

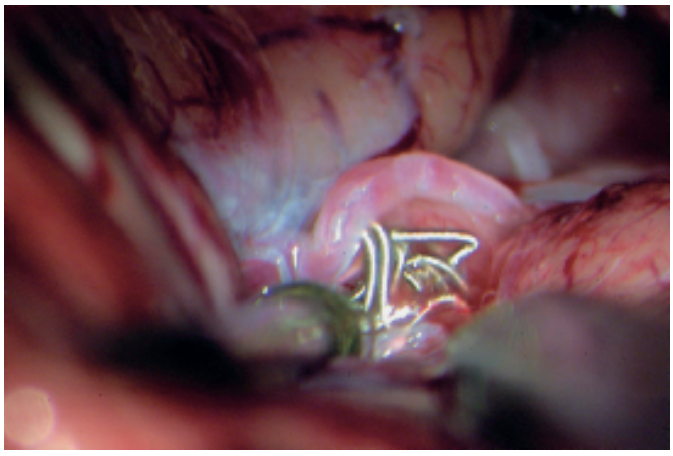

Fig. **5** Intraoperative image shows coil herniation through the aneurysm fundus.

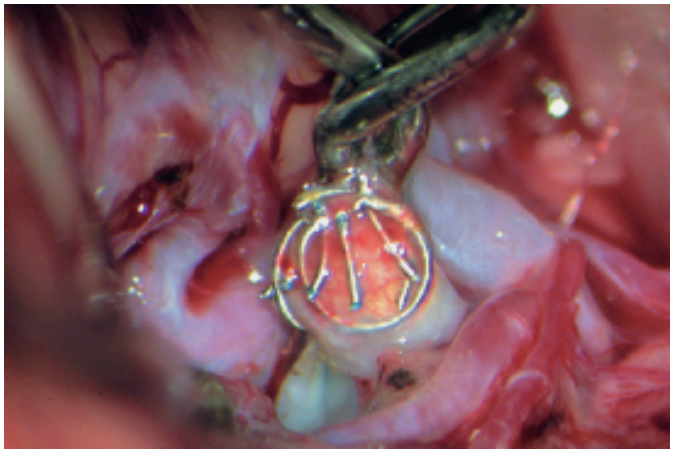

Fig. **6** The aneurysm is clipped without compromise of the parent or branch vessels.

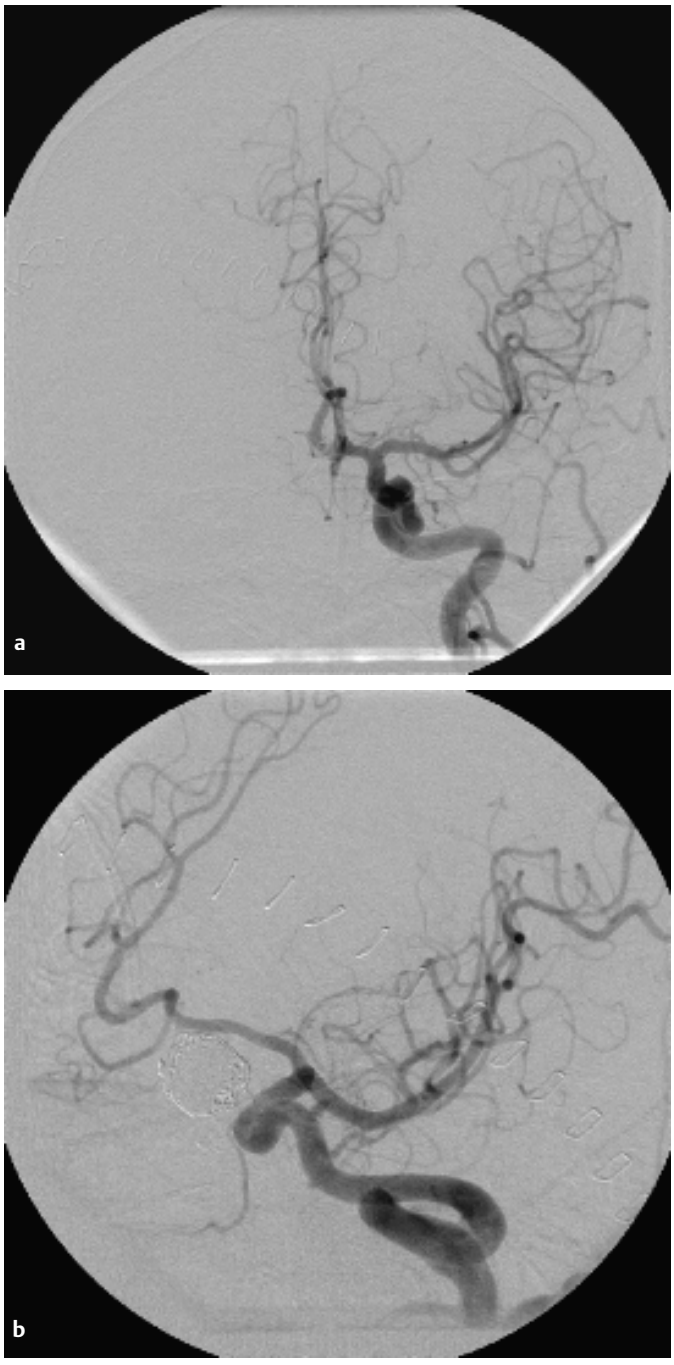

Fig. **7** Postoperative (**a**) anteroposterior and (**b**) transorbital angiograms show no residual aneurysm and no lumenal compression of the parent or branch vessels.

Postoperative course

Postoperative angiography (Figs. **7a** and **7b**) showed no residual aneurysm and a widely patent parent vessel in both patients. Their postoperative course was uncomplicated.

Discussion

Surgical management of recurrent aneurysms after endovascular coil embolization is well described [3 – 12]. The presence of coils in the aneurysm lumen makes surgical clipping of complex aneurysms technically difficult. After several weeks or longer, coils become incorporated into a fibrotic mass, making resection difficult [5]. During surgery, the presence of a large coil mass within an aneurysm can prevent adequate visualization of the aneurysm neck for clipping [5]. The bulk of a coil mass in a small aneurysm and thrombus in the region of the neck also can preclude adequate clip placement [5]. This situation is further complicated by the potential risks associated with coil removal, which include parent vessel occlusion [3] and traction injury to perforating vessels.

Exposure is the key to successful treatment of recurrent aneurysms after endovascular coil embolization [4,10]. Proximal and distal control of vessels [4,9], careful dissection around a previously coiled dome [6,10], and intraoperative angiography [5] are recommended to prevent complications. To date, standard pterional craniotomies or orbitozygomatic approaches [3] have been used to treat previously coiled aneurysms of the anterior circulation [4,7,10]. We were able to clip previously coiled aneurysms through a small craniotomy (3 × 3 cm). Therefore, we propose that a minimal fronto-orbital craniotomy is sufficient for safe surgical clipping of some recurrent, previously coiled anterior circulation aneurysms.

Recently, the virtues of minimally invasive microsurgical approaches to aneurysms of the anterior circulation have been described [1,2,13 – 15]. A minimally invasive approach is defined as one that poses minimal trauma during exposure and dissection of a given lesion. The size of the craniotomy does not dictate minimal invasiveness. Rather, a small craniotomy that does not adequately address a lesion should be considered maximally invasive. A craniotomy tailored to the specific location and size of a lesion and to a patient's anatomical characteristics is ideal [16].

The supraorbital minicraniotomy and fronto-orbital keyhole craniotomy allow adequate exposure of the anterior skull base. Opening the Sylvian fissure also allows structures of the middle cranial fossa to be approached. The location of a craniotomy is determined by the location of a lesion. Anterior communicating artery aneurysms require removal of the temporal bone with the head turned 45 to 60 degrees. In contrast, middle cerebral artery aneurysms require removal of the frontal bone with minimal head turning. Such careful preoperative planning helps to achieve the desired results and improves cosmesis. Avoiding dissection of the temporalis muscle prevents its atrophy and necrosis of the flap, which is occasionally associated with pterional craniotomies [1]. Others report that a smaller craniotomy decreases the psychological impact on a patient [14].

We prefer the fronto-orbital approach to the supraorbital approach because the former offers a more capacious working space. From our experience, this approach adds no operative time compared to a pterional orbitozygomatic exposure. Dare et al. [2] applied this approach to several aneurysms of the anterior circulation. They found that minimal frontal lobe retraction was required to obtain an adequate view of the anterior cranial fossa.

As the merits of this fronto-orbital minicraniotomy are appreciated, more surgical applications beyond aneurysms of the anterior circulation become obvious. One such application is the resection of tumors of the anterior cranial fossa and sellar region [17,18]. A minimally invasive and cosmetically superior craniotomy should be considered if its application does not compromise radiographic and clinical outcomes.

Conclusion

These cases demonstrate that the fronto-orbital keyhole craniotomy allows a sufficiently capacious operative window to the anterior cranial fossa to clip recurrent, previously coiled aneurysms of the anterior circulation with minimal manipulation of the temporalis muscle and minimal brain retraction.

References

[1] Steiger HJ, Schmid-Elsaesser R, Stummer W, Uhl E. Transorbital keyhole approach to anterior communicating artery aneurysms. Neurosurgery 2001; 48: 347 – 351

[2] Dare AO, Landi MK, Lopes DK, Grand W. Eyebrow incision for combined orbital osteotomy and supraorbital minicraniotomy: application to aneurysms of the anterior circulation. Technical note. J Neurosurg 2001; 95: 714 – 718

[3] Mizoi K, Yoshimoto T, Takahashi A, Nagamine Y. A pitfall in the surgery of a recurrent aneurysm after coil embolization and its histological observation: technical case report. Neurosurgery 1996; 39: 165 – 168

[4] Horowitz M, Purdy P, Kopitnik T, Dutton K, Samson D. Aneurysm retreatment after Guglielmi detachable coil and nondetachable coil embolization: report of nine cases and review of the literature. Neurosurgery 1999; 44: 712 – 719

[5] Gurian JH, Martin NA, King WA, Duckwiler GR, Guglielmi G, Vinuela F. Neurosurgical management of cerebral aneurysms following unsuccessful or incomplete endovascular embolization. J Neurosurg 1995; 83: 843 – 853

[6] Civit T, Auque J, Marchal JC, Bracard S, Picard L, Hepner H. Aneurysm clipping after endovascular treatment with coils: a report of eight patients. Neurosurgery 1996; 38: 955 – 960

[7] Thornton J, Dovey Z, Alazzaz A, Misra M, Aletich VA, Debrun GM, Ausman JI, Charbel FT. Surgery following endovascular coiling of intracranial aneurysms. Surg Neurol 2000; 54: 352 – 360

[8] Boet R, Poon WS, Yu SC. The management of residual and recurrent intracranial aneurysms after previous endovascular or surgical treatment – a report of eighteen cases. Acta Neurochir (Wien) 2001; 143: 1093 – 1101

[9] Conrad MD, Pelissou-Guyotat I, Morel C, Madarassy G, Schonauer C, Deruty R. Regrowth of residual ruptured aneurysms treated by Guglielmi's detachable coils which demanded further treatment by surgical clipping: report of 7 cases and review of the literature. Acta Neurochir (Wien) 2002; 144: 419 – 426

[10] Zhang YJ, Barrow DL, Cawley CM, Dion JE. Neurosurgical management of intracranial aneurysms previously treated with endovascular therapy. Neurosurgery 2003; 52: 283 – 293

[11] Veznedaroglu E, Benitez RP, Rosenwasser RH. Surgically treated aneurysms previously coiled: lessons learned. Neurosurgery 2004; 54: 300 – 303

[12] Ladouceur DL. Transcranial clipping of recurrent cerebral aneurysms after endovascular treatment. Stroke 1993; 24: 1087 – 1089

[13] Lindert E van, Perneczky A, Fries G, Pierangeli E. The supraorbital keyhole approach to supratentorial aneurysms: concept and technique. Surg Neurol 1998; 49: 481 – 489

[14] Ramos-Zuniga R, Velazquez H, Barajas MA, Lopez R, Sanchez E, Trejo S. Trans-supraorbital approach to supratentorial aneurysms. Neurosurgery 2002; 51: 125 – 130

[15] Andaluz N, Loveren HR van, Keller JT, Zuccarello M. Anatomic and clinical study of the orbitopterional approach to anterior communicating artery aneurysms. Neurosurgery 2003; 52: 1140 – 1148

[16] Perneczky A, Muller-Forell W, Lindert E van, Fries G. Keyhole Concept in Neurosurgery with Endoscope-Assisted Microsurgery and Case Studies. Stuttgart: Georg Thieme Verlag, 1999

[17] Revuelta R, Arriada-Mendicoa N, Ramirez-Alba J, Soto-Hernandez JL. Simultaneous treatment of a pituitary adenoma and an internal carotid artery aneurysm through a supraorbital keyhole approach. Minim Invas Neurosurg 2002; 45: 109 – 111

[18] Wiedemayer H, Sandalcioglu IE, Wiedemayer H, Stolke D. The supraorbital keyhole approach via an eyebrow incision for resection of tumors around the sella and the anterior skull base. Minim Invas Neurosurg 2004; 47: 221 – 225

Percutaneous Endoscopic Transforaminal Lumbar Discectomy: A Critical Appraisal

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Original Article

Abstract

Percutaneous endoscopic transforaminal lumbar discectomy (PETD) is one of the surgical techniques for the treatment of the lumbar disc herniations. Fenestration of the annulus and partial resection of the nuclear substance are achieved percutaneously by a posterolateral approach under local anaesthesia. The results of the first 42 patients are evaluated regarding the learning curve and indications for this procedure. The mean follow-up time was 15 months. Excellent and good results were evaluated as successful and the overall success rate is 77%. All six patients with foraminal disc herniations in whom a free fragment could be removed had excellent results. Military personnel can return to work quickly without deficits with the use of this technique.

Key words

Percutaneous discectomy · minimal invasive spine surgery · herniated disc · learning curve

Introduction

Although endoscopic techniques have been widely used in different parts of human body such as the gastrointestinal tract or in arthroscopic surgery, it took a long time for these techniques to be applied to spinal procedures. This was because of the difficulty to access the spinal region and the narrow working spaces. Technical difficulties have also been a specific problem for endoscopic spinal surgery.

Open surgical techniques for lumbar disc surgery began with Dandy [1] and Mixter and Barr [2] 70 years ago. Simply there has been no great change in surgical approach since application of the microdiscectomy technique by Caspar and Iwa [3], Williams [4] and Yaşargil [5]. In 1975 Hijikata [6] described a new method for the removal of disc material through a posterolateral approach: percutaneous nucleotomy. Consequently in 1983 Kambin [7] improved the arthroscopic technique. In the early 1990s Mayer and Brock [8], Kambin [9] and Dittsworth [10] performed different percutaneous endoscopic lumbar discectomy techniques.

In this prospective study we describe the results, limitations of surgical techniques and indication criteria for percutaneous endoscopic transforaminal lumbar discectomy (PETD).

Patients and Methods

Between 2000 and 2002 percutaneous discectomy was performed in a total of 42 patients (40 males, 2 females) ranging in age from 18 to 74 years. These 42 patients ranged in age groups as follows: 35 patients, 18–30 years; 5 patients, 30–50 years; and 2 patients, over 50 years. Preoperative symptoms had lasted 1 month to more than one year averaging 5.4 months. Most of the patients had been unable to perform their daily social activ-

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Bibliography
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ities for 1 or 2 months. All patients had had conservative therapy including bed rest and medical therapy.

A modified Suezawa and Schreiber [11] clinical scoring system was used to evaluate pre- and postoperative results. The total score is calculated by adding the score from each symptom for a maximum of 10 and a minimum of 0. A total score of 9 to 10 indicates an excellent condition, 7 to 8 good, 6 to 5 moderate, 4 or less poor (Table **1**). For data analysis we used a commercially available statistical software package (SPSS version 6.0; Inc., Chicago, IL) for all statistical analysis. McNemar and Wilcoxon tests are used for statistical analysis.

MRI and CT were performed in all patients. An additional abdominal CT for the corresponding level was also performed in order to calculate the distance of the entrance from the midline and its angle. This study also provided information about abdominal structures and variations.

Table **1** Modified Suezawa and Schreiber clinical scoring system for lumbar disc disease

Symptoms	*Score*		
	2	*1*	*0*
Low-back pain	none	activity-related	at rest
Sciatica	none	with SLRT	at rest
Sensory deficit	none	dysaesthesia	hypaesthesia
		paraesthesia	anaesthesia
Motor weakness	none	full function	full function
		with slight resistance	against gravity
Reflex changes	none	one reflex impaired	two reflexes impaired

SLRT = straight leg raising test.
Results: excellent: 10 – 9 points; good: 8 – 7 points; moderate: 6 – 5 points; poor: 4 – 0 points. Modified from the system of Suezawa and Schreiber by Mayer [11, 14].

Indications for percutaneous discectomy include persistent radicular pain with radiologically proven disc herniations compromising the nerve root, a positive straight leg raising test, not responding to conservative treatment, and when the patient is obese or in a poor general condition so that anaesthesia carries a certain risk. This technique was already considered as optimal for foraminal disc herniations.

We considered severe spinal stenosis, previous open surgery, significant spinal instability, calcified disc herniations, inaccessible free median disc herniations, root compressions caused by bony spurs, and facet or ligamentous hypertrophy as contraindications for surgery.

Operations are performed in the operating theatre under sterile conditions. The anaesthetist provides monitoring and sedation with midazolam. All patients received a single dose antibiotic prophylaxis (second generation cephalosporin). The patient is placed on the operating table in a lateral decubitus position, so that the symptomatic side is facing upwards. Under sterile fluoroscopic control the level, entrance point and angle are confirmed (Fig. **1**). Entrance point is also calculated from the abdominal CT, which provides precise planning, and safety. It is generally between 8 – 12 cm from the midline. Depending on the obesity of the patient the entrance point may exceed 12 cm (Fig. **2**). Using a local anaesthetic, a skin opening 5 mm in length is made at the predetermined entrance point. Under fluoroscopic control the guide wire and trocar are placed. Following introduction of the working cannula the trocar is removed and with a 0-degree rigid endoscope the disc level and foramen are inspected. An opening is made in the annulus by cutting a circular window with the aid of a trephine. The annulotomy site is believed to provide a decompression site away from the herniation, decreasing the likelihood of recurrent herniation. Therefore wide opening of the annulus fibrosus is desired. Rigid forceps are introduced through the working cannula to remove disc material and create a cavity

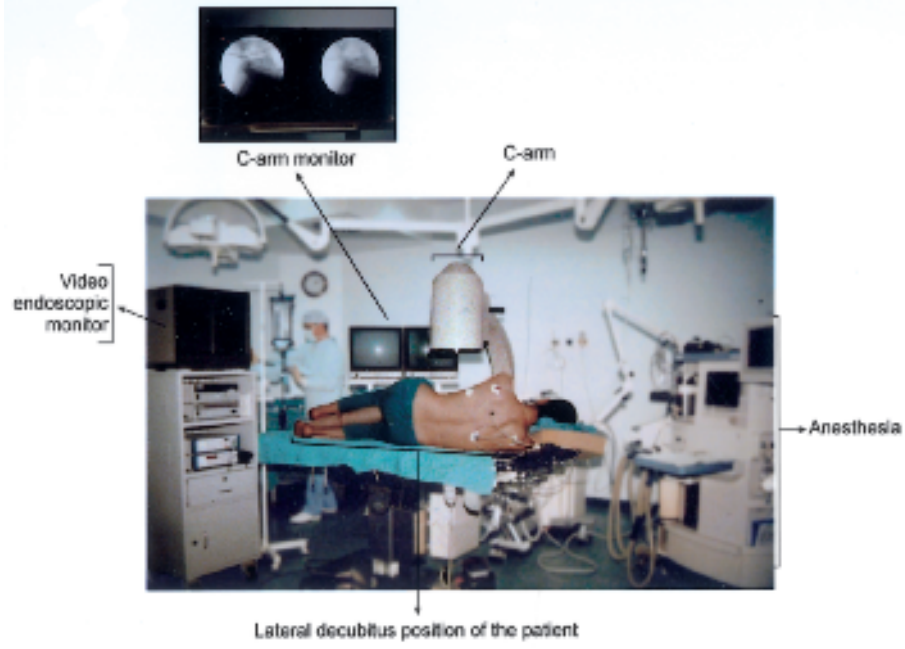

Fig. **1** The fluoroscopic C-arm is placed in the surgical field, so that real-time lateral fluoroscopic images could be obtained. The surgeon stands on the side of the approach with the monitors of the C-arm and endoscope placed opposite to her/him.

Fig. **2** Entry point and angle are calculated from the abdominal CT, it is generally 8 – 12 cm from the midline. Note the angle of the dilation sleeve, dilation rod and operating cannula directing to the surgical level.

in the nucleus pulposus before inserting with the endoscope. This step of the operation is done in a blind fashion without the endoscope. Endoscopy of the disc is performed using a rigid endoscope with a working channel (Fig. **3**). The disc material and side of the herniation are inspected and it is possible to remove certain parts of the nucleus pulposus using reverse-opening forceps. With the aid of fluoroscopy a safe control of the tip location for all instruments within the intervertebral space is achieved. At the end of the operation, the working cannula is withdrawn and the skin opening is closed with a single suture.

Results

Percutaneous discectomy was performed at the L4/5 level in all patients. Radiological examinations revealed that 8 patients had foraminal disc herniations and 34 patients had contained central disc herniations. All patients complained of low back pain and radicular pain. The straight leg raising sign was positive in all patients. A total of 28 patients (66%) had preoperative sensory disturbances: hypaesthesia was present in 16 and paraesthesia in 12. Only 4 patients had weakness of the extensor hallucis longus muscle and 3 patients had reflex changes.

In 8 patients discectomy could not be performed because of the anatomic relationship between the foramen and root. The patients perceived pain and the procedure had to be stopped. Three of these 8 patients have been operated with open surgery and the others had further conservative treatment.

Of the 34 patients operated with PETD, in 6 patients it was possible to remove a free single fragment through the foramen. In 28 patients only discectomy and removal of the contained disc have been achieved. Four patients operated with the percutaneous endoscopic discectomy technique have been reoperated and a microdiscectomy was performed.

We had venous bleeding in 8 patients and only irrigation was sufficient to control the bleeding. Two patients had transient ipsilateral monoparesis, which was due to epidural application of local anaesthesia at the beginning of our surgical experience. In one patient we had dural tear without persistent CSF fistula. The mean operation time ranged from 35 to 75 minutes. X-ray exposure for the entire procedure was calculated as 3 mRad. All patients have been hospitalised on the night after the surgery for early detection of possible complications and they have been mobilised one hour after the surgery.

We initially evaluated all patients at 6 weeks after the procedure. The patients were followed up for 6 – 24 months and mean follow-up time was 15 ± 4 months. Patients were evaluated according to modified Suezawa and Schreiber [11] scoring system as described above. Of the 34 patients operated with PETD, 10 had excellent results, 15 had good results, 6 had moderate results and 3 had no change. Comparison and statistical analysis of pre- and postoperative symptoms and signs are shown in Fig. **4**. The clinical score calculated from the scoring system averaged 5.17 ± 0.82 in the preoperative period. Mean score after 12 months was

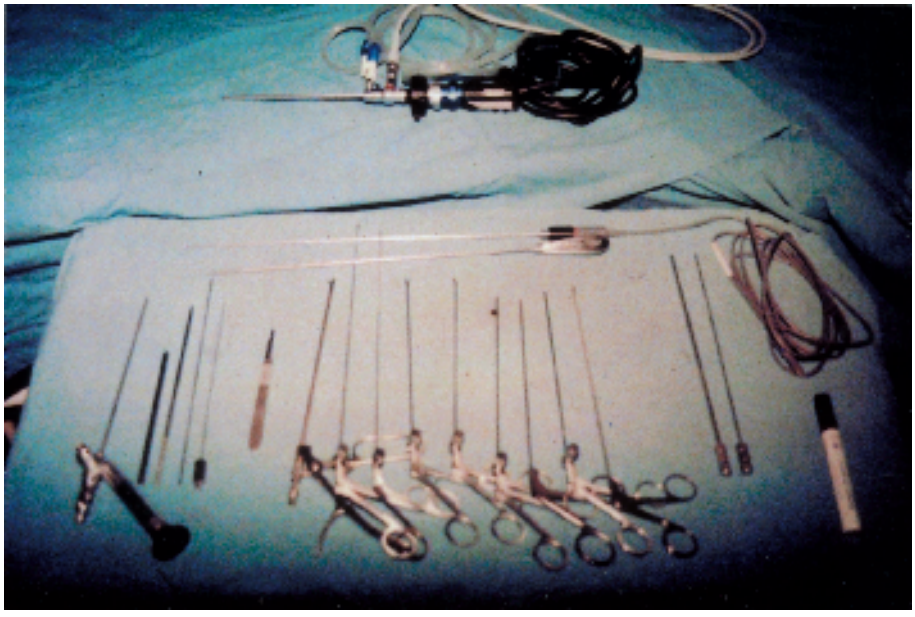

Fig. **3** Endoscopic and surgical equipment. A straight forward telescope 0 (4 mm diameter) and a wide-angle telescope 6 with angled eyepiece and instrument channel (3 mm diameter) were used (Karl Storz, GmbH & Co, Germany).

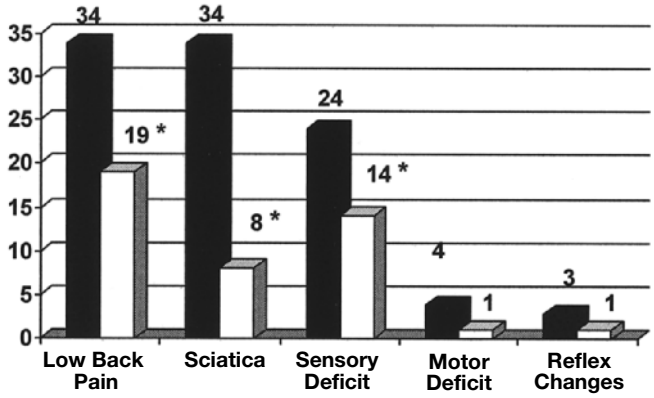

Fig. **4** Clinical details and comparison of preoperative and postoperative symptoms and signs in 34 patients undergoing PETD. Black bars represent preoperative and white bars represent postoperative symptoms and signs. *$p < 0.05$ (McNemar test).

7.58 ± 1.77. The change of pre- and postoperative clinical scores was statistically significant ($p < 0.05$, Wilcoxon test). Excellent and good results were evaluated as successful and the overall success rate is 77%. All six patients in whom a free fragment could be removed had excellent results.

Of the three poor results, all underwent open surgery with microdiscectomy. The failures were due to free fragments located too centrally which we were unable to remove through this technique and instrumentation. All of these three patients then had excellent results. One patient with a moderate result had persistent sciatica and numbness. He had been operated two months after PETD and the operative finding was a protrusion and compression on the nerve root. The posterior ligament was found to be intact and after opening the ligament only a small amount of disc material could be removed, actually the disc space was empty. This patient had also an excellent result.

Three out of eight patients who could not be operated through the PETD technique have been reoperated with open surgery. In two patients bony osteophytes have been removed. The surgical finding was consistent with a moderate spinal stenosis. The third patient had a massive protrusion and microdiscectomy was performed. The other five patients have also been followed-up and had conservative treatment. In the long-term they were classified as good results.

Discussion

Percutaneous endoscopic spine surgery is a newly emerging field. Since the first application of percutaneous nucleotomy by Hijikata in 1975 [6], different techniques and instruments have been designed and certain improvements have been achieved with the application of the endoscope in regard of surgical safety and capability [7,9,12–15]. Various endoscopic techniques have been described including biportal, automated percutaneous discectomy, a transforaminal approach and microendoscopic discectomy [16,17]. The PETD technique is a relatively new method for the treatment of lumbar disc herniations. Since a decade this method has been widely used and developed. Mayer and Brock showed that the clinical results are comparable and in some respects superior to those of microdiscectomy [8]. The surgical aim of PETD is the selective removal of the nucleus pulposus under intermittent or constant visual control through a posterolateral approach. Different studies are reported comparing percutaneous discectomy and other techniques [18–20]. Selection criteria of the patients play a significant role for surgical success in a disease like lumbar disc herniations, namely protrusions where the natural history is known to be beneficial [21–27].

We treated a relatively young male population; 35 of 42 patients being under 30 years of age. The preoperative clinical scores according to Suezawa and Schreiber were higher than other series [8,11]. Only four patients had motor weakness and three had reflex changes. These facts show that we were confronted with a patient population in a fairly good clinical status excluding sciatica. This might have led to good clinical results if we consider that this study was done in a relatively low volume hospital (150–200 operations/year) and that this operative technique was only introduced recently in our hospital. As mentioned before, like every new emerging technique PETD has its own learning curve. In order to set certain limitations for indications we evaluated our results every fourth month. It was interesting to see how the results changed in consecutive periods. In the first eight months 19 patients were operated and 6 reoperations were performed. Only one of the 13 operated patients was reoperated during the second eight months. In the last eight months there were no reoperations in 10 operated patients (Table **2**). All of the complications were in the first 16 months. This observation showed that the PETD technique is safe and effective after a certain learning curve if patient selection criteria are followed strictly. During the initial period of our study the indications also included protrusions in order to decrease the intradiscal pressure. But during the short follow-up time it could be shown that these patients have not benefited from this surgical procedure as much as patients with foraminal disc herniations. Evacuating a certain space in the centre of the disc and allowing collapse of the herniation into the disc space does not always adequately decompress the nerve root in a large majority of cases [19]. Yasuma et al. have shown that disc herniations are often fractured annular fragments trapped within the outer layers of the annulus [28]. This dorsal part of the annulus is difficult and dangerous to access with posterolateral percutaneous techniques. So the clear-cut indication of this technique is foraminal disc herniation. Performing PETD to decrease the intradiscal pressure in patients with protrusions may not be helpful or can be considered as a failure, because most of these patients recover with conservative treatment. This finding is consistent with the known natural history of low back pain and lumbar disc disease [29].

Table **2** Number of operations and reoperations during the entire period

	*First Period**	*Second Period*	*Third Period*
PETD operations	19 patients	13 patients	10 patients
Re-operation (open surgery)	6 patients	1 patient	0 patients

*Each period is 8 months.

Discography or post-discography CT has been shown to be the most reliable method for preoperative evaluation of disc morphology [30–32]. With the help of careful evaluation of MRI scans a sequestered disc material can be excluded. Sequestered midline discs are a contraindication for PETD too, because of the limitations of the technique and working space.

We divided reoperations into two groups as early (first week postoperatively) and late (two months postoperatively). Three patients were operated in the first week because of incapacitating sciatica and a free fragment was found. In late re-explorations bony osteophytes and protrusions were the operative findings. We also found out that the disc space was empty in our late reoperations (Table **3**). This finding is also consistent with those of Mayer [8,14]. The possible explanation for persistent sciatica in these patients might be continuing compression of the nerve root by the expanded posterior longitudinal ligament, which was intact and harder than normal.

Mathews in 1996 and Dittsworth in 1998 attempted to expand the indications for the endoscopic technique by using a uniportal approach with a small fiberoptic endoscope [10,33]. However, this technique has also certain limitations like the small size of the endoscope, foramen and has a very steep learning curve. These factors limited the use and popularity of this technique. Our results also showed that PETD has a steep learning curve and it could be hazardous to the patients at the early periods of the learning curve. Recently Nowitzke has also determined the learning curve of microendoscopic discectomy [34].

In order to decrease the risk of percutaneous techniques, correct placement of the probe and detailed evaluation of the preoperative abdominal CT images for possible variations will provide more safety [35–37].

Table **3** Detailed documentation of re-operated patients and operative findings

Case	*Could PETD be performed?*	*Re-operation time*	*Operative finding*	*Outcome*
2	no	8 weeks	Bony osteophytes and spinal stenosis	GR
6	yes	1 week	Median free fragment	ER
9	no	10 weeks	Lateral recess stenosis	GR
12	no	7 weeks	Spinal stenosis and median disc prolapse	GR
15	yes	1 week	Foraminal free fragment	ER
17	yes	1 week	Median free fragment	ER
26	yes	9 weeks	Massive protrusion, nerve root compression	ER

GR = good result; ER = excellent result (according to Suezawa and Schreiber).

If we consider that 6 out of 10 excellent results are foraminal disc herniations it can be advised to limit the indication only for foraminal disc herniations right from the beginning of the learning curve. This indication limiting is not widely used. In most of the series protrusions are operated too.

With a better understanding of the particular pathology and anatomy in the selected patient and by using the best suited surgical technique and instruments, much better results can be achieved. Training and experience of the surgeon is essential. We must follow the predetermined surgical indications and not to try to create new ones with the formerly established and widely used endoscopic techniques. Concerning the PETD technique, a limitation of the indication to foraminal disc herniation can be advised for better outcomes. According to our results we have to except that PETD technique has a steep learning curve, which can be overcome with training and suitable patient selection for this technique.

It is not unusual to be fascinated by the technological developments and application to the spinal surgery, but this fascination might lead to a misuse of this techniques. In order to have better results we have to evaluate and criticise our results fairly and as early as possible when we begin to use a new endoscopic technique. As a minimally invasive surgery, this technique provides safe and quickly return to work for military personnel.

References

[1] Dandy WE. Loose cartilage from intervertebral disk simulating tumor of the spinal cord. Arch Surg 1929; 19: 660–672
[2] Mixter WJ, Barr JS. Rupture of intervertebral disc with involvement of the spinal canal. N Engl J Med 1934; 211: 210–215
[3] Caspar W, Iwa H. A microsurgical operation for lumbar disc herniations. Neurol Surg (Tokyo) 1979; 6: 657–662
[4] Williams RW. Microlumbar discectomy: A conservative surgical approach to the virgin herniated lumbar disc. Spine 1978; 3: 175–182
[5] Yaşargil MG. Microsurgical operation for herniated disc. In: Wullenweber R, Brock M, Hamer J, Klinger M, Spoerri O (eds), Advances in Neurosurgery. Berlin: Springer-Verlag, 1977: pp 81–82
[6] Hijakata S, Yamgishi M, Nakayama T, Oomori K. Percutaneous discectomy: a new treatment method for lumbar disc herniation. J Toden Hosp 1975; 5: 5–13
[7] Kambin P, Gellman H. Percutaneous lateral discectomy of the lumbar spine. Clin Orthop 1983; 174: 127–132
[8] Mayer HM, Brock M. Percutaneous endoscopic discectomy: surgical technique and preliminary results compared to microsurgical discectomy. J Neurosurg 1993; 78: 216–225
[9] Kambin P. Arthroscopic microdiscectomy. Arthroscopy 1992; 8: 287–295
[10] Dittsworth DA. Endoscopic transforaminal discectomy and reconfiguration: A posterolateral approach into the spinal canal. Surg Neurol 1998; 49: 588–598
[11] Suezawa Y, Schreiber A. Komplexe Indikationen in der Chirurgie des lumbalen Spinalkanals. Z Orthop 1987; 125: 308–319
[12] Choy DSJ, Ascher PW, Saddekni S, Alkaitis D, Lieber W, Hughes J, Diwan S, Altman P. Percutaneous laser disc decompressions: a new therapeutic modality. Spine 1992; 17: 949–956
[13] Maroon JC, Holst RA, Osgood CP. Chemopapain in the treatment of ruptured lumbar discs: Preliminary experience in 48 patients. J Neurol Neuosurg Psychiatry 1976; 39: 508–513
[14] Mayer HM, Brock M. Percutaneous endoscopic lumbar discectomy (PELD). Neurosurg Rev 1993; 16: 115–120
[15] Schreiber A, Leu H. Percutaneous nucleotomy: Technique with discoscopy. Orthopedics 1991; 14: 439–444

[16] Maroon JC. Current concepts in minimally invasive discectomy. Neurosurgery 2002; 51 (Suppl 2): 137 – 145
[17] Smith MW, Foley KT. Microendoscopic discectomy: The first 100 cases. Presented at the Annual Meeting of the Congress of Neurological Surgeons, Seattle, WA, October, 1998
[18] Hermantin FU, Peters T, Quartararo L, Kambin P. A prospective randomized study comparing the results of open discectomy with those of video-assisted arthroscopic microdiscectomy. J Bone Joint Surg [Am] 1999; 81: 958 – 965
[19] Kahanovitz N, Viola K, Goldstein T, Dawson E. A multicenter analysis of percutaneous discectomy. Spine 1990; 15: 713 – 715
[20] Revel M, Payan C, Valee C, Laredo JD, Lassale B et al. Automated percutaneous lumbar discectomy versus chemonucleolysis in the treatment of sciatica: A randomized multicenter trial. Spine 1993; 18: 1 – 7
[21] Atlas SJ, Chang Y, Kammann E, Deyo RA, Singer DE. Long-term disability and return to work among patients who have a herniated lumbar disc: the effect of disability compensation. J Bone Joint Surg [Am] 2000; 82: 4 – 15
[22] Atlas SJ, Deyo RA, Keller RB et al. The Maine Lumbar Spine Study. II. 1-Year outcomes of surgical and nonsurgical management of sciatica. Spine 1996; 21: 1777 – 1786
[23] Bozzao A, Gallucci M, Masciocchi C, Aprile I, Barile A, Passariello R. Lumbar disc herniation: MR imaging assessment of natural history in patients treated without surgery. Radiology 1992; 185: 135 – 141
[24] Coste J, Delecoeuillerie G, Cohen de Lara A, Le Marc JM, Paolaggi JB. Clinical course and prognostic factors in acute low back pain: an inception cohort study in primary care practice. BMJ 1994; 308: 577 – 580
[25] Croft PR, Macfarlane GJ, Papageorgiou AC, Thomas E, Silman AJ. Outcome of low back pain in general practice: a prospective study. BMJ 1998; 316: 1356 – 1359
[26] Delauche-Cavallier M-C, Budet C, Laredo J-D. Lumbar disc herniation: computed tomography scan changes after conservative treatment of nerve root compression. Spine 1992; 17: 927 – 933
[27] Weber H. Lumbar disc herniation: a controlled prospective study with 10 years of observation. Spine 1983; 8: 131 – 140
[28] Yasuma T, Makino E, Saito S, Inui M. Histological development of intervertebral disc herniation. J Bone Joint Surg [Am] 1986; 68: 1066 – 1072
[29] Deyo RA, Weinstein JN. Low back pain. N Engl J Med 2001; 344: 363 – 370
[30] Deburge A, Benoist M, Boyer D. The diagnosis of disc sequestration. Spine 1984; 9: 496 – 501
[31] Hijakata S. Percutaneous nucleotomy: a new concept technique and 12 years experience. Clin Orthop 1989; 238: 9 – 23
[32] Sachs BL, Vanharanta H, Spivey MA et al. Dallas discogram description. a new classification of CT/discography in low-back disorders. Spine 1987; 12: 287 – 294
[33] Mathews HH. Transforaminal endoscopic microdiscectomy. Neurosurg Clin North Am 1996; 7: 59 – 63
[34] Nowitzke MA. Assessment of the learning curve for lumbar microendoscopic discectomy. Neurosurgery 2005; 56: 755 – 762
[35] Epstein NE. Surgically confirmed cauda equina and nerve root injury following percutaneous discectomy at an outside institution: a case report. J Spinal Disord 1990; 3: 380 – 382
[36] Hopper K, Sherman JL, Luethke JM, Ghaed N. The retrorenal colon in the supine and prone patient. Radiology 1987; 162: 443 – 446
[37] Onik G, Maroon JC, Jackson R. Cauda equina syndrome secondary to an improperly placed nucleotome probe. Neurosurgery 1992; 30: 412 – 415

A New Full-Endoscopic Technique for the Interlaminar Operation of Lumbar Disc Herniations Using 6-mm Endoscopes: Prospective 2-Year Results of 331 Patients

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Abstract

Even with good results, conventional disc operations may result in consecutive damage due to traumatisation. Endoscopic techniques have become the standard in many areas because of the advantages they offer in surgical technique and in rehabilitation. The transforaminal operation is the most common full-endoscopic procedure in surgery of the lumbar spine. It is frequently necessary to reach the spinal canal directly in order to achieve sufficient resection of lumbar disc herniations. Even in using a lateral approach, the authors recognise the clear limitations of the transforaminal procedure. The objective of this prospective study was to examine the technical possibility of a full-endoscopic interlaminar access. The focus was on questions of sufficient decompression, as well as advantages and disadvantages of the minimally invasive procedure. 331 patients were followed for 2 years. The results show that 82% reported no longer having leg pain, and 13% had only occasional pain. The decompression results are equivalent to those of conventional procedures. Traumatisation of both the access pathway and the spinal canal structures was reduced. Epidural scarring was minimised. The recurrence rate was 2.4%. No serious surgical complications were observed. The authors view the technique described, which offers the advantage of a truly minimally invasive procedure, as a sufficient and safe alternative to conventional procedures, when the appropriate indication criteria are heeded. There are technical problems because of the small instruments. In conjunction with the transforaminal procedure, this is an expansion of the spectrum for full-endoscopic surgery of lumbar disc herniations.

Key words

Endoscopic nucleotomy · interlaminar nucleotomy · minimally invasive spine surgery · lumbar disc herniation

Introduction

Conventional procedures in the surgical therapy of lumbar disc herniation show good results [1–8]. Nonetheless, there is scarring of the epidural space [9–14], which may be unremarkable in the MRI [9,15] but become clinically symptomatic in 10% or more of cases [10,11,14]. Study results reveal operation-induced destabilisation due to necessary resection of spinal canal structures [5,16–22]. The access influences the stabilisation and coordination system in the innervation area of the dorsal spinal nerve system [12,23,24]. The combination of these parameters may explain poor revision results in the post-discotomy syndrome [11,25,26]. Microsurgical techniques have reduced tissue damage and its consequences [27–29]. Although conditions of postoperative pain are treatable [13,30,31], continuous optimisation should be attempted. The goal must be to achieve at least the current results [32] while minimising traumatisation and its negative long-term consequences.

Interlaminar access has been described since the early 20th century [33–38]. 30 years after its introduction, alternative methods for operating disc pathologies were developed [39]. Percutaneous intradiscal decompression via chemonucleolysis [40] has

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Bibliography
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been applied since the early 1970s [41 – 45]. The posterolateral access for vertebral body biopsies was described in the late 1940s [46]. Optical systems have been used since the early 1980s for inspection of the intervertebral space [47]. Most endoscopic operations now are performed in the uniportal technique under fluid flow with transforaminal access. Laser and bipolar current may be applied [48,49]. Numerous articles describe clinical results and technical advances [50 – 62]. In the late 1970s, a microsurgical procedure using a microscope was developed for interlaminar access [63 – 66]. Endoscope-assisted procedures were published in the late 1990s [28,67 – 70].

Endoscopic operations have become the standard in many areas. The most widely-used full-endoscopic procedure for the lumbar spine is the transforaminal or extraforaminal operation with posterolateral access and predominantly intradiscal and foraminal working area [50 – 52,54,56,58 – 62]. The bony perimeter of the foramen limits the mobility and resection of dislocated sequesters [51,60]. Moreover, the pelvis may block access to the lower levels. Thus, contrary to several publications [51,52,60 – 62], the authors recognise clear limitations to the transforaminal procedure.

The goal of the prospective study was to investigate the technical possibilities of an interlaminar access for the full-endoscopic uniportal operation of lumbar disc herniations which present as technically inoperable in the transforaminal approach. The focus was on questions of sufficient decompression compared to the results of conventional procedures, possible effects of less traumatisation, possible specific complications and the technical creation of access depending on pathological and anatomic correlates.

Patients/Materials and Methods

In 2001/2002, 423 patients underwent operations in the full-endoscopic uniportal technique with interlaminar access. 51 patients did not speak German. Since the scores applied are in part validated for use in German, these patients were excluded. The preoperative parameters of these 51 patients did not differ from those of the remaining patients. The study population consisted thus of 372 patients.

203 patients were women, 169 men. The age range was 17 to 76 years (mean: 41 years). The stress profile of occupation and sports was evenly distributed. None of the patients was retired because of the reported complaints. 16 patients were unemployed, 233 on sick leave. Height and weight were evenly distributed.

All patients presented with clinically symptomatic disc herniation. 351 underwent MRI and 21 CT examinations because of indwelling implants or claustrophobia. The duration of pain ranged from 1 day to 16 months (mean: 87 days). 202 patients presented with neurological deficits. 26 patients had bilateral symptoms, 5 contralateral, 6 a cauda equina syndrome caused by disc prolapse. 22 patients had undergone previous microscope-assisted surgery at the same level, 20 at a different level. 293 patients had received a mean of 10 weeks conservative treatment, 79 with uncontrollable pain symptoms, pronounced acute paralysis or cauda equina syndrome were operated immediately. The indication was defined according to today's standards based on radicular pain symptoms and existing neurological deficits [71,72]. 249 interventions were performed at level L5/S1, 107 at L4/5, 14 at L3/4 and 2 at L2/3, whereby the designation L4/5 is taken as the definition of the penultimate free level. Surgery was performed 358 times on one side, 14 times on both sides (13 times in bilateral symptoms, once with contralateral disc prolapse). General anaesthesia was administered 366 times and local anaesthesia 6 times.

The inclusion criteria for interlaminar access were disc herniations which, in the authors' experience, were technically inoperable in transforaminal approach due to the following parameters: sequestering toward cranial beyond the lower edge of the cranial pedicle or toward caudal over the middle of the caudal pedicle, lateral radiological overlay of the foramen by the pelvis beyond the middle of the cranial pedicle. Furthermore, due to the limited possibilities of osseous resection, the following conditions had to be present: the interlaminar window between the cranial and caudal lamina and between middle line and mediodorsal border of the processus articularis inferior had to measure at least 6 mm, maximal cranicaudal sequestering to half the adjacent vertebral body. There were no limitations set for extent of dorsal or lateral prolapse. Isolated back pain or spinal canal stenosis without disc herniation were not considered as inclusion criteria. Beyond general surgical contraindications, there were no exclusion criteria with reference to general illness.

The intervention was made with the patient prone under radiological control. The skin incision was made as nearly medial in the craniocaudal middle of the interlaminar window as possible. A dilator, 6 mm in outer diameter, was inserted bluntly to the lateral edge of the interlaminar window, then an operation sheath with 7-mm outer diameter and bevelled opening was directed toward the ligamentum flavum (Fig. **1**). The further procedure was performed under visual control and constant irrigation (Fig. **2**). A lateral incision was made in the ligamentum flavum, which was extended to about 5 mm. The neural structures were exposed, preserving the epidural lubricating fat tissue (Figs. **3 – 5**). The operating sheath with bevelled opening can be turned and used as a second instrument and nerve hook. Medial and lateral as well as cranial and caudal mobility within the spinal canal was controlled using optics on the joystick principle.

All of the operating instruments and optics were products supplied by Wolf (Knittlingen, Germany). The rod lens optics have a diameter of 6 mm with a 2.7-mm intraendoscopic working channel. In addition, high-voltage bipolar probes manufactured by Ellman (Ellman Innovations, New York, USA) and Select (Select Medizin Technik Herman Sutter GmbH, Freiburg, Germany) were used.

Follow-up examinations were made 1 day then 3, 6, 12 and 24 months postoperative. In addition to general parameters, the following measurement instruments were used: visual analogue scale (VAS) for back and leg pain, German version of the North American Spine Society instrument (NASS) [73,74], Oswestry low-back-pain disability questionnaire [75].

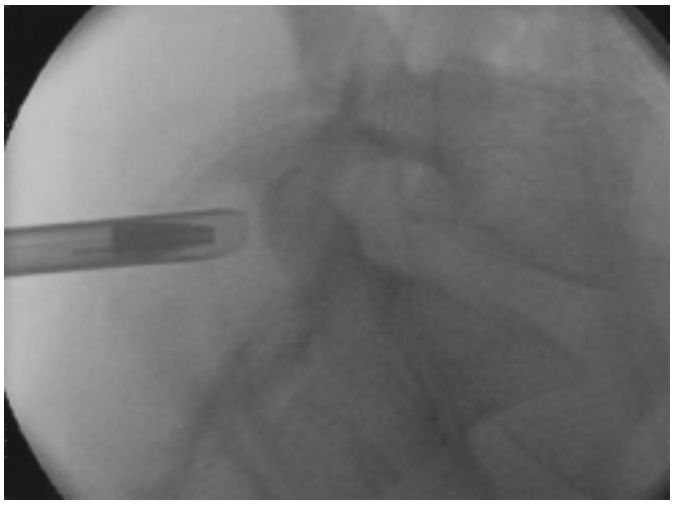

Fig. **1** Blunt insertion of the dilator and the bevelled operation sheath to the ligamentum flavum.

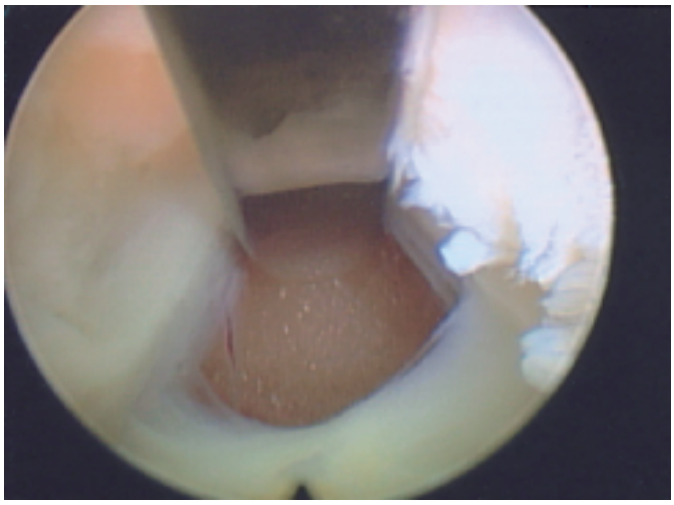

Fig. **3** Incision of the ligamentum flavum.

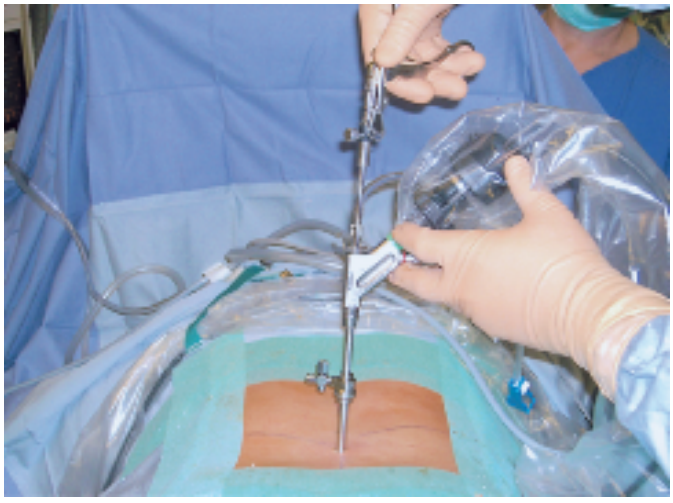

Fig. **2** Full-endoscopic interlaminar operation.

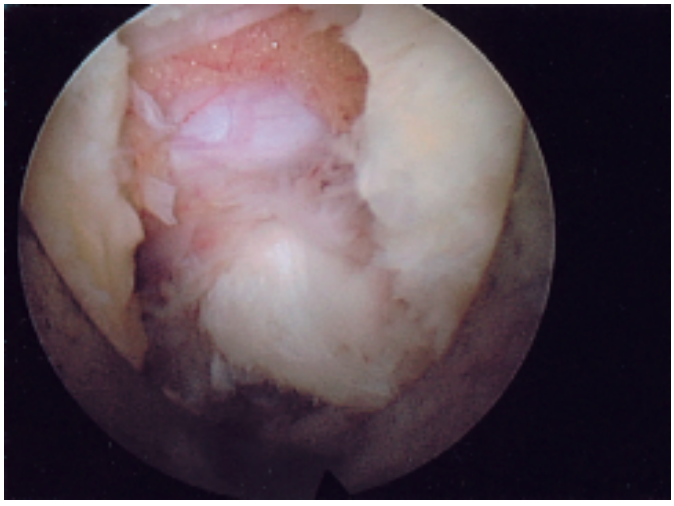

Fig. **4** Opened ligamentum flavum, traversing spinal nerve displaced toward dorsal by sequestered disk material.

The descriptive assessments and analytical statistics were performed depending on the group characteristics with the programme package SPSS Version 10.0.7. A positive significance level was assumed at $p < 0.05$.

Results

331 (89%) patients were included in follow-up. Exclusion of the remaining patients was for the following reasons: 2 operation-unrelated deaths, 9 patients moved away and left no forwarding address, 30 patients did not respond to letters or telephone calls.

None of the results obtained showed any dependence on sex, age, height, weight, employment status or concomitant diseases. The operating time ranged from 19 to 47 minutes (mean: 29 min). There was no measurable blood loss or serious complications, such as postoperative bleeding, injury to dura or nerves. 3 patients developed a transient postoperative dysaesthesia. Postoperative pain medication was not required. Mobilisation was immediate, depending on narcosis. No rehabilitative measures

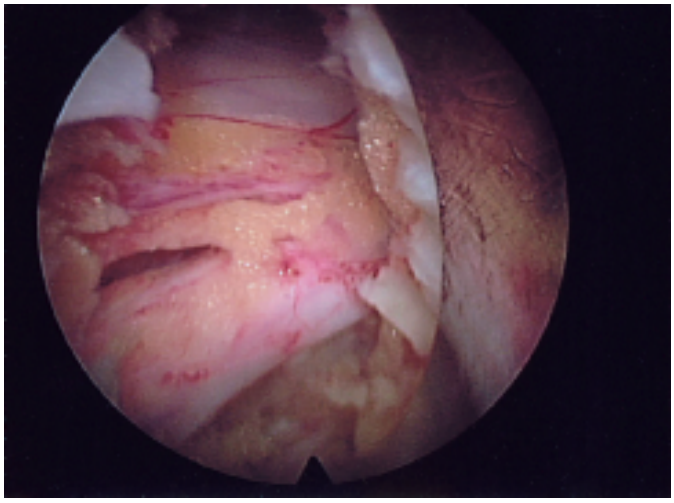

Fig. **5** Cauda equina with traversing spinal nerve and axilla after decompression.

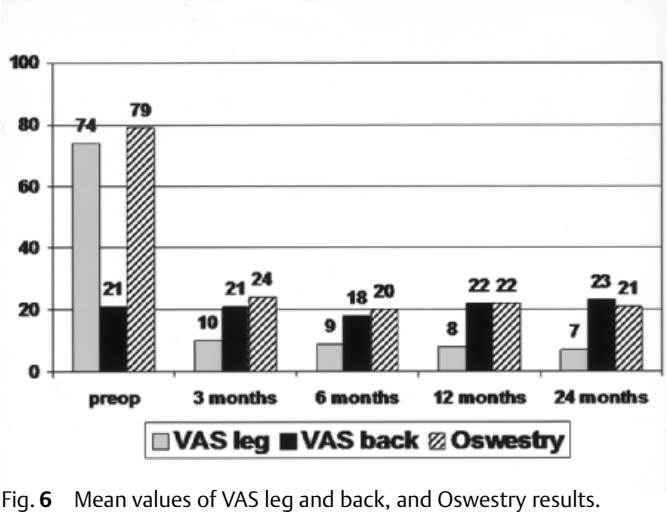

Fig. **6** Mean values of VAS leg and back, and Oswestry results.

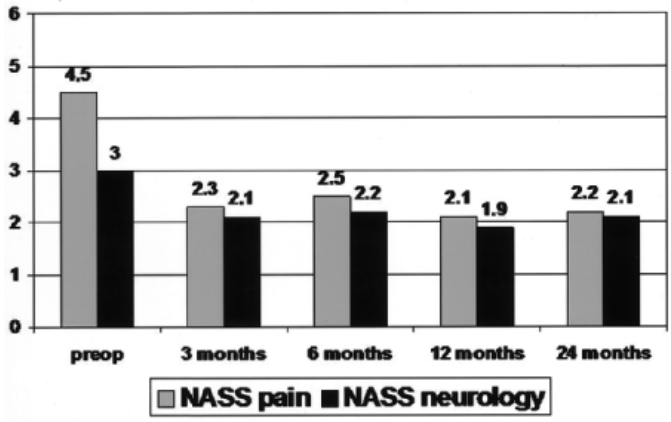

Fig. **7** Mean values of NASS pain and neurology.

were performed except for patients with pareses. Measurement of the lavage fluid inflow and outflow showed maximal 100 mL remaining intracorporal.

122 (37%) of 330 patients without prior operation presented epidural adhesions, which could not be diagnosed preoperative. In 26 (8%), contrary to the MRI findings, there was only compression by hard tissue. Histologically, this was annulus, disc or cartilage. Back pain and complaint duration more than 7 months showed a significant relationship to this finding ($p = 0.027$). Of these patients, 8 underwent revision with conventional spinal canal decompression and 6 with fusion.

There were 8 (2.4%) recurrences within 6 months postoperative which were re-operated in the same technique. 1 patient suffered another recurrence. Histologically, the recurrences consisted to at least 75% of endplate material.

Figs. **6** and **7** show the data of the scales for 309 (93%) non-revised patients. There is a constant improvement in leg pain and daily activates. There was no influence on back pain. 254 (82%) patients no longer had leg pain, 40 (13%) had pain occasionally or the pain was greatly reduced and 15 (5%) experienced no essential improvement. Five of the latter had undergone previous operation at the same level, 10 had compression by hard tissue. There was no significant operation-related deterioration in leg or back pain. Neurological deficits were significantly ($p = 0.013$) better reduced with a history of less than 6 days. All 6 patients with cauda equina syndrome undergoing acute operation achieved complete regression of their bladder-rectal deficits, in 2 cases a unilateral weakness of the foot with hypaesthesia remained. The 8 patients who suffered recurrence reported in extra follow-up examinations having no leg pain after the primary operation in 6 cases and only occasional or considerably reduced leg pain in 2 cases, and after the revision operation no pain in 7 cases and occasional or greatly reduced pain in 1 case. Among all 331 patients, 301 (91%) reported subjective satisfaction and would undergo the procedure again. Overall, of all 331 patients, 29 patients (9%) had a poor result in the sense of no reduction in leg pain (15 patients) or had to undergo open surgery later. 247 patients who were not unemployed or retired returned to their occupation or sports activities, 4 were unable do to so because of persistent pareses. Sick leave following hospitalisation ranged from 5 to 33 days, mean: 16 days.

An MRI with administration of dye was prepared 48 times postoperatively after a period of at least 3 months. In 19 cases, changes in the lateral epidural space were observed, which were considered operation-related. The craniocaudal and dorsoventral expansion was maximally 5 mm and corresponded to the size of the flavum defect. The intraepidural expansion was less than 3 mm in all cases. There were no scars in the access area. This was confirmed macroscopically in the revision procedures. The adjacent vertebral bodies showed no increase in Modic reactions. The revision procedure was neither made more difficult nor lengthened due to the primary operation. The closure in the ligamentum flavum defect was performed macroscopically without involvement of the epidural space, the fatty tissue was preserved. There were no clinical symptoms in the sense of a post-discotomy syndrome.

In the 6 operations under local anaesthesia, intrathecal anaesthesia was required in addition to the systemic sedation. In two cases, intraoperative complications with hypotension and bradycardia occurred which required intervention.

Discussion

The procedure discussed attains the results of the microscopic-assisted procedures in between 75 and 100% of the cases [1–8]. The avoidance or reduction of resection of spinal canal structures which it enables and the minimally-traumatic disc resection appear capable of reducing operation-induced segment instability [5,76–85]. Operation time, tissue traumatisation and complications are low compared to conventional procedures [29,87–94]. The preoperative activity level is attained to a comparably high extent [95]. Operation-related rehabilitative measures are not necessary. There is no operation-related aggravation of existing symptoms, which is consistent with the minimally-invasive epidural and intervertebral procedure [77,82,85,96]. Concomitant diseases do not lead to increased morbidity [89,91,92]. The re-

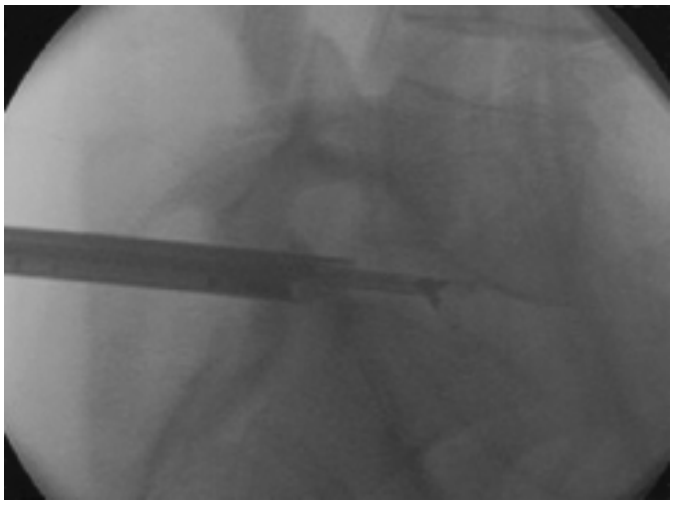

Fig. **8** Limited evacuation of the intervertebral disk because of divergence between interlaminar window and level of the intervertebral space.

duction of neurological deficits could not be predicted on the basis of known results [11,97].

The 29 patients (9%) with poor results all had additional back pain and duration of complaints of more than 7 months. 5 of the patients had previously undergone conventional surgery at the same level, the other 24 were found intraoperatively to have only hard tissue and epidural adhesions instead of soft disc prolapse. Epidural fibroses cannot always be clearly diagnosed in imaging [15,98] and may occur as a consequence of degenerative-inflammatory processes, even without prior surgery or the presence of a disc prolapse [89,99,100]. Still, such findings cannot be considered clearly as a contraindication, since 17 of 22 patients with prior conventional operation at the same level and 96 of 122 patients with epidural fibrosis or hard tissue did attain a sufficient result. Despite the relationship between longer history of complaints and more insufficient results, the authors are of the opinion that there is presently no adequate indication for earlier operative intervention.

Resection of the intradiscal nucleus material is frequently limited due to the divergent level between the interlaminar window and the intervertebral space (Fig. **8**). This may be partly responsible for the recurrence rate of 2.4%, which is slightly above that of conventional techniques but below selective sequestrotomies [101–104]. The authors attempt as complete a resection as possible of the dorsal third of the nucleus space. Due to the histologically-proven high percentage of endplate material in the recurrences, recurrence will not be entirely avoidable. The possible negative effects of excision of a degenerated nucleus of questionable biomechanical function have not yet been completely elucidated [11,12,82,105]. Minimisation of the operation-related annulus defect, which is attained in the technique presented here, is discussed as a protective biomechanical factor [105].

Postoperative MRI examinations show no scarring in the access area or extending to the epidural space, the epidural lubricating fat tissues are preserved. This finding was confirmed in repeated procedures which, unlike following conventional techniques, were neither made more difficult nor required longer operation time [106]. By contrast, epidural scarring, which may become clinically symptomatic in up to 10% of cases, must be expected in conventional techniques [9–12,14,15]. Reduced traumatisation of the ligamentum flavum appears to bring advantages [97,107]. Opening of the ligament to insert the endoscope into the spinal canal can be limited to ca. 5 mm. It must be remembered, however, that epidural scarring may be unremarkable in the MRI [9,15]. Overall, the combination of a lack of clinical symptoms, the MRI findings and the intraoperative revision findings demonstrate reduced scarring due to the procedure described.

Prone positioning of the patient may give rise to hard-to-treat anaesthesiological problems when the operation is performed under local anaesthesia. For this reason, procedures under local anaesthesia are limited to rare cases, taking all risks into consideration.

The optics used have an intraendoscopic working channel of 2.7 mm in diameter. Only correspondingly small, not actively-flexible instruments can be used. Thus, technical problems may arise in the resection of hard tissue and in mobility. The results may not be sufficient in patients with existing scars, epidural fibroses or compression by hard tissue. It may also be that the bony perimeter of the interlaminar window limits access and mobility. Bony resection of the mediodorsal edge of the processus articularis inferior by a few mm is possible, but determining the exact diameter of the interlaminar window in imaging may be difficult. Another problem in mobility may arise because of the divergent level between the interlaminar window and intravertebral space in limited resection of the intradiscal nucleus material.

In order to guarantee complete decompression, disc prolapses usually have to be resected under visual control, even in the full-endoscopic technique. Contrary to various publications [51,52,60,61], the authors see the following limitations in performing a transforaminal procedure, even with lateral access: cranial sequestering beyond the lower edge of the cranial pedicle, caudal sequestering beyond the middle line of the caudal pedicle, and radiological lateral overlay of the foramen intervertebrale by the pelvis to beyond the middle line of the cranial pedicle. Therefore, the authors use the interlaminar approach in herniations which are technically inoperable in the transforminal technique. The following criteria apply as guidelines: radicular compression symptoms due to lumbar disc herniation within the spinal canal, craniocaudal sequestering to maximum half of the adjacent vertebral body, size of the interlaminar window between cranial and caudal lamina and between the middle line and mediodorsal border of the processus articularis inferior at least 6 mm. Concomitant osteochondrosis and spinal canal stenosis are not contraindications. Bilateral and bisegmental procedures, such as may be required also in conventional techniques, are technically possible, taking the indication criteria under consideration. Isolated spinal canal stenoses and back pain are not indications.

In conclusion, the study results presented here show that the operation of lumbar disc herniations is technically possible using

the full-endoscopic interlaminar access. Sufficient decompression under visual control and short operation times are given. The results of conventional operations, which must serve as the standard to be met by new techniques, are attained. There are advantages of the minimally invasive procedure in the form of reduced traumatisation, affecting not only the access pathway, but also the spinal canal structures. In general, patient acceptance is high. Technical problems due to the small instruments may arise in the resection of hard tissue, in achieving sufficient evacuation of the intravertebral space and in creating the access in a bony, too-narrow interlaminar window. The authors consider the technique described to be a sufficient and safe alternative to conventional procedures when the indication criteria are heeded. Coupled with the transforaminal procedure, this provides a considerable expansion of the spectrum for full-endoscopic operation of lumbar disc herniations. New optics with larger working channels and corresponding instruments are currently being developed to reduce the technical problems cited. In the long run, comparative studies with less invasive procedures should be undertaken. However, it appears that open procedures are still necessary and will remain so in the future.

References

[1] Andrews DW, Lavyne MH. Retrospective analysis of microsurgical and standard lumbar discectomy. Spine 1990; 15: 329 – 335
[2] Ebeling U, Reichenberg W, Reulen HJ. Results of microsurgical lumbar discectomy. Review of 485 patients. Acta Neurochir 1986; 81: 45 – 52
[3] Ferrer E, Garcia-Bach M, Lopez L et al. Lumbar microdiscectomy: analysis of 100 consecutive cases. Its pitfalls and final results. Acta Neurochir Suppl 1988; 43: 39 – 43
[4] Hermantin FU, Peters T, Quartarato LA. A prospective, randomized study comparing the results of open discectomy with those of video-assisted arthroscopic microdiscectomy. J Bone Joint Surg [Am] 1999; 81: 958 – 965
[5] Kotilainen E, Valtonen S. Clinical instability of the lumbar spine after microdiscectomy. Acta Neurochir 1993; 125: 120 – 126
[6] McCulloch JA. Principles of microsurgery for lumbar disc diseases. New York: Raven Press, 1989
[7] Nystrom B. Experience of microsurgical compared with conventional technique in lumbar disc operations. Acta Neurol Scand 1987; 76: 129 – 141
[8] Williams RW. Microlumbar discectomy. A 12-year statistical review. Spine 1986; 11: 851 – 852
[9] Annerzt M, Jonsson B, Stromqvist B et al. No relationship between epidural fibrosis and sciatica in the lumbar postdiscectomy syndrome. A study with contrast-enhanced magnetic resonance imaging in symptomatic and asymptomatic patients. Spine 1995; 20: 449 – 453
[10] Fritsch EW, Heisel J, Rupp S. The failed back surgery syndrome: reasons, intraoperative findings and long term results: a report of 182 operative treatments. Spine 1996; 21: 626 – 333
[11] Krämer J. Intervertebral Disk Diseases. Stuttgart: Thieme, 1990
[12] Lewis PJ, Weir BKA, Broad RW et al. Long-term prospective study of lumbosacral discectomy. J Neurosurg 1987; 67: 49 – 54
[13] Ruetten S, Komp M, Godolias G. Spinal cord stimulation using an 8-pole electrode and double-electrode system as minimally invasive therapy of the post-discotomy and post-fusion syndrome. Z Orthop 2002; 140: 626 – 631
[14] Schoeggl A, Maier H, Saringer W et al. Outcome after chronic sciatica as the only reason for lumbar microdiscectomy. J Spinal Disord Tech 2002; 15: 415 – 419
[15] Ruetten S, Meyer O, Godolias G. Epiduroscopic diagnosis and treatment of epidural adhesions in chronic back pain syndrome of patients with previous surgical treatment: first results of 31 interventions. Z Orthop 2002; 140: 171 – 175
[16] Abumi K, Panjabi MM, Kramer KM et al. Biomechanical evaluation of lumbar spinal stability after graded facetectomies. Spine 1990; 15: 1142 – 1147
[17] Haher TR, O'Brien M, Dryer JW et al. The role of the lumbar facet joints in spinal stability. Identification of alternative paths of loading. Spine 1994; 19: 2667 – 2670
[18] Hopp E, Tsou PM. Post-decompression lumbar instability. Clin Orthop 1988; 227: 143 – 151
[19] Kaigle AM, Holm SH, Hansson TH. Experimental instability in the lumbar spine. Spine 1995; 20: 421 – 430
[20] Kato Y, Panjabi MM, Nibu K. Biomechanical Study of lumbar spinal stability after osteoplastic laminectomy. J Spinal Disord 1998; 11: 146 – 150
[21] Kotilainen E. Clinical instability of the lumbar spine after microdiscectomy. In: Gerber BE, Knight M, Siebert WE (eds). Lasers in the musculoskeletal system. Berlin, Heidelberg, New York: Springer, 2001: 241 – 243
[22] Sharma M, Langrana NA, Rodrigues J. Role of ligaments and facets in lumbar spinal stability. Spine 1995; 20: 887 – 900
[23] Cooper R, Mitchell W, Illimgworth K et al. The role of epidural fibrosis and defective fibrinolysis in the persistence of postlaminectomy back pain. Spine 1991; 16: 1044 – 1048
[24] Waddell G, Reilly S, Torsney B et al. Assessment of the outcome of low back surgery. J Bone Joint Surg [Br] 1988; 70: 723 – 727
[25] Hedtmann A. The so-called post-discotomy syndrome – failure of intervertebral disc surgery? Z Orthop 1992; 130: 456 – 466
[26] Kim SS, Michelsen CB. Revision surgery for failed back surgery syndrome. Spine 1992; 17: 957 – 960
[27] Parke WW. The significance of venous return in ischemic radiculopathy and myelopathy. Orhop Clin North Am 1991; 22: 213 – 220
[28] Schick U, Doehnert J, Richter A et al. Microendoscopic lumbar discectomy versus open surgery: an intraoperative EMG study. Eur Spine 2002; 11: 20 – 26
[29] Weber BR, Grob D, Dvorak J et al. Posterior surgical approach to the lumbar spine and its effect on the multifidus muscle. Spine 1997; 22: 1765 – 1772
[30] Devulder J, De Laat M, Van Batselaere M et al. Spinal cord stimulation: a valuable treatment for chronic failed back surgery patients. J Pain Symptom Manage 1997; 13: 296 – 301
[31] Rainov NG, Heidecke V, Burkert W. Short test-period spinal cord stimulation for failed back surgery syndrome. Minim Invas Neurosurg 1996; 39: 41 – 44
[32] Maroon JC. Current concepts in minimally invasive discectomy. Neurosurgery 2002; 51: 137 – 145
[33] Adson AW, Ott WO. Results of the removal of tumors of the spinal cord. Arch Neurol Psychiatry 1922; 8: 520 – 538
[34] Bucy PC. Chondroma of intervertebral disc. JAMA 1930; 94: 1552
[35] Mixter WJ, Barr JS. Rupture of the intervertebral disc with involvement of the spinal canal. N Engl J Med 1934; 211: 205 – 210
[36] Putti V. Pathogenesis of sciatic pain. Lancet 1927; 2: 53
[37] Steinke CR. Spinal tumors: Statistics on a series of 330 collected cases. J Nerv Ment Dis 1918; 47: 418 – 426
[38] Stookey B. Compression of spinal cord due to ventral extradural chondromas: diagnosis and surgical treatment. Arch Neurol Psychiatry 1928; 20: 275 – 291
[39] Hult L. Retroperitoneal disc fenestration in low back pain and sciatica. Acta Orthop Scand 1956; 20: 342 – 348
[40] Smith L, Gorvin PJ, Gesler RM et al. Enzyme dissolution of the annulus pulposus. Nature 1963; 198: 1311 – 1312
[41] Gottlob C, Kopchok G, Peng SH et al. Holmium:YAG laser ablation of human intervertebral disc: Preliminary evaluation. Lasers Surg Med 1992; 12: 86 – 91
[42] Hijikata S. Percutaneous discectomy: a new treatment method for lumbar disc herniation. J Toden Hosp 1975; 5: 5 – 13
[43] Kambin P, Gellman H. Percutaneous lateral discectomy of the lumbar spine: a preliminary report. Clin Orthop 1983; 174: 127 – 132
[44] Maroon JC, Onik G, Sternau L. Percutaneous automated discectomy: a new approach to lumbar surgery. Clin Orthop 1989; 238: 64 – 70
[45] Onik G, Helms C, Ginsburg L et al. Percutaneous lumbar discectomy using a new aspiration probe. Am J Roentgenol 1985; 144: 1137 – 1140
[46] Valls J, Ottolenghi CE, Schajowicz F. Aspiration biopsy in diagnosis of lesions of vertebral bodies. JAMA 1948; 136: 376
[47] Forst R, Hausmann G. Nucleoscopy: A new examination technique. Arch Orthop Trauma Surg 1983; 101: 219 – 221

[48] Epstein J, Adler R. Laser-assisted percutaneous endoscopic neurolysis. Pain Physician 2000; 3: 43 – 45
[49] Ruetten S, Meyer O, Godolias G. Application of holmium:YAG laser in epiduroscopy: extended practicabilities in the treatment of chronic back pain syndrome. J Clin Laser Med Surg 2002; 20: 203 – 206
[50] Kambin P, Casey K, O'Brien E et al. Transforaminal arthroscopic decompression of the lateral recess stenosis. J Neurosurg 1996; 84: 462 – 467
[51] Kambin P, O'Brien E, Zhou L et al. Arthroscopic microdiscectomy and selective fragmentectomy. Clin Orthop 1998; 347: 150 – 167
[52] Kambin P, Sampson S. Posterolateral percutaneous suction-excision of herniated lumbar intervertebral discs: Report of interim results. Clin Orthop 1986; 207: 37 – 43
[53] Kambin P, Zhou L. History and current status of percutaneous arthroscopic disc surgery. Spine 1996; 21: 57 – 61
[54] Kambin P. Arthroscopic microdiscectomy. Baltimore: Urban & Schwarzenberg, 1991
[55] Lew SM, Mehalic TF, Fagone KL. Transforaminal percutaneous endoscopic discectomy in the treatment of far-lateral and foraminal lumbar disc herniations. J Neurosurg 2001; 94: 216 – 220
[56] Mathews HH. Transforaminal endoscopic microdiscectomy. Neurosurg Clin North Am 1996; 7: 59 – 63
[57] Mayer HM, Brock M. Percutaneous endoscopic discectomy: surgical technique and preliminary results compared to microsurgical discectomy. J Neurosurg 1993; 78: 261
[58] Savitz MH. Same-day microsurgical arthroscopic lateral-approach laser-assisted (SMALL) fluoroscopic discectomy. J Neurosurg 1994; 80: 1039 – 1045
[59] Siebert W. Percutaneous nucleotomy procedures in lumbar intervertebral disc displacement. Orthopade 1999; 28: 598 – 608
[60] Stücker R. The transforaminal endoscopic approach. In: Mayer HM (ed). Minimally invasive spine surgery. Berlin, Heidelberg, New York: Springer, 2000: 201 – 206
[61] Tsou PM, Yeung AT. Transforaminal endoscopic decompression for radiculopathy secondary to intracanal noncontained lumbar disc herniations: outcome and technique. Spine J 2002; 2: 41 – 48
[62] Yeung AT, Tsou PM. Posterolateral endoscopic excision for lumbar disc herniation: Surgical technique, outcome and complications in 307 consecutive cases. Spine 2002; 27: 722 – 731
[63] Caspar W. A new surgical procedure for lumbar disc herniation causing less tissue damaging through a microsurgical approach. In: Wüllenweber R, Brock M (eds). Advances in Neurosurgery. Berlin: Springer, 1977; Vol 7: 74 – 77
[64] Goald HJ. Microlumbar discectomy – Follow-up of 147 patients. Spine 1978; 3: 183 – 185
[65] Goald HJ. Microlumbar discectomy: follow-up of 477 patients. J Microsurg 1981; 2: 95 – 100
[66] Wilson DH, Kenning J. Microsurgical lumbar discectomy: preliminary report of 83 consecutive cases. Neurosurgery 1979; 42: 137 – 140
[67] Brayda-Bruno M, Cinnella P. Posterior endoscopic discectomy (and other procedures). Eur Spine J 2000; 9: S24 – S29
[68] Destandau J. A special device for endoscopic surgery of lumbar disc herniation. Neurol Res 1999; 21: 39 – 42
[69] Nakagawa H, Kamimura M, Uchiyama S et al. Microendoscopic discectomy (MED) for lumbar disc prolapse. J Clin Neurosci 2003; 10: 231 – 235
[70] Perez-Cruet MJ, Foley KT, Isaacs RE et al. Microendoscopic lumbar discectomy: technical note. Neurosurgery 2002; 51: 129 – 136
[71] Andersson GBJ, Brown MD, Dvorak J et al. Consensus summary on the diagnosis and treatment of lumbar disc herniation. Spine 1996; 21: 75 – 78
[72] McCulloch JA. Focus issue on lumbar disc herniation: macro- and microdiscectomy. Spine 1996; 21: 45 – 56
[73] Daltroy LH, Cats-Baril WL, Katz JN et al. The North American Spine Society (NASS) Lumbar Spine Outcome Instrument: Reliability and validity tests. Spine 1996; 21: 741 – 749
[74] Pose B, Sangha O, Peters A et al. Validation of the North American Spine Society Instrument for assessment of health status in patients with chronic backache. Z Orthop 1999; 137: 437 – 441
[75] Fairbank JCT, Couper J, Davies JB et al. The Oswestry low back pain questionnaire. Physiotherapy 1980; 66: 271 – 273
[76] Ebara S, Harada T, Hosono N et al. Intraoperative measurement of lumbar spinal instability. Spine 1992; 17: 44 – 50
[77] Faulhauer K, Manicke C. Fragment excision versus conventional disc removal in the microsurgical treatment of herniated lumbar disc. Acta Neurochir 1995; 133: 107 – 111
[78] Goel VK, Nishiyama K, Weinstein JN et al. Mechanical properties of lumbar spinal motion segments as affected by partial disc removal. Spine 1986; 11: 1008 – 1012
[79] Iida Y, Kataoka O, Sho T et al. Postoperative lumbar spinal instability occurring or progressing secondary to laminectomy. Spine 1990; 15: 1186 – 1189
[80] Johnsson KE, Redlund-Johnell I, Uden A et al. Preoperative and postoperative instability in lumbar spinal stenosis. Spine 1989; 14: 591 – 593
[81] Kambin P, Cohen L, Brooks ML et al. Development of degenerative spondylosis of the lumbar spine after partial discectomy: comparison of laminotomy, discectomy and posterolateral discectomy. Spine 1994; 20: 599 – 607
[82] Mochida J, Nishimura K, Nomura T et al. The importance of preserving disc structure in surgical approaches to lumbar disc herniation. Spine 1996; 21: 1556 – 1564
[83] Mochida J, Toh E, Nomura T. The risks and benefits of percutaneous nucleotomy for lumbar disc herniation. A 10-year longitudinal study. J Bone Joint Surg [Br] 2001; 83: 501 – 505
[84] Natarajan RN, Andersson GB, Padwardhan AG et al. Study on effect of graded facetectomy on change in lumbar motion segment torsional flexibility using three-dimensional continuum contact representation for facet joints. J Biomech Eng 1999; 121: 215 – 221
[85] Ross JS, Robertson JT, Frederickson RC et al. Association between peridural scar and recurrent radicular pain after lumbar discectomy: Magnetic resonance evaluation. Neurosurgery 1996; 38: 861 – 863
[86] Zander T, Rohlmann A, Kloeckner C et al. Influence of graded facetectomy and laminectomy on spinal biomechanics. Eur Spine J 2003; 12: 427 – 434
[87] Caspar W, Campbell B, Barbier DD et al. The Caspar microsurgical discectomy and comparison with a conventional standard lumbar disc procedure. Neurosurgery 1991; 28: 78 – 87
[88] Mayer HM. The microsurgical interlaminar, paramedian approach. In: Mayer HM (ed). Minimally Invasive Spine Surgery. Berlin, Heidelberg, New York: Springer, 2000: 79 – 91
[89] Ramirez LF, Thisted R. Complications and demographic characteristics of patients undergoing lumbar discectomy in community hospitals. Neurosurgery 1989; 25: 226 – 231
[90] Rantanen J, Hurme M, Falck B et al. The lumbar multifidus muscle five year after surgery for a lumbar intervertebral disc herniation. Spine 1993; 18: 568 – 574
[91] Rompe JD, Eysel P, Zollner J et al. Intra- and postoperative risk analysis after lumbar intervertebral disk operation. Z Orthop 1999; 137: 201 – 205
[92] Stolke D, Sollmann WP, Seifert V. Intra- and postoperative complications in lumbar disc surgery. Spine 1989; 14: 56 – 59
[93] Wildfoerster U. Intraoperative complications in lumbar intervertebral disc operations. cooperative study of the spinal study group of the German Society of Neurosurgery. Neurochirurgica 1991; 34: 53 – 56
[94] Wilson DH, Harbaugh R. Lumbar discectomy: a comparative study of microsurgical and standard technique. In: Hardy RW (ed). Lumbar disc disease. New York: Raven Press, 1992: 147 – 156
[95] Donceel P, Du Bois M. Fitness for work after lumbar disc herniation: a retrospective study. Eur Spine 1998; 7: 29 – 35
[96] Balderston RA, Gilyard GG, Jones AM et al. The treatment of lumbar disc herniation: simple fragment excision versus disc space curettage. J Spinal Disord 1991; 4: 22 – 25
[97] Aydin Y, Ziyal IM, Dumam H et al. Clinical and radiological results of lumbar microdiscectomy technique with preserving of ligamentum flavum comparing to the standard microdiscectomy technique. Surg Neurol 2002; 57: 5 – 13
[98] Ruetten S, Meyer O, Godolias G. Endoscopic surgery of the lumbar epidural space (epiduroscopy): results of therapeutic intervention in 93 patients. Minim Invas Neurosurg 2003; 46: 1 – 4
[99] Knight MTN, Goswami A, Patko JT. Endoscopic foraminiplasty: a prospective study on 250 consecutive patients with independent evaluation. J Clin Laser Med Surg 2001; 19: 73 – 81
[100] Saberski LR, Kitahata LM. Persistent radiculopathy diagnosed and treated with epidural endoscopy. J Anesth 1996; 10: 1 – 4

[101] Boyer P, Srour R, Buchheit F et al. Lumbar disc hernia. Excision of hernia with or without complementary discectomy? Neurochirurgie 1994; 40: 259 – 262
[102] Hirabayashi S, Kumano K, Ogawa Y et al. Microdiscectomy and second operation for lumbar disc herniation. Spine 1993; 18: 2206 – 2211
[103] Stambough JL. Lumbar disk herniation: an analysis of 175 surgically treated cases. J Spinal Disord 1997; 10: 488 – 492
[104] Wenger M, Mariani L, Kalbarczyk A et al. Long-term outcome of 104 patients after lumbar sequestrectomy according to Williams. Neurosurgery 2001; 49: 329 – 334
[105] Zollner J, Rosendahl T, Herbsthofer B et al. The effect of various nucleotomy techniques on biomechanical properties of the intervertebral disc. Z Orthop 1999; 137: 206 – 210
[106] Suk KS, Lee HM, Moon SH et al. Recurrent lumbar disc herniation: results of operative management. Spine 2001; 26: 672 – 676
[107] De Devitiis E, Cappabianca P. Lumbar discectomy with preservation of the ligamentum flavum. Surg Neurol 2002; 58: 68 – 69

Endoscopic Endonasal Approach for Cerebrospinal Fluid Fistulae

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Abstract

Different techniques have been proposed to repair cerebrospinal fluid rhinorrhea. Advances in nasal surgery led to a high success rate and low morbidity for the endonasal approach. It has become the favorite route for treating cerebrospinal fluid leaks of the anterior skull base. Better results have been obtained with the improvement of rigid endoscopes and intrathecal sodium fluorescein. In a prospective study, twenty-four patients with cerebrospinal fluid rhinorrhea were evaluated and treated by endoscopic endonasal surgery. In all cases intrathecal sodium fluorescein enabled a precise localization of the bone defect. The most common causes of CSF rhinorrhea were traumatic (8 cases, 33%), spontaneous (6 cases, 25%), and iatrogenic (5 cases, 20.8%). Preoperative radiological evaluations (plane CT, CT cisternogram and MRI) showed the exact site and size of the defect in all patients. The most common site of leakage was the ethmoidal roof-cribriform plate. Primary closure was achieved in all patients. There were no major operative or postoperative complications. The endoscopic endonasal approach can be considered the first choice in the treatment of cerebrospinal fluid rhinorrhea.

Key words

Cerebrospinal fluid · fistulae · endoscopic endonasal approach · paranasal sinus

Introduction

Cerebrospinal fluid (CSF) rhinorrhea involves a breakdown of the barriers that separate the subarachnoid space from the upper aerodigestive tract, namely, the nasal cavity mucosa or paranasal sinus, skull base (i.e., bone), dura mater, and arachnoid membrane. The etiology of CSF leaks is diverse. Although the incidence of CSF fistula after endoscopy sinus surgery is less than 1%, it is still a common cause of iatrogenic CSF fistula. Blunt trauma to the head is another frequent cause which is diagnosed in 3% of all patients who have a closed head injury and in over 30% of patients who have skull base fractures. Although less common, conditions that increase the ventricular pressure, such as intracranial tumors and post-traumatic and post-infectious hydrocephalus are also frequent causes of CSF leaks [1]. Many of the CSF leaks that occur after blunt trauma or skull base surgery are solved by conservative measures, such as bed rest, elevation of the head, avoidance of straining activities, and/or decreasing the CSF pressure with spinal taps or drains.

The history of surgical repair of CSF leaks began with Walter Dandy who performed the first successful intracranial repair in 1926 [2]. In 1948, Dohlman described the first extracranial approach to repair CSF rhinorrhea using a nasoorbital incision [3]. In 1952, the Austrian Oskar Hirsch was the first to use the transseptal approach to repair a sphenoidal leak [4]. In 1981, Wigand was the first to introduce the usage of nasal endoscopes to repair CSF fistulas at the University of Erlangen, Germany. That technique was developed and diffused worldwide by Stammberger from the University of Graz, Austria [5].

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Bibliography
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The surgical management of a CSF fistula remains controversial as it depends on the etiology of the leak, the location of the fistula and the temporal relationship of the leak with the inciting factor [6]. The open frontal craniotomy procedure has consistently been chosen as the neurosurgical procedure applied. Some authors reported excellent results in 90% [7] while other groups have seen lower success rates of approximately 60% [8]. The surgical repair of CSF leaks has improved as the result of technological advances and increased experience with transnasal endoscopic techniques. The purpose of this study is to ascertain the outcome of endoscopic repair of CSF leaks and whether the usage of specific techniques and materials offers significant advantages regarding outcome.

Patients and Methods

Between April 2001 and December 2004, twenty-four patients with CSF rhinorrhea were managed at Federal University of São Paulo. Patient's age ranged from 10 to 79 years (average: 39 years). There were 13 males and 11 females.

The etiologies of the leaks were traumatic in 8 cases, iatrogenic in 5 cases, spontaneous (normal pressure leak) in 5 cases, meningeo-encephalocele in 3 cases, treatment of prolactinoma (dopamine agonist bromocriptine) in 2 cases, and neoplasm invading the skull base in 1 case. Data regarding location and clinical features are summarized in Table **1**.

All patients presented unilateral CSF rhinorrhea (intermittent in 17 and continuous in 7 cases), 12 noticed headache, and 10 presented meningitis.

Preoperative high-resolution plane computed tomography (CT), CT with intrathecal non-ionic contrast (cisternogram) in axial and coronal cuts and magnetic resonance imaging (MRI) of the brain and paranasal sinuses using 2 mm slice thickness were done for patients who showed any causative intracranial lesions, to identify bony abnormalities within the sinuses or skull base, or to determine the site and size of the defect. A preoperative nasal endoscopic examination was performed in uncertain cases.

All patients had postoperative antibiotic cover, second-generation cephalosporins (Cefuroxime) for 24 hours. Postoperative lumbar CSF drainage was not necessary in any case.

All patients have undergone surgery under general anesthesia. Operations were performed with Karl Storz rigid endoscopes of 0 , 30 and 45 with a diameter of 4 mm.

Fluorescein was injected in all patients under general anesthesia after lumbar tap. With aspiration of 10 mL of water, adding 5% sodium fluorescein in a 0.1 mL/10 kg rate, with a limit rate of 1 mL. The head of the patient was placed slightly above the heart level [9].

The endoscopic approach was fairly standardized. The nasal cavity was prepared with topic pledgets dripped 1 : 1000 adrenaline. Intranasal endoscopy was performed. An anterior or posterior ethmoidectomy was performed when a fistula was located in the cribriform plate or in the superior border of the sphenoid sinus (Figs. **1** and **2**). In these cases, removal of the middle turbinate was performed in order to improve exposure of the region. In all cases, active leakage of a bright yellow-green fluid was demonstrated. All bleeding was carefully controlled with suction cautery. The leak site was identified by direct visualization. The sphenoid sinus ostium was carefully identified (medial to middle turbinate) and enlarged when a fistula was located in the sphenoid sinus (Figs. **3** and **4**).

Table **1** Age, sex, etiology, site and follow-up in patients treated surgically for CSF rhinorrhea

No.	*Age*	*Sex*	*Etiology*	*Site*	*Follow-up (months)*
1	25	m	trauma	ethmoid (right anterior)	44
2	16	m	trauma	ethmoid (cribriform plate)	42
3	79	m	during FESS for sinonasal polyposis	ethmoid (left posterior)	42
4	54	m	spontaneous	sphenoid (right roof)	42
5	48	f	meningeo-encephalocele	sphenoid (left roof)	40
6	53	f	after treatment for prolactinoma	sphenoid (right roof)	37
7	47	f	spontaneous	ethmoid (right anterior)	37
8	22	m	trauma	ethmoid (right anterior)	34
9	68	m	during FESS for sinonasal polyposis	ethmoid (left anterior)	34
10	35	f	spontaneous	sphenoid (left roof)	33
11	51	f	spontaneous	ethmoid (cribriform plate)	32
12	66	m	during FESS for chronic ethmoidal sinusitis	ethmoid (left anterior)	31
13	38	f	after sublabial-trans-septal-transsphenoid hypophysectomy	sphenoid (right roof)	29
14	38	m	during FESS for chronic ethmoidal sinusitis	ethmoid (left anterior and posterior)	29
15	47	f	after treatment for prolactinoma	sphenoid (right roof)	27
16	40	m	trauma	ethmoid (posterior)	22
17	16	f	trauma	frontal (posterior)	18
18	22	m	meningeo-encephalocele	ethmoid (cribriform plate)	16
19	20	m	trauma	ethmoid (right anterior)	15
20	27	m	trauma	ethmoid (anterior) and frontal	15
21	44	f	spontaneous	ethmoid (anterior and posterior)	14
22	31	f	trauma	ethmoid (left anterior)	11
23	42	m	meningeo-encephalocele	ethmoid (cribriform plate) and sphenoid (roof)	7
24	10	f	spontaneous	rhinopharynx	6

* FESS = functional endoscopic sinus surgery.

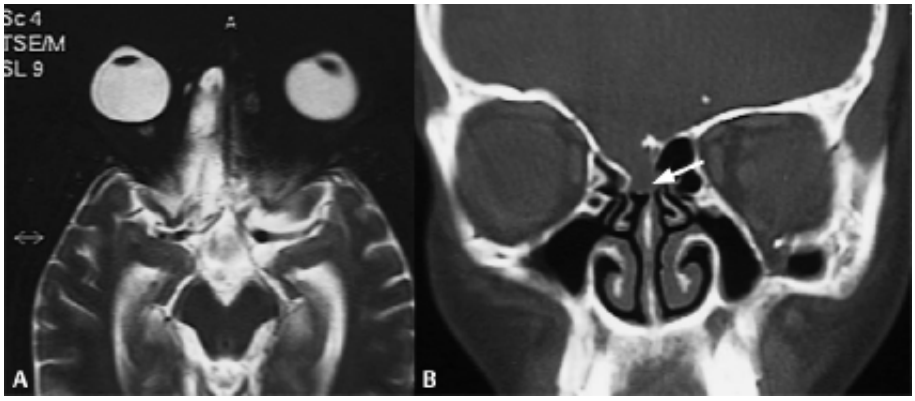

Fig. **1** **A** Axial T_2-weighted MRI. Bright signal from trapped CSF. **B** Coronal CT. CSF fistula (red arrow) at the cribriform plate.

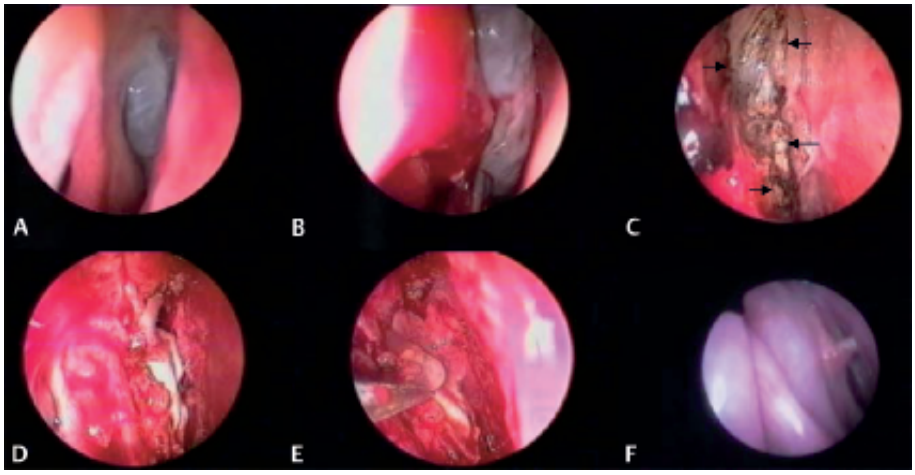

Fig. **2** Endoscopic image of the right nasal fossa (0 endoscope). **A** and **B** Meningeal protrusion, anatomically sited below the cribriform plate. **C** After cauterization of the meningoencephalocele. **D** Graft positioning. **E** Placing fibrin glue. **F** Postoperative image at 6 weeks.

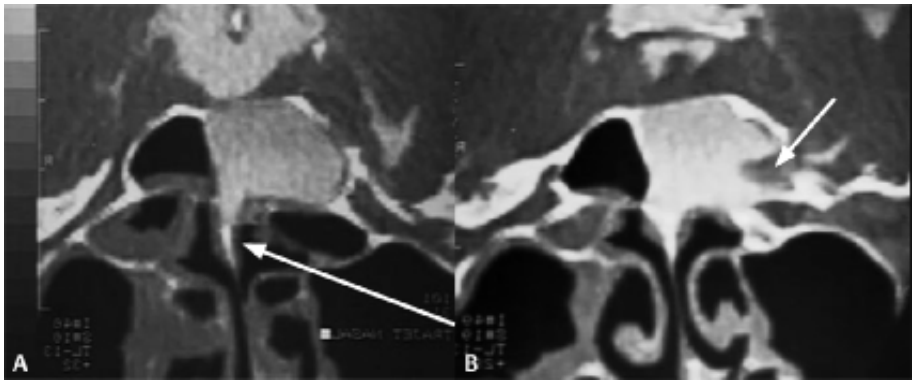

Fig. **3** Coronal CT cisternogram. **A** and **B** Meningeal protrusion occupying the left sphenoid sinus (red arrow).

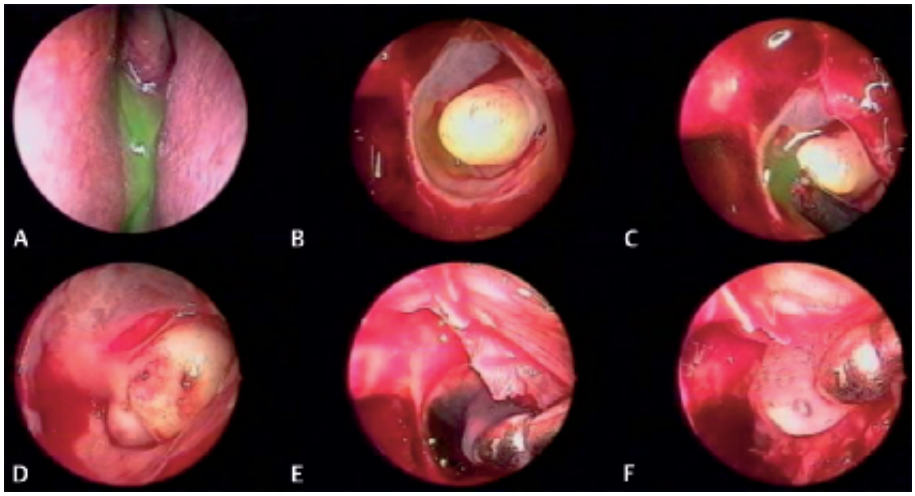

Fig. **4** Endoscopic image of the left nasal fossa. Green fluorescent dye. **B** Meningeal protrusion is highlighted with fluorescein. **C** Cauterization of the meningoencephalocele. **D** Graft positioning. **E** and **F** Placing Surgicel® and fibrin glue.

Once the defect was identified, the surrounding bony edges and mucosa around it were freed from soft tissues with small-cupped forceps in order to allow the graft to firmly adhere to the skull base. The underlay technique was used in all cases. The fistula was repaired by placing the grafting material as follows: Surgicel®, fibrin glue (rapidly polymerizing fibrin glue, Beriplast®), strips of mucoperiosteum from the middle turbinate and a piece of septal cartilage (obtained by septoplasty) and/or abdominal fat and finally another layer of fibrin glue.

The patient was subjected to the Valsalva maneuver by the anesthesiologist and its effect at the leakage site was observed. If further leakage was seen, the abdominal fat or mucoperiosteum plug was modified and replaced until no further leakage was visualized. Then, fibrin glue was dribbled over the mucoperiosteum creating a seal. After the operation patients were kept in bed rest from 3 to 5 days.

Patients were reviewed weekly as outpatients for the first two months. Follow-up ranged from 6 to 44 months (average: 27.4 months).

Results

The most common causes of CSF rhinorrhea in this work were traumatic (8 cases, 33%), spontaneous (6 cases, 25%), and iatrogenic (5 cases, 20.8%) (Table **1**).

Preoperative radiological evaluations (plane CT, CT cisternogram and MRI) showed the exact site and size of the defect in all patients. MRI showed a bright signal from trapped CSF or herniated arachnoid in the dural bone defect, T_2-weighted images showed the same finding as the CT cisternogram regarding the site of the CSF fistula.

The most common site of leakage was the ethmoidal roof-cribriform plate (Table **1**). Defects in the cribriform plate were mainly in the fovea ethmoidalis adjacent to the anterior ethmoidal artery. There were no major operative or postoperative complications.

Complete closure of the leaks was achieved in all patients. In one patient (case no. 23), the leak recurred postoperatively and was treated with a second endoscopic endonasal approach. In another patient (case no. 20), a craniotomy was performed to close the bone defect.

Discussion

The operative management of CSF rhinorrhea can be divided into intracranial and extracranial approaches. There are advantages and disadvantages for each of them [5–8,10–20]. Extracranial repairs are associated with decreased morbidity, decreased incidence of anosmia, and superior exposure of the ethmoid and sphenoid regions with success rates from 80 to 90% [18].

Considering less invasive procedures does not eliminate the option for craniotomy, if these are unsuccessful. The success of these approaches depends on the surgeon's experience. Acceptable closure rates can be obtained from any of these approaches [21].

With the advent of the surgical microscope and the rigid endoscope, the endonasal approach has become the most commonly used one for the initial closure of CSF leaks in this area. It allows excellent visualization of the leakage site, easy lifting of the surrounding mucosa and easy placement of the graft over the defect [14,19].

Initially, extracranial endonasal repairs of CSF leaks involved the use of a mucosal flap from the sinonasal tract, such as septal [22] and osteomucoperiosteal flaps from the middle turbinate [23]. In general, the advantage of a flap over a graft is its immediate viability which, in theory, increases the ability to heal. However, free tissue grafts are not much technically demanded and do not yield similar results. Furthermore, free grafts and flaps can be combined to reinforce the repair [1].

Throughout the literature, the choice of materials used during microscopic or endoscopic repair of CSF fistulas seems to depend on the experience and familiarity of the operating surgeons with the various techniques. Wigand [12] and Stankiewicz [13] described repairing CSF fistulas using a turbinate mucosa free graft with fibrin glue and post-auricular fat and temporalis facia, respectively. Papay et al. [24] described the endoscopic repair of spontaneous or traumatic CSF rhinorrhea using facia lata, muscle, and fat. Lanza et al. [14] repaired 42 skull base defects in 36 patients using mucoperichondrial and mucoperiosteal graft and septal cartilage.

It is also controversial whether the underlay or the overlay technique is superior. During the underlay technique, intact dura is detached from the edge of the bony defect to expose an adequate buttress for stable graft insertion. The graft is designed in such a way that it can be pushed a few millimeters between the bone and the raised intact dura on all sides of the defect as was indicated in our cases. The overlay (onlay) technique would be used if there was any risk that nerves or vessels could be damaged when raising dura from the surrounding bone or when the inlay technique was not technically possible. The graft was placed over the dural lesion and over exposed bony margins that had been denuded. Afterwards, the graft was supported in the place with layers of some types of fixators, such as Gelfoam®, Surgicel®, or fibrin glue [15–19,24]. Some studies reported that the form of graft positioning is not a critical factor in predicting the success of the procedure [12,16,24].

Fibrin glues have been widely used in neurosurgery. These glues are mainly used for preventing CSF leakage but they are also used for achieving homeostasis on the dura mater, for cranioplasty using resected autologous bone fragments, for anastomoses of nerves and vessels, and for the inclusion of antibiotics [25]. In the current study, fibrin glue was used as a sealant rather than an adhesive and also to form a tough fibrin clot plate that sufficiently sealed dural tears to prevent (CSF) leakage. It was used as an adjunct and not as a substitute for water-tight closure providing the most assured means of avoiding CSF leaks.

Failure to repair the defect by the endoscopic approach may be related to the inability to localize the defect successfully, to graft displacement, to insufficient graft size, to incomplete apposition of the graft to the skull base defect, and/or to patient non-compliance with postoperative instructions [19].

Contraindications to the endoscopic treatment of CSF fistulas include the presence of an intracranial lesion, a fracture of the posterior wall of the frontal sinus, lateral extensions of the frontal sinus and CSF rhinorrhea from a temporal bone defect [20].

Complications in repairing CSF fistulas include meningitis, chronic headache, pneumocephalus, intracranial hematomas, frontal lobe abscess, and anosmia which can all be consequences of transcranial or transendoscopic repair. Failure to repair the fistula or a recurrence of the CSF leak with associated neurological signs of meningeal irritation or both were also reported. On a meta-analysis, Hegazy [1] revealed a very low incidence of surgical complications such as meningitis (0.3%), smell disorders (0.6%), and headache (0.3%). Whether endoscopic approaches improve this tendency remains to be analyzed. Our patients have not had the common complications to nasal surgery such as nasal obstruction, headaches, and chronic or recurrent sinusitis.

Conclusion

The transnasal endoscopic technique provides superior visualization, facilitates precise graft placement and repairs cranionasal fistulae with excellent results effectively.

References

[1] Hegazy HM, Carrau RL, Snyderman CH, Kassam A, Zweig J. Transnasal endoscopic repair of cerebrospinal fluid rhinorrhea: a meta-analysis. Laryngoscope 2000; 110: 1166 – 1172

[2] Dandy W. Pneumocephalus (intracranial pneumatocele or aerocele). Arch Surg 1926; 12: 949 – 982

[3] Dohlman G. Spontaneous cerebrospinal rhinorrhea. Acta Otolaryngol 1948; 67 (Suppl): 20 – 23

[4] Hirsch O. Successful closure of cerebrospinal fluid rhinorrhea by endonasal surgery. Arch Otolaryngol 1952; 56: 1 – 13

[5] Stammberger H, Greistorfer K, Wolf G, Luxemberger W. Operativer Verschluß von Liquorfisteln der vorderen Schädelbasis unter intrathekaler Natrium-Fluoreszeinanwendung. Laryngol Rhinol Otol 1997; 76: 595 – 607

[6] Stamm AC, Freire LAS. Microendoscopic surgery of the paranasal sinuses and the skull base. In: Stamm AC, Draf W (eds). Microscopic and endoscopic surgery of the nose and sinuses. Heidelberg, New York, Berlin, Springer Verlag, 2000: 451 – 463

[7] Costa H, Cerejo A, Baptista A, Vaz R, Gonçalves M, Guimarães A et al. The galea frontalis myofascial flap in anterior fossa CSF leaks. Br J Plast Surg 1993; 46: 503 – 507

[8] Park JI, Strelzow VV, Friedman WH. Current management of cerebrospinal fluid rhinorrhea. Laryngoscope 1983; 93: 1294 – 1300

[9] Guimarães R, Becker H. A new technique for the use of intrathecal fluorescein in the repair of CSF rhinorrhea using a hypodense diluent. Rev Laryngol Otol Rhinol 2001; 122 (3): 195 – 200

[10] Jho HD, Alfieri A. Endoscopic endonasal pituitary surgery: evolution of surgical technique and equipment in 150 operations. Minim Invas Neurosurg 2001; 44: 1 – 12

[11] Cappabianca P, Alfieri A, de Divitiis E. Endoscopic endonasal transsphenoidal to the sella:towards functional endoscopic pituitary surgery. Minim Invas Neurosurg 1998; 41: 66 – 73

[12] Wigand WE. Transnasal ethmoidectomy under endoscopic control. Rhinology 1981; 19: 7 – 15

[13] Stankiewicz JA. Cerebrospinal fluid fistula and endoscopic sinus surgery. Laryngoscope 1991; 101: 250 – 256

[14] Lanza DC, O'Brien DA, Kennedy DW. Endoscopic repair of cerebrospinal fluid fistulae and encephaloceles. Laryngoscope 1996; 106: 1119 – 1125

[15] Burns JA, Dodson EE, Gross CW. Transnasal endoscopic repair of cranionasal fistulae: a refined technique with long-term follow-up. Laryngoscope 1996; 106: 1080 – 1083

[16] Mattox DE, Kennedy DW. Endoscopic management of cerebrospinal fluid leaks and cephaloceles. Laryngoscope 1990; 100: 857 – 862

[17] Applebaum EL, Chow JM. Otolaryngology head and neck surgery, volume 2-A, 3rd edn. In: Cummings CW, Fredrickson JM, Harker LA et al. (eds). London: Mosby, 1999

[18] Daly DT, Lydiatt WM, Ogren FP, Moore GF. Extracranial approaches to repair of cerebrospinal fluid rhinorrhea. Ear Nose Throat J 1992; 71: 311 – 313

[19] El-Banhawy OA, Halaka AN, El-Dien AES, Ayad H. Subcranial transnasal repair of cerebrospinal fluid rhinorrhea with free autologous grafts by the combined overlay and underlay techniques. Minim Invas Neurosurg 2004; 47: 197 – 202

[20] Landeiro JA, Flores MS, Lázaro BCR, Melo MH. Surgical management of cerebrospinal fluid rhinorrhea under endoscopic control. Arq Neuropsiquiatr 2004; 62 (3-B): 827 – 831

[21] Kelley TF, Stankiewicz JA, Chow JM, Origitano TC, Shea J. Endoscopic closure of post surgical anterior cranial fossa cerebrospinal fluid leaks. Neurosurgery 1996; 39: 743 – 746

[22] Montgomery WW. Cerebrospinal rhinorrhea. Otolaryngol Clin North Am 1973; 6: 757 – 771

[23] Yessenow RS, McCabe BF. The osteomucoperiosteal flap in repair of CSF rhinorrhea: a 20-year experience. Otolaryngol Head Neck Surg 1989; 101: 555 – 558

[24] Papay FA, Maggiano H, Dominquez S, Hassenbusch SJ, Levine HL, Lavertu P. Rigid endoscopic repair of paranasal sinus cerebrospinal fluid fistulas. Laryngoscope 1989; 99: 1195 – 1201

[25] Velthoven V van, Clarici G, Auer LM. Fibrin tissue adhesive sealant for the prevention of CSF leakage following transsphenoidal microsurgery. Acta Neurochir (Wien) 1991; 109: 26 – 29

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Image-Guided Endonasal Transsphenoidal Microsurgical Treatment of Recurrent Microadenomas of the Pituitary Gland

Abstract

Background: Neuronavigation is a commonly used technology that provides continuous, three-dimensional information for the precise localization of and surgical trajectory to brain lesions. This study was performed to evaluate the role that navigation can play in assisting microsurgical transsphenoidal surgery for precise localization and removal of recurrent pituitary tumours while simultaneously preserving pituitary gland function. **Method:** During a 6-month period – July 2004 until December 2004 – 9 patients with recurrent pituitary tumours (5 female and 4-male) were treated with navigation-guided transsphenoidal microsurgical resection. Surgery was performed via a paraseptal or endonasal transsphenoidal approach. The navigation system Vector Vision (Brain Lab, Heimstetten, Germany) allowed precise localization of the tumours (7 hormonal active and 2 inactive microadenomas) in respect to the pituitary gland, the carotid arteries and the cavernous sinus. **Results:** Postoperative MRI investigations of the 9 patients treated with image-guided transsphenoidal microsurgery, showed total tumour removal in 7 (77%) patients and subtotal removal in 2 patients (23%). One patient (11%) developed a cerebral spinal fluid (CSF) leak and was treated conservatively. One patient (11%) had preoperative insufficiency of the corticotrope axis which remained unchanged postoperatively. Of the remaining 8 patients who did not have preoperative endocrinological disturbance, only one (12%) developed postoperative insufficiency of the corticotrope axis. Out of the 7 patients with hormone active tumours, 5 (72%) patients showed no more postoperative hormonal activity. **Conclusion:** Microneurosurgical transsphenoidal techniques combined with image-guided systems can precisely define the localization and removal of lesions in the sella region with respect to the margins of important anatomical structures in the neighbourhood and the endocrinological functionality of the pituitary gland.

Key words

Pituitary surgery · neuroendoscopy · neuronavigation · recurrence · transsphenoidal surgery

Introduction

Since the introduction of transnasal transsphenoidal pituitary surgery and the development of technical skills for assisting this kind of surgery, the morbidity associated with the treatment of sella region lesions has significantly decreased [1]. Image-guided surgical procedures date back to the time of the discovery of X-ray technology. Furthermore, the introduction of the fluoroscopy in the 1960s revolutionized the transsphenoidal approach [2,3]. The use of frameless stereotaxy with computed tomography (CT) or magnetic resonance imaging (MRI) for general neurosurgery has prospered in the last decade. The extension to transsphenoidal surgery and its utilization had been well assessed by Laws et al. [4–7]. Three-dimensional navigation systems were used to obtain a more suitable approach to the sella region, and to improve localization of the anatomical landmarks and the margins of the pathologies [8–10]. Transnasal transsphenoidal microscopic surgery can be performed easily and without great complications in patients who have not previously undergone surgery, but it can be disastrous if the anatomical landmarks and

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Bibliography
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the midline structures are absent as seen in repeat surgeries. Since July 2004 we have used the Brain Lab neuronavigation system, which is compatible with the NC4 microscope (Zeiss, Oberkochen, Germany) for matching the MRI data in patients with recurrent pituitary tumours.

This study was performed to describe the usefulness of neuronavigation in repeat pituitary surgery to obtain a precise approach to the sella region, the exact localization of the lesion intrasellar and to allow at least total removal of the tumour while simultaneously preserving the endocrinological function of the pituitary gland.

Material and Methods

Patient population

Between July 2004 and December 2004, at the Department of Neurosurgery, University of Mainz, Mainz, Germany, 9 patients (5 females and 4 males) underwent transnasal transsphenoidal microsurgical resection of recurrent microadenomas under neuronavigation conditions. The patients age ranged from 20 years to 54 years (mean age, 37 years). All patients had recurrent microadenomas, 2 hormonal inactive and 7 hormonal active. The active tumours were 3 growth hormone (GH), 2 prolactin and 2 adrenocorticotropine hormone (ACTH) producing adenomas. Indication for surgical treatment was based on the clinical, endocrinological and radiological findings. The goal of the surgical therapy was total removal of the tumour and normalization of hormonal levels without induced insufficiency of the pituitary gland. Preoperative study included: a) neuroradiological examination performed with magnetic resonance imaging (MRI) in the sagittal, coronary and axial planes showing the exact anatomy of the endonasal, sphenoidal, sella, suprasella regions and the configuration of the pituitary lesion, b) complete endocrine evaluation in basal conditions and after hormonal stimulation of the pituitary gland and c) clinical examination of the symptoms of the patient. Postoperative evaluation was performed with clinical, endocrinological and MRI examination after 3 and 6 months.

Surgical technique

One day preoperatively high quality MRI of the entire head was performed with 1 – 2 mm thin slices (MP RAGE 3D dataset). Surgery was performed under general anaesthesia. The patient was positioned supine with the head held firmly in the Mayfield clamp to prevent patient movement after intraoperative navigational registration (Fig. **1**). We approached the sphenoid sinus after enlargement of the hiatus sinus sphenoidalis at which point the navigation system was used (Fig. **2**) to confirm the visualized structures in comparison to the preoperative MRI images. The sella floor was identified and the navigation pointer was used before (Fig. **3**) opening the dura to optimize the small opening of the dura, where the adenoma was expected to be located. This step prevented injury to important structures in the neighbourhood and also to the normal pituitary gland. After precise planning of the dura opening, the tumour was always identified and removed with conventional microinstruments for pituitary surgery. Finally, reconstruction of the sella cavity was performed using gel foam. Due to the small opening postoperative nasal packing was not necessary.

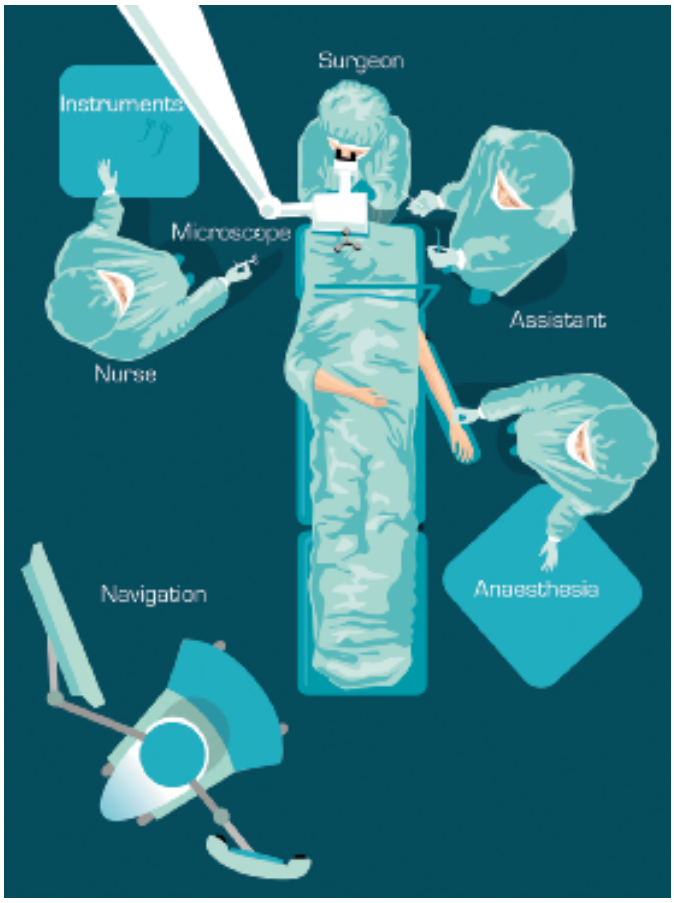

Fig. **1** Scheme of the set-up in the operation theatre.

Navigation system

The navigation platform (Vector vision, Brainlab, Heimstetten, Germany) allows the patient to be registered via an intuitive laser interface (z-touch) without using fiducial markers (markerless patient registration), by directly projecting hundreds of "virtual" markers onto the patient. The "z-touch" approach avoids unnecessary errors added through transforming points from a laser co-ordinate into the tracking co-ordinate system. Due to the compatibility of the used navigation system with our microscopes (NC4, Zeiss, Oberkochen, Germany) we were able to render the data of the navigation system into the microscope. This technical skill offered a tracking of spatial orientation, viewing direction, and associated focal point of the microscope optical head. Furthermore, the system offered multiplanar reconstruction of diagnostic scan data that mirrors the orientation and scaling of the microscope image, superpositions of 3D projections and reformatted contours of pre-planned anatomic structures, targets and trajectories.

Results

Eight patients had been operated on previously (in our institution or abroad) with standard microsurgical approaches and one with endoscopic endonasal transsphenoidal technique. Two patients had non-functioning tumours and 7 had hormone-secreting tumours, 3 GH-, 2 ACTH-secreting tumours and 2 prolactinomas (Table **1**).

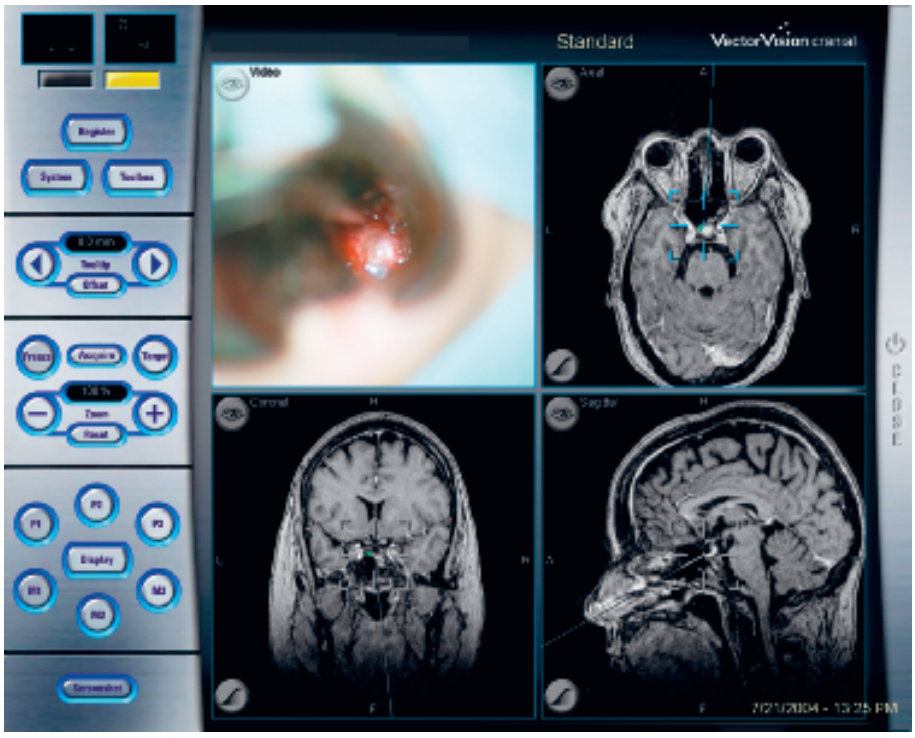

Fig. **2** View approaching the sphenoid sinus with enlargement of the hiatus sinus sphenoidalis and at this point the navigation system is used to confirm the visualized structures with the preoperative MRI images.

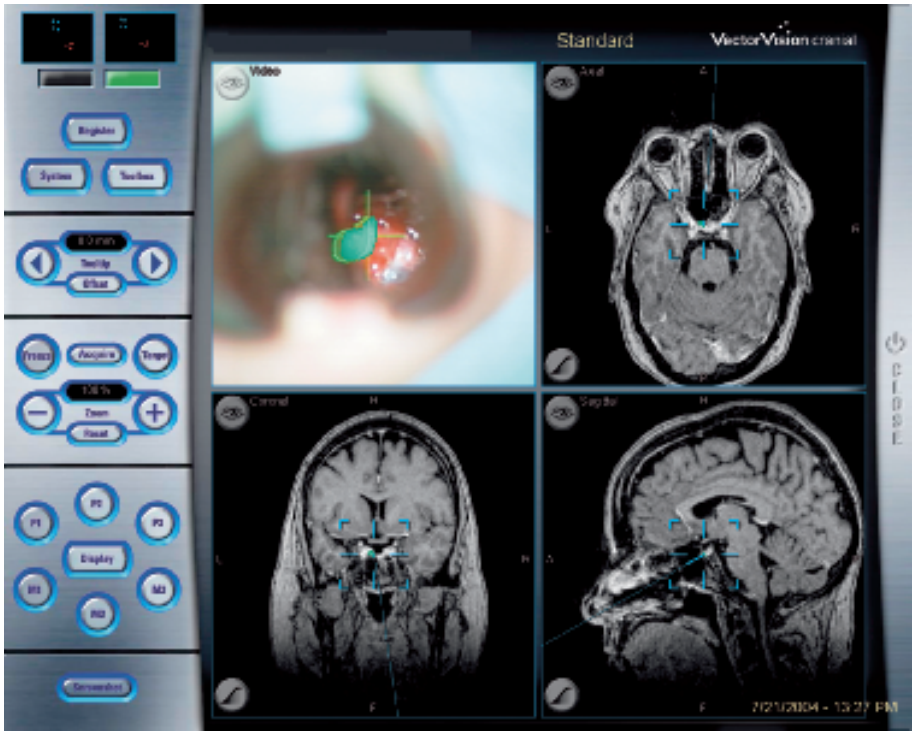

Fig. **3** The sella floor is identified and the navigation pointer is used before opening the dura to optimize the small opening of the dura, where the adenoma is expected.

Surgery was performed via a transnasal transsphenoidal route as described above in all 9 patients treated with the neuronavigation technique. All patients had normal free airways through both nostrils immediately after extubation and did not need nasal packing. Postoperative discomfort such as headache, vomiting or dizziness was minimal. The postoperative hospital stay was on average of 5 days. One patient developed a CSF leak during the postoperative course and was conservatively treated for 4 days with a lumbar drain. One patient had preoperative insufficiency of the corticotrope axis and remained unchanged postoperatively. Of the remaining 8 patients who did not present with preoperative endocrinological disturbances, 7 (88%) remained without pituitary gland insufficiency and 1 (12%) patient developed postoperatively a partial insufficiency (only corticotrope axis insufficiency) (Table **2**). Of the 7 patients with hormone active tumours, 5 (72%) patients showed no postoperative hormonal activity (Table **3**).

Table **1** Histopathological findings in 9 patients with tumours in the sella region

Histopathology	*No. of cases*
Non-functional pituitary adenomas	2
Prolactinomas	2
GH producing	3
ACTH producing	2

Table **2** Endocrine function of the pituitary gland pre- and postoperatively

Function of pituitary gland	*Preoperative*	*Postoperative*
Intact	8	7
Partial insufficiency	1	2
Total insufficiency	0	0

Table **3** Endocrinological results of 7 patients with hormonal secreting tumours

Tumour diagnosis	*3-months post-op. hormonal secretion of tumour*	
	Normal values	*High values*
Prolactinomas (2 patients)	1	1
ACTH (2 patients)	2	0
GH (3 patients)	2	1

Table **4** Surgical results shown in the 3-month postoperative MRI investigation

Tumour diagnosis	*Surgical removal*	
	Total	*Subtotal*
Non-functioning	1	1
Prolactin	1	1
ACTH	–	2
GH	–	3

The first postoperative MRI examination of the 9 patients showed total tumour removal in 7 (77%) patients and subtotal removal in 2 (23%) patients (Table **4**). Endocrinological evaluation in 5 of 7 patients (72%) with hormone-secreting tumours, revealed postoperative normalization of the hormonal levels. In one acromegalic patient the hormonal levels remained postoperatively high but the MRI showed no morphological correlation. This patient received postoperative sandostatin medication.

Non-functioning pituitary tumours

Among the 2 patients with non-functioning pituitary adenomas, tumour removal was achieved in 1 patient, but only a subtotal resection was possible in the second patient due to the infiltration of the cavernous sinus. This patient received postoperative stereotactic radiation. Concerning the function of the pituitary gland, 1 patient had pre- and postoperative normal pituitary function, whereas the second patient had preoperative insufficiency of the corticotrope axis and remained postoperatively unchanged. Diabetes insipidus has not occurred. No patient developed a synechia in the nasal mucosa or infection in the nasal-sphenoidal-sellar complex.

Hormone secreting pituitary adenomas

Two patients with ACTH-producing microadenomas (Cushing's disease) were treated. In both patients, complete removal of the tumour was successful, resulting in normal cortisol levels. Intraoperative complications were absent in both patients. Both patients had normal pre- and postoperative pituitary function. No diabetes insipidus has developed.

Two patients suffered from microprolactinomas, neither of whom received medical treatment before surgery. Total tumour removal with normal function of the pituitary gland postoperatively was achieved in 1 patient. The other patient continued to suffer from high prolactin levels postoperatively and was therefore treated with a prolactin antagonist. No intraoperative complications occurred.

Three patients suffered from GH-producing adenomas. In all 3 patients medical pre-treatment was not performed. Total tumour removal, as shown in the MRI postoperatively, was achieved in all 3 patients. In 2 patients the postoperative endocrinological evaluation showed complete healing of the acromegaly. The third patient continued to have high levels of GH after glucose stimulation and was therefore treated with a GH antagonist. His MRI scan showed no residual tumour. In all 3 patients pre- and postoperative function of the pituitary gland was intact.

In general, image-guided transsphenoidal pituitary microsurgery for resection of microadenomas allowed high success rates for hormonal normalization (5 – 72% – of 7 patients with hormonal active tumours had normal postoperative hormonal levels).

Discussion

Neuronavigation is an increasingly commonly used technology that provides continuous, three-dimensional information for anatomic orientation and target point trajectory. The use of frameless stereotactic devices in the transnasal transsphenoidal pituitary surgery for guidance has been reported by others to be particularly useful in re-operations [5,9]. Repeated surgery is known to be technically more challenging and risky due to the destruction of the anatomy and because of postoperative scarring [11,12]. The anatomic landmarks are distorted in these patients and identification of the midline deep in the sphenoid sinus can often be difficult [13]. Unfortunately, misdirected approaches in repeated surgery still result in major complications, sometimes fatal [1]. The rate of severe complications resulting

from misdirected approaches was underestimated in the literature, due to a preponderance of reports from highly skilled teams or the reluctance to report failures. Neuronavigation allows the surgeon to remain on track and avoid entering the cavernous sinus and carotid arteries or being too anterior and approaching the floor of the anterior fossa [13].

In repeated transsphenoidal pituitary surgery for the removal of microadenomas the most important steps were: 1) to find the correct approach to the sella without destruction of the important surrounding structures; 2) the identification of the microadenomas and their complete removal; and 3) safety of the functional pituitary gland.

The evolution of our transsphenoidal approach used in re-operation included neuronavigation to precisely determine the sella exposure and identify the microadenoma without destruction of the pituitary gland. This system was also useful in adding value to microscopic navigated surgery in either small lateral or deep seated microadenomas. The sella could be approached with more confidence because the midline trajectory was constantly available to the surgeon. As demonstrated in our results in the case of microadenomas a more precise localization was possible allowing a more limited sella opening and preservation of normal pituitary gland tissue during tumour dissection. We currently use the Brain Lab navigation system because of its ease of laser registration without fiducial markers, its precision and its adaptability to our microscopes. The use of image-guided systems warrants a correctly directed midline approach with excellent results in identification and removal of the microadenomas while preserving the pituitary gland. In difficult cases it is especially advantageous and also allows higher safety in transsphenoidal re-operations. The ease in checking the trajectory of microscopic exploration, that the system provides, is a very welcome technical addition for the operating team.

As our results show, neuronavigation can help make re-operations 1) *easier* for approaching the nasal, sphenoidal and sellar complex and identifying the absent midline structures, 2) *safer* either for protection of the surrounding important structures in the sphenoid sinus (carotid arteries, cavernous sinus and optic system) or to protect the functionality of the healthy pituitary gland and 3) *faster* by reducing the surgical time.

Conclusion

Microscope-neuronavigated transnasal transsphenoidal pituitary surgery for repeat microadenomas is a minimally invasive method which allows a simple image-guided transsphenoidal approach in conjunction with the operating microscope. It can make re-operations for removal microadenomas faster in surgical time, easier in approaching the sella in the direction where the microadenoma is expect. Furthermore, the surgeon can identify and remove the tumour while preserving normal function of the pituitary gland tissue.

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References

[1] Ciric I, Ragin A, Baumgartner C, Pierce D. Complications of transsphenoidal surgery: results of a national survey, review of the literature, and personal experience. Neurosurgery 1997; 40: 225 – 236; discussion 236 – 227

[2] Hardy J. Neuronavigation in pituitary surgery. Surg Neurol 1999; 52: 648 – 649

[3] Hardy J. Frameless stereotaxy for transsphenoidal surgery. Neurosurgery 2000; 46: 1269 – 1270

[4] Jane Jr JA, Laws Jr ER. Surgical management of pituitary adenomas. Singapore Med J 2002; 43: 318 – 323

[5] Jane Jr JA, Thapar K, Alden TD, Laws Jr ER. Fluoroscopic frameless stereotaxy for transsphenoidal surgery. Neurosurgery 2001; 48: 1302 – 1307; discussion 1307 – 1308

[6] Jane Jr JA, Thapar K, Kaptain GJ, Maartens N, Laws Jr ER. Pituitary surgery: transsphenoidal approach. Neurosurgery 2002; 51: 2002; 51: 435 – 442; discussion 442 – 434

[7] Laws ER, Jane Jr JA. Pituitary tumors – long-term outcomes and expectations. Clin Neurosurg 2001; 48: 306 – 319

[8] Abe M, Udono H, Tabuchi K, Uchino A. Transsphenoidal surgery assisted by navigation system. No Shinkei Geka 2001; 29: 31 – 38

[9] Elias WJ, Chadduck JB, Alden TD, Laws Jr ER. Frameless stereotaxy for transsphenoidal surgery. Neurosurgery 1999; 45: 271 – 275; discussion 275 – 277

[10] Wong GK, Poon WS, Lam MK. The impact of an armless frameless neuronavigation system on routine brain tumour surgery: a prospective analysis of 51 cases. Minim Invas Neurosurg 2001; 44: 99 – 103

[11] Laws Jr ER, Fode NC, Redmond MJ. Transsphenoidal surgery following unsuccessful prior therapy. An assessment of benefits and risks in 158 patients. J Neurosurg 1985; 63: 823 – 829

[12] Long H, Beauregard H, Somma M, Comtois R, Serri O, Hardy J. Surgical outcome after repeated transsphenoidal surgery in acromegaly. J Neurosurg 1996; 85: 239 – 247

[13] Pillay PK, Leo CW, Sethi DS. Computer-aided/image-guided and video-endoscopic resection of pituitary tumors. Stereotact Funct Neurosurg 2000; 74: 203 – 209

Analysis of Surgical Management of Calvarial Tumours and First Results of a Newly Designed Robotic Trepanation System

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Abstract

This study was performed to evaluate the surgical strategy in patients with calvarial tumours, in order to design and modify a robot-assisted trepanation system. A total of 75 patients underwent craniectomy for the treatment of calvarial tumours during the 10-year period from 1993 to 2002. The patients' complaints, the size, location and histology of the tumour, and the various cranioplasty techniques used were analysed retrospectively. In a second procedure several craniectomies at typical locations according to the study's results were performed in a laboratory setting using a hexapod robotic tool, constructed at the Helmholtz-Institute, RWTH Aachen University, and plastic model heads. The workflow was documented and the reproducibility and the accuracy of the procedure were registered. A total of 83 surgical procedures were performed on 75 patients. The majority (87%) of lesions treated surgically were located in the frontal, temporal and anterior parts of the parietal region. Histological examination revealed benign lesions in 66% of the patients and dural involvement in 46%. According to these results craniectomies were performed using the robotic system. Mean positioning accuracy of the robotic system while milling was 0.24 mm, with a standard deviation of 0.04 mm, and maximum error under 1 mm. Craniectomies leaving a 1-mm layer of the tabula interna intact to ensure a healthy dura were performed in several regions successfully. The majority of calvarial tumours, requiring surgical treatment in our patients, were located in cosmetically relevant areas in which drilling can be carried out with the robotic trepanation system. Consequently, the surgical approach had to be planned carefully in order to achieve a good cosmetic outcome.

Key words

Trepanation · robotic assisted surgery · calvarial tumours · neurosurgery

Introduction

Osseous tumours of the skull are rare entities characterized by a large variety of histological findings, as described by Arana et al. [1,2], Ciray et al. [3], and Hunt et al. [4]. The majority of such tumours encountered in the field of neurosurgery are either meningiomas or metastases [5,6]. Symptoms include changes in the patient's appearance and neurological deficits due to intracranial expansion of the tumour. Although resection of the lesion is always the primary objective of surgical treatment, increased attention has also been devoted recently to restoration of the concomitant defect leading to a cosmetically satisfying outcome [7–10].

Drilling of the skull by means of a robotic system has proved to be a valuable surgical technique for precise insertion of cochlea implants [11,12] or has been evaluated intraoperatively for the development of a system for craniotomy [13]. The craniectomy could be a new application for a robotic system in patients with

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Bibliography
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osseous tumours, especially in cosmetically important areas of the skull.

The aim of this study, which is supported by the German Research Foundation (DFG) within the SPP 1124, was to evaluate osseous lesions with regard to location, histological findings and surgical management. Furthermore, first drilling tests with a plastic model head were carried out in a laboratory setting, according to the evaluated workspace area.

Patients, Materials and Methods

A total of 75 patients (54 females and 21-males) with a mean age of 57 years (range: 4 – 95 years) who had been treated surgically for calvarial tumours during the 10-year period from 1993 to 2002 were included in the study. The demographic data, clinical and pathological findings, and information on the preoperative diagnostic procedures used for surgical planning were obtained from the files. Lesions were classified according to their location, size and histology; cosmetic impairments were documented. The surgical management was analysed, with special emphasis on dural involvement and repair and the type of cranioplasty used. Fisher's exact test [14] was used to test for dependence in contingency tables; the level of significance was set at 0.05.

The data on location and size were also analysed to identify requirements for a hexapod robot system and to perform the first craniectomies in a plastic model skull. The robotic system used was a hexapod parallel robot with platforms of 440 and 200 mm in diameter; the legs could be varied in length from 430 mm to 580 mm. Preliminary tests have been conducted to evaluate the robotic drilling parameters and the accuracy of craniectomy in a laboratory setting with a plastic model head.

Several craniectomies were performed in typical locations, according to the statistical evaluation of calvarial tumours, in order to acquire data on accuracy and reproducibility. Furthermore, several robot settings differing in parameters such as speed of drilling and movement were evaluated and compared.

Results

A total of 83 surgical procedures were performed in 75 patients. Cosmetic changes of the cranial vault were detected in 46% of the patients, whereas neurological deficits were diagnosed in only 13%. Twenty-two percent of the patients complained of headaches at admission (Table **1**). Forty-five percent of the lesions were located in the frontal region of the skull.

The preoperative diagnostic work-up included CT or MRI in all patients; both were carried out in 39 patients. Starting in 1997, the technique of neuronavigation was used in 33% of cases (n = 14). A total of 13 of the navigated lesions were located in the frontal and/or parietal region; half of them were small tumours below 2 cm in size. The mean size of the craniotomy performed was 4.5 cm overall (range: 1 – 17 cm). Infiltration of the dura was present in 46% of the lesions. Sixty-three percent of the lesions with dural infiltration were meningiomas; the remainder consisted of metastatic lesions of the skull. Infiltration of venous sinuses was verified during surgery in 13%. The correlation between histological classification of the tumour and the presence of dural or sinus infiltration was statistically significant (p = 0.047). As shown in Table **2**, a broad spectrum of pathology was encountered. The majority (66%) of the lesions treated were benign lesions and tumours of the skull.

In 43% of the patients with benign lesions, craniotomy and resection of the infiltrated part of the bone followed by reinsertion of the non-affected part was possible; acrylic bone cement was

Table **1** Symptoms and clinical findings in patients with osseous tumours on admission (*n* = 75)

		Patients	*%*
Cosmetic disfigurement	Localised swelling	38	46
	Palpable bone defect	3	4
	Skin infiltration	4	5
	No visible signs	38	46
Neurological impairment	Exophthalmos	7	8
	Headache	18	22
	Neurological deficits	11	13
	No neurological impairment	47	57

Table **2** Histological findings in resected lesions of the skull (*n* = 83)

			Number of lesions	*%*
Benign lesions	Fibrous dysplasia	10	18	22
	Encephalocele, cyst	3		
	Hyperostosis	2		
	Growth fracture	1		
	Bone cysts	1		
	Tuberculosis	1		
Benign tumours	Meningioma, benign	30	36	43
	Haemangioma	3		
	Astrocytoma	1		
	Multiple myeloma	1		
	Osteoma	1		
Malignant tumours	Adenocarcinoma metastasis	14	28	34
	Meningioma, malignant	6		
	Basal cell carcinoma	3		
	Breast cancer metastasis	2		
	Angiosarcoma	1		
	Metastasis, primary unknown	1		
	Malignant histiocytoma	1		
No differentiation	Malignant	1	1	1
Total		83	83	100

Table **3** Distribution of the osseous lesions of the cranial vault ($n = 83$)

Location	*Number of procedures*	*%*
frontal	37	45
parietal	23	28
temporal	12	14
occipital	6	7
periorbital	5	6
total	83	100

used in 46% of cases. In three patients, individually prefabricated titanium implants were inserted after resection of the tumour. In patients with small defects (i.e., less than 2 cm in diameter) without cosmetic relevance, cranioplasty was not performed.

Analysing the location of tumours, we were able to define a working space covering 87% of all lesions including the frontal, temporal and the anterior part of the parietal skull (Table **3**). Tumour diameter was greater than 6 cm in 16% of the patients, partly with several differently oriented bony surfaces to be drilled. Supine positioning intraoperatively was used in 86% of the lesions.

Owing to the cosmetic relevance of these tumours, navigational control and prefabricated cranioplasty were indicated.

Depending on the tumour location, some of the craniectomies were simulated using a hexapod parallel robotic system and plastic head models. A 1-mm layer of the tabula interna was planned to be left intact to ensure a healthy dura. The positioning and the progress of drilling were controlled by means of a navigated drilling tool fixed to the top of the robot. The drill used was a 6-mm cut drill. The mean positioning accuracy of robot was 0.24 mm, 0.04 mm standard deviation, and maximum error under 1 mm. The lines were 0.85 mm apart, and the speed of advancement was 3 mm per second. Accuracy of fiducial marker-based registration between the physical space of skull phantom and reconstructed 3D cranial model from CT was 0.53 ± 0.12 mm. The registration is performed in order to transform data from the preoperative planning to the robotic system (Fig. **1a**) [15,16]. After performed resection, with 1 mm safety distance from the dura planned, a layer of approximately 0.25 mm is noticeable (Fig. **1c**). A drill volume of 6500 – 7000 mm^3 was possible. A force of 20 N was possible; in practice, the mean force used was less than 2 N. The robotic system was able to create all of the craniectomies that were necessary according to the analysis of location of the calvarial tumours (Fig. **1b**).

Discussion

In this study osseous tumours and their surgical treatment were analysed in order to design a robotic trepanation system. Commonly accepted treatment strategies for osseous tumours include surgical resection of lesions causing neurological impairment, tumours displaying rapid growth and benign lesions accompanied by cosmetic disfigurement [17 – 20]. In this study 46% of the patients presented with swelling above the lesion. The diameter of this swelling was greater than 6 cm in 16%.

The majority of the lesions treated in this study were located in the frontal or parietal region; this correlated well with the findings of studies by Constans and Donzelli [5] and Wecht and

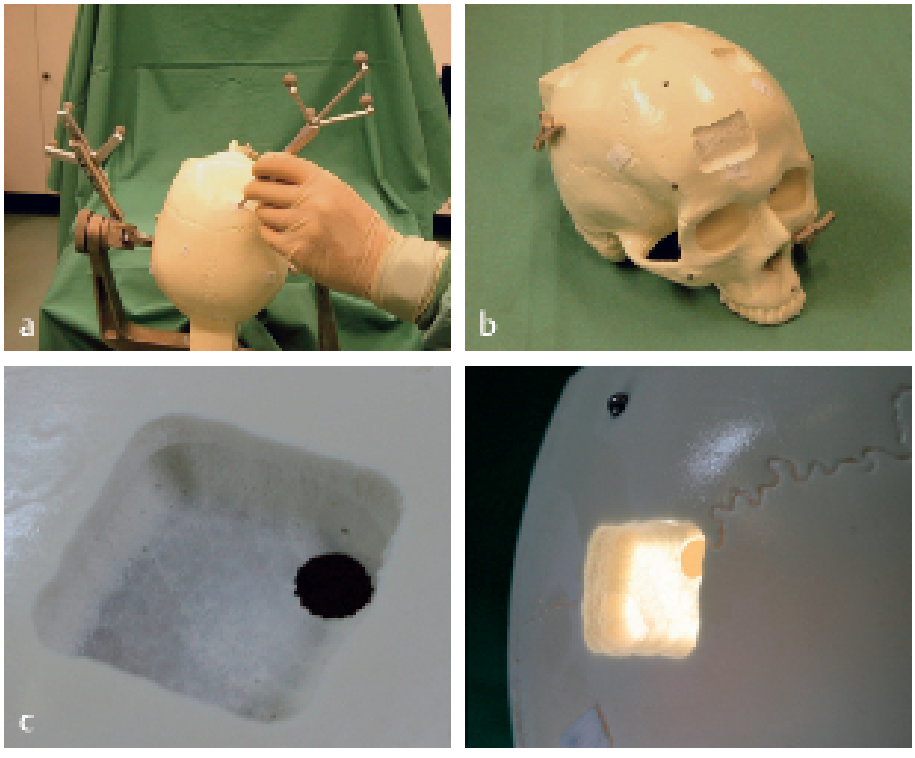

Fig. **1** **a** Registration of the head using implemented markers and a navigation system, allowing constant tracking of the drill. **b** Results after robot milling of several craniectomies according to the analysed data of osseous tumours. **c** Demonstration of a layer of the tabula interna. Drilling performed by the hexapod robot.

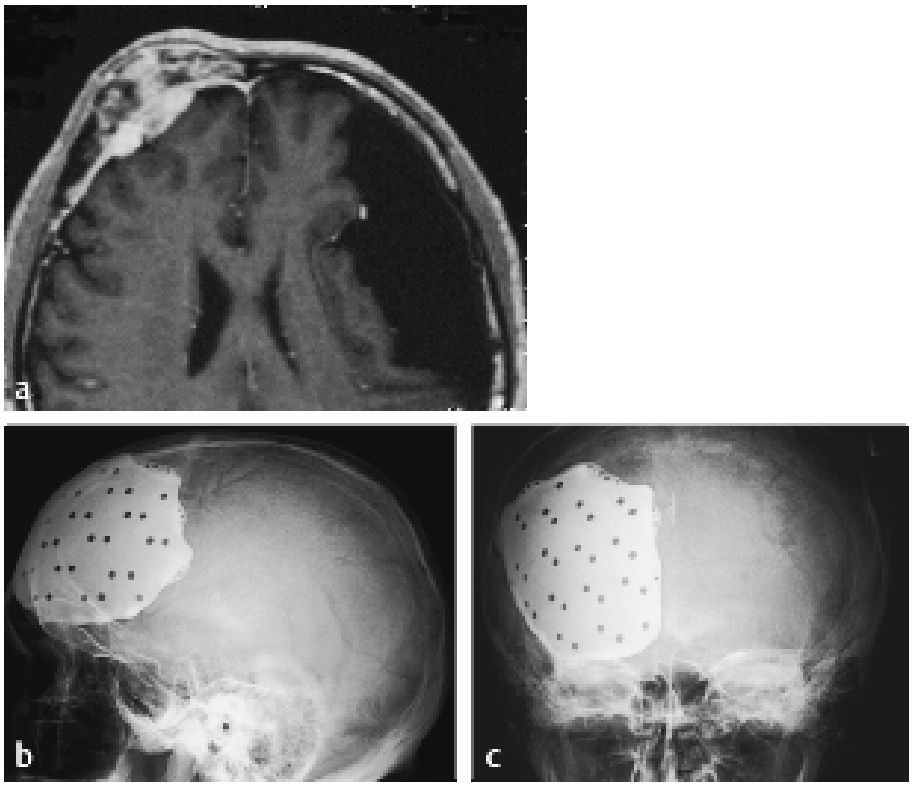

Fig. **2** **a – c** A 47-year-old male patient with enlargement of the skull and localised pain. No neurological deficits were noted at admission. MRI revealed a large tumour with enlargement of bone and dural infiltration. The tumour was resected in toto including a dural repair with fascia lata and cranioplasty with a prefabricated titanium implant. The lesion was classified histologically as a meningioma.

Sawaya [10]. In contrast, Artico et al. [7] found no preferred region of the skull for tumours in their study population.

The variety of histological entities found in our study is consistent with the findings of other authors [5, 7, 10]. In one case the pathologist could not classify the lesion definitively. This was consistent with the findings of Wecht and Sawaya [10], who reported five cases in which histological classification was impossible.

In contrast to Sekhar [9], who used fluoroscopy and preoperative scintigraphic scanning, in this study CT and MRI were employed, since the interpretation of the information in navigation is well established and necessary to control the robot intraoperatively.

Infiltration of the dura and/or the sinus was present in nearly twice as many patients as in other studies (46% vs. 20–26%) [5, 7, 10], mainly due to the large number of meningiomas found in our series. Sixty-three percent of the meningiomas and 31% of the metastases had already infiltrated into the dura. Of the patients with dural involvement, 19% exhibited infiltration of the sinus. Involvement of these structures required special surgical planning to prevent laceration of the dura and brain tissue. Furthermore, dural infiltration has important technical implications for the design of the robotic trepanation system, especially the distance from the healthy brain tissue.

Following resection of the infiltrated dura, the resulting defects were repaired. In our study autologous material was used for this purpose in the vast majority of cases. A similar management strategy was used in the studies of Artico et al. [7] and Constans and Donzelli [5]. In this study Lyodura® or Teflon® implants were employed in only two cases. We preferred to use autologous materials such as galea periosteum or muscle fascia, taken either from the temporalis muscle or the fascia lata, because these natural materials resemble normal dura more closely.

In patients with small lesions we performed only soft tissue replacement without cranioplasty, in common with Wecht and Sawaya [10]. Constans and Donzelli [5], however, never performed cranioplasty; they and others used acrylic bone cement to repair defects resulting from the excision of larger malignant lesions. A different method was described by Saringer et al. [20], who used individual carbon fibre polymer. The relationship between defect size and cranioplasty was statistically significant ($p = 0.043$).

In a large number of cases, therefore, cranioplasty is mandatory for cosmetic reasons, with the insertion of a prefabricated implant usually being the restoration modality of choice. Moreover, enhanced circulation and improved cognitive ability have been reported by Agner et al. [21] following the performance of cranioplasty to repair a large osseous defect.

In patients with larger benign lesions involving cosmetically relevant structures of the forehead and the face, we have found prefabricated titanium implants to be suitable, especially in cases where exact preoperative planning of the resection was possible as described by Eufinger et al. [22]. Fig. **2** shows a patient with a large meningioma extending into the frontal area of the face. Resection was followed by cranioplasty with a titanium implant; this resulted in a perfect cosmetic outcome. Since titanium implants are expensive, several authors have advocated the use of bone cement during elective cranioplasty.

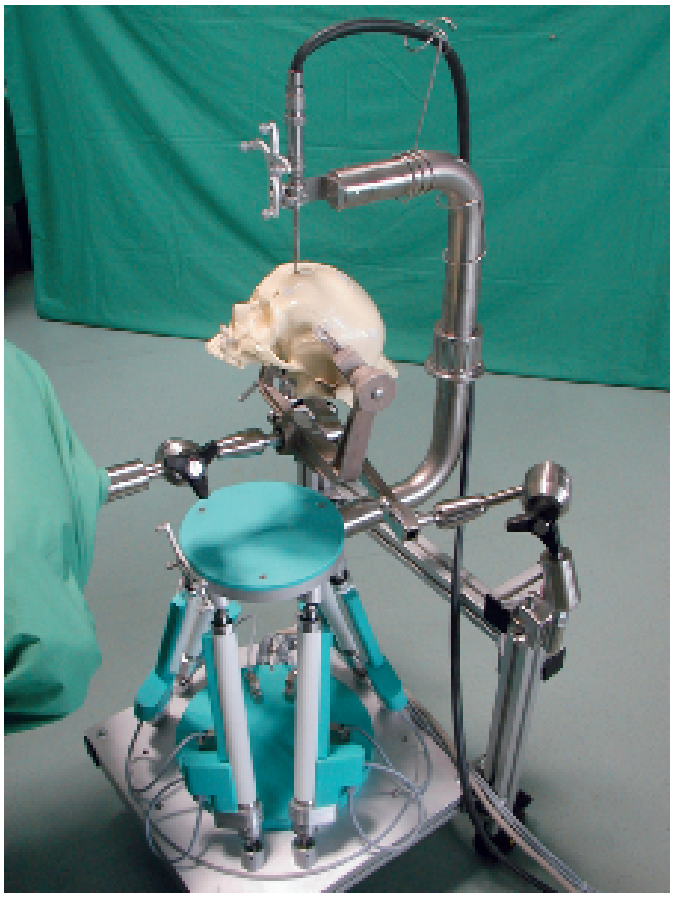

Fig. **3** Hexapod robotic system in laboratory surrounding, placed beneath the patient's head with connected high-speed drill and navigational array (enlarged in Fig. **4**).

Fig. **4** High-speed drill and navigational array of hexapod robotic system.

In patients with skin involvement, a rotational skin flap or split-skin graft was put in place during the initial operation or during a second surgical procedure, as also mentioned by Constans and Donzelli [5] and Wecht and Sawaya [10]. Four patients with skin involvement were treated with a rotational skin flap.

Other authors [11 – 13] reported about drilling of the skull, whereby they used different robotic platforms. The hexapod robotic system we used demonstrated the ability to drill the calvaria accurately. Furthermore, it was possible to reach all necessary locations, based on the analysis of the lesions in this study. In this test setting the robotic system, with six degrees of freedom, performed a craniectomy by drilling the skull to a thickness of 1 mm to ensure a healthy dura in natural circumstances (Figs. **3** and **4**).

The potential advantages of robot-assisted resection are: precise drilling at different bone surface angles and the possibility of performing a planned resection and inserting a prefabricated alternative. Further drilling tests have to be done to refine parameters of the robotic system such as speed of advancement and temperature increase, with the danger of bone necrosis and a disturbed healing process of the bone, possibly influencing the cosmetic outcome.

Apart from these refinements we would state the following three preconditions:

a) Preoperative planning including an adequate diagnostic work-up is mandatory.
b) Navigational support has to be provided for the localisation and surveillance of the resection area.
c) The working range of the robotic system has to cover the entire region in question.

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References

[1] Arana E, Marti-Bonmati L, Paredes R, Bautista D. Focal calvarial bone lesions: comparison of logistic regression and neural network models. Invest Radiol 1999; 33: 738 – 745
[2] Arana E, Marti-Bonmati L, Bautista D, Paredes R. Qualitative diagnosis of calvarial metastasis by neural network and logistic regression. Acad Radiol 2004; 11: 45 – 52
[3] Ciray I, Astrom G, Sundstrom C, Hagberg H, Ahlstrom H. Assessment of suspected bone metastases. CT with and without clinical information compared to CT-guided bone biopsy. Acta Radiol 1997; 38: 890 – 895
[4] Hunt JA, Hobar PC. Common craniofacial anomalies: conditions of craniofacial atrophy/hypoplasia and neoplasia. Plast Reconstr Surg 2003; 111: 1497 – 1508
[5] Constans JP, Donzelli R. Surgical features of cranial metastases. Surg Neurol 1981; 15: 35 – 38
[6] Couldwell WT, Fankhauser H, de Tribolet N. Osseous metastases from a benign intraventricular meningioma. Case report. Acta Neurochir (Wien) 1992; 117: 195 – 199
[7] Artico M, de Garo GMF, Salvati M, Carloja S, Rastelli E, Wierzbicki V, Manni M. Solitary metastases of the cranial vault – report of ten cases. J Neurosurg 2000; 44: 33 – 38

[8] Bogaev CA. Cosmetic considerations in cranial base surgery. Neurosurg Clin North Am 2002; 13: 421 – 441
[9] Sekhar LN. The cosmetic aspects of neurosurgery. Neurosurg Clin North Am 2002; 13: 401 – 403
[10] Wecht D, Sawaya R. Lesions of the calvaria: surgical experience with 42 patients. Ann Surg Oncol 1997; 4: 28 – 36
[11] Federspil PA, Geisthoff UW, Henrich D, Plinkert PK. Development of the first force-controlled robot for otoneurosurgery. Laryngoscope 2003; 113: 465 – 471
[12] Plinkert PK, Federspil PA, Plinkert B, Henrich D. Force-based local navigation in robot-assisted implantation in the lateral skull base. An experimental study. HNO 2002; 50: 233 – 239
[13] Eggers G, Wirtz C, Korb W, Engel D, Schorr O, Kotrikova B, Raczkowsky J, Wörn H, Mühling J, Hassfeld S, Marmulla R. Robot-assisted craniotomy. Minim Invas Neurosurg 2005; 48: 154 – 158
[14] Campbell MJ, Machin D. Medical statistics. A commonsense approach. New York: Wiley, 1990
[15] Popovic A, Engelhardt M, Heger S, Radermacher K. Efficient non-invasive registration with A-mode ultrasound in skull surgery: Method and first clinical trials. International Congress Series (2005). In: Lemke HU et al. (eds.). CARS 2005; Elsevier Science: 821 – 826
[16] Bast P, Engelhardt M, Popovic A, Schmieder K, Radermacher K. CRANIO – Entwicklung eines Systems zur computer- und roboterunterstützten Kraniotomie. Biomedizinische Technik 2002; 47 (Suppl 1): 9 – 11
[17] Clauser L, Vinci R, Curioni C. Dismantling and reassembling of the facial skeleton in tumor surgery of the craniomaxillofacial area. History, surgical anatomy, and notes of surgical technique: Part 1. J Craniofac Surg 2000; 11: 318 – 325
[18] Hefti F, Jundt G. Langerhans cell histiocytosis. Orthopaede 1995; 24: 73 – 81
[19] Howarth DM, Gilchrist GS, Mullan BP, Wiseman GA, Edmonson JH, Schomberg PJ. Langerhans cell histiocytosis: diagnosis, natural history, management and outcome. Cancer 1999; 85: 2278 – 2290
[20] Saringer W, Nobauer-Huhmann I, Knosp E. Cranioplasty with individual carbon fibre reinforced polymer (CFRP) medical grade implants based on CAD/CAM technique. Acta Neurochir (Wien) 2002; 144: 1193 – 1203
[21] Agner C, Dujovny M, Gaviria M. Neurocognitive assessment before and after cranioplasty. Acta Neurochir (Wien) 2000; 144: 1033 – 1040
[22] Eufinger H, Wehmoeller M, Machtens E, Heuser L, Harders A, Kruse D. Reconstruction of craniofacial bone defects with individual alloplastic implants based on CAD/CAM – manipulated CT-data. J Craniomaxillofac Surg 1995; 23: 175 – 181

Medial Microsurgical Approach to the Orbit: An Anatomic Study

D. Gürkanlar
E. Gönül

Original Article

Abstract

The authors have identified and described three medial approaches to the intraorbital portion of the optic nerve in cadavers. The structures exposed via the superior, inferior or central approaches were approached through the medial orbital wall. The superior approach in which the medial rectus muscle is retracted inferiorly exposes the superomedial aspect of the orbit. The inferior approach in which the medial rectus muscle is retracted superiorly, provided the inferomedial aspect of the optic nerve from the globe to the muscle cone. The central approach in which the ethmoidectomy was performed and the medial rectus muscle was disinserted and retracted, provided excellent exposure of the structures of the medial part of the orbit and the optic nerve. There were no structures blocking access to the two third anterior optic nerve and medial surface of the globe. The structures encountered in these approaches are demonstrated under magnification in cadavers, and the exposure of the optic nerve is discussed.

Key words

Medial orbit · anatomy · microsurgical approach

Introduction

Several surgical routes have been used to expose orbital lesions. The transcranial approach is used for all tumors with intracranial extension, for tumors located in the apex and/or optic canal, and for tumors in the apex medial to the optic nerve [1]. Various transcranial approaches to the orbit have been developed [2–6]. The lateral microsurgical approach is used for tumors located in the superior, temporal or inferior compartment of the orbit and those in the lateral apex [7–9]. The medial microsurgical approach is used for tumors located medial to the optic nerve but not deep in the apex [1].

The medial microsurgical approach is simple, quickly performed, and is not associated with the potential complications of an intracranial operation. It is less invasive than transcranial approaches; it can be applied not only for the excision of intraorbital tumors, but also for other purposes, such as orbital decompression for thyroid-related orbitopathy. Orbital wall fractures can be successfully repaired [10].

The aim of our work is to study three possible microsurgical medial approaches to the intraorbital portion of the optic nerve and medial orbital area. In the first approach the medial rectus muscle is retracted inferiorly (superior approach), in the second approach the medial rectus muscle is retracted superiorly (inferior approach), and in the third, an ethmoidectomy is performed and the medial rectus muscle is disinserted and retracted (central approach).

Materials and Methods

Ten cadaver heads fixed in formalin were dissected for this study. The arteries and veins were perfused with colored latex and silicone to facilitate dissection. Twenty orbits were examined under

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Bibliography
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3 to 25 × magnification (Zeiss opmi 6; Carl Zeiss, Oberkochen, Germany). All photographs were taken with a Kodak DC4800 digital camera (Eastman Kodak Co., Rochester, NY) through the binocular of the operating microscope. The orbital structures were exposed through a medial orbitotomy. The periorbita was opened, the orbital fat was removed, and the muscles, nerves and vessels adjoining the medial wall of the orbit were dissected (Fig. **1**). The anatomic features of the three approaches to the intraorbital portion of the optic nerve and medial orbital area were compared (Figs. **2**, **3** and **4**).

Results

Surgical approaches

During the dissection of 20 orbits of cadavers with the medial approach, the head was fixed with a 3-point fixation head holder in a supine position, and then it was turned 15 degrees to the other side. A standard 30-mm long medial curvilinear skin incision (Lynch incision) was made along the inner wall of the orbit from the medial part of the eyebrow. The medial orbital incision extends between the medial orbit and nose along the frontal process of the maxillary bone. The exposure is extended using subperiosteal and subperiorbital dissection except at the medial canthal ligament, which is attached to the anterior and posterior margins of the lacrimal groove, and which should be divided and elevated in such a way that it can be preserved and reapproximated when divided. The lacrimal sac which sits in the lacrimal groove, can usually be elevated. Behind this, the infratrochlear artery and the anterior ethmoidal branch of the ethmoidal artery is encountered as it penetrates the orbita to enter the anterior ethmoidal canal. The artery is divided if a more posterior exposure is needed. As the exposure proceeds, posteriorly along the orbital plate of the ethmoid, the posterior ethmoidal artery is encountered entering the posterior ethmoidal canal. It passes medially along the planum sphenoidale and can be divided.

The medial orbital tissues are relatively loose and easily spread so that a blunt dissection using the curved Stevens scissors can avoid unnecessary bleeding and trauma. Therefore, the incision was easily extended inferiorly or superiorly when the exposure of the inferior or superior portion of the medial orbital wall was necessary.

After the fronto-maxillo-lacrimal suture was revealed with subperiosteal dissection, the lacrimal sac and medial canthal tendon were dissected laterally. Then a 15-mm diameter oval bone window was opened with a high-speed drill, with the suture at the centre. The mucosa and septa of ethmoidal sinus were removed with dissection. Some measurements of anatomic structures encountered through the medial orbital approach are provided in Table **1**.

The medial superior approach

For the medial superior approach, the medial rectus muscle must be retracted inferiorly. Adipose tissue surrounding the bulbous portion of the nerve just behind the globe is gently retracted. The fat is divided into lobules by fine connective tissue septae; these lobules often billow over the edges of the retractomy obscuring the plane of dissection. Care should be taken not to trau-

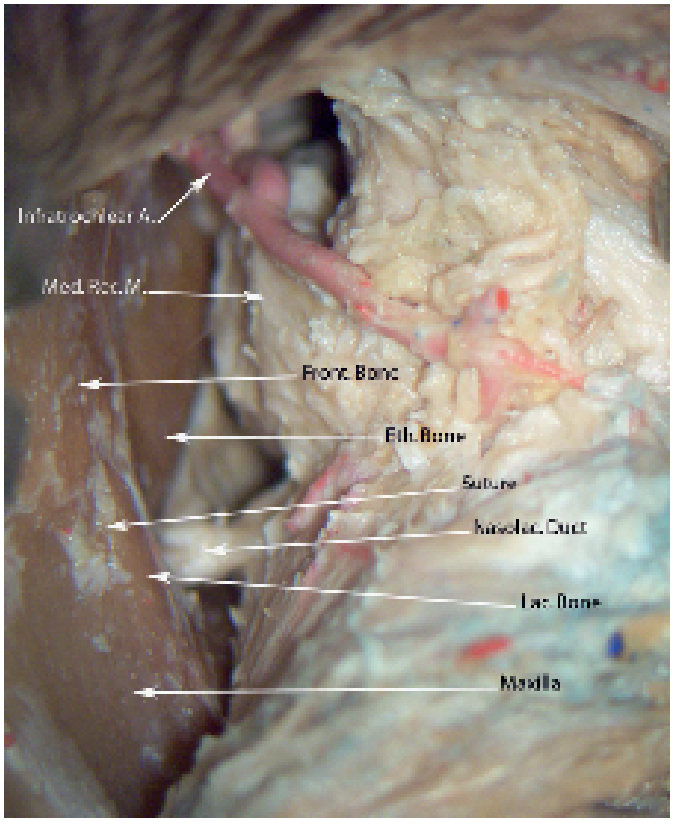

Fig. **1** Cadaver dissection exposing anatomic structures through the medial approach (left orbit). After the removal of periorbita and orbital fat tissue, globe is retracted laterally. The medial orbital wall consisting of frontal bone (Front. Bone), ethmoid bone (Eth. Bone), lacrimal bone (Lac. Bone) and maxilla is seen. Infratrochlear artery (Infratrochlear A.), medial rectus muscle (Med. Rec. M.) and nasolacrimal duct (Nasolac. Duct) are also seen in this exposure.

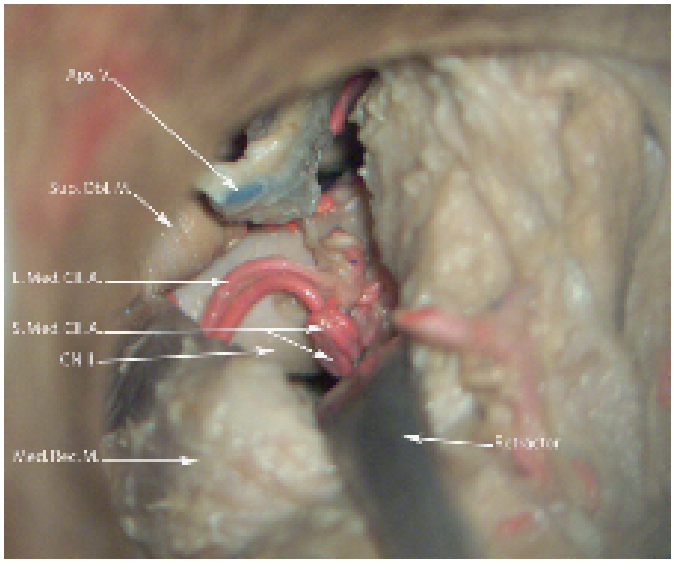

Fig. **2** The medial rectus muscle (Med. Rec. M.) is retracted inferiorly. After the retraction of the medial rectus muscle apsidal vein (Aps. V.), the superior oblique muscle (Sup. Obl. M.), posterior long medial ciliary arteries (L. Med. Cil. A.), posterior short medial ciliary arteries (S. Med. Cil. A.) and optic nerve (CN II) are exposed.

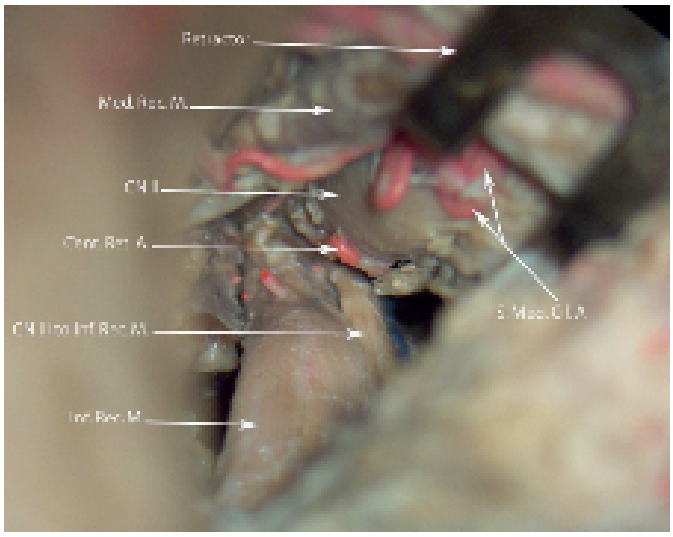

Fig. **3** The medial rectus muscle is retracted superiorly. After the retraction of the medial rectus muscle (Med. Rec. M.) the optic nerve (CNII), central retinal artery (Cent. Ret. A.), inferior division of oculomotor nerve (CN III to Inf. Rec. M.), inferior rectus muscle (Inf. Rec. M.) and posterior short medial ciliary arteries (S.Med.Cil.A.) are seen in this exposure.

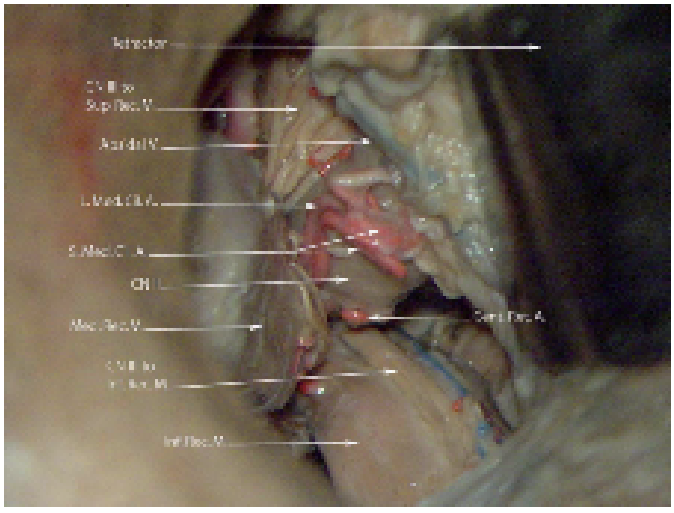

Fig. **4** The medial rectus muscle is disinserted from the globe and retracted medially following removal of the ethmoid bone. This approach provides excellent exposure of the structures of the medial part of the orbit and the optic nerve. Superior division of oculomotor nerve (CN III to Sup. Rec. M.), apsidal vein, posterior long medial ciliary arteries (L. Med. Cil. A.), posterior short medial ciliary arteries (S. Med. Cil. A.), central retinal artery (Cent. Ret. A.), optic nerve (CNII), medial rectus muscle (Med. Rec. M.), division of oculomotor nerve (CN III to Inf. Rec. M.) and inferior rectus muscle (Inf. Rec. M.) are well visualized.

matize the neural and vascular structures that pass through the orbital fat. After the removal of the orbital fat, the nerves and vessels can be seen. The retrobulbous portion and the superior and medial of the optic nerve is exposed (Fig. **2**). Structures seen in the exposure include the superior oblique muscle, anastomotic apsidal vein (between superior and inferior ophthalmic vein), medial rectus muscle, posterior long and short medial ciliary arteries and optic nerve. The medial superior approach, in which the medial rectus muscle is retracted inferiorly, exposes the superomedial aspect of the orbit. However, exposure of the deep inferior area is limited because the medial rectus muscle blocks the line of view.

The medial inferior approach

In the medial inferior approach the medial rectus muscle is retracted superiorly. This approach exposes the inferior and medial aspect of the optic nerve from the globe to the muscle cone (Fig. **3**). Structures seen in the exposure include the posterior long and short medial ciliary arteries, inferior rectus muscle and the inferior division of the oculomotor nerve to the inferior rectus muscle. The central retinal artery arises from the ophthalmic artery and passes forwards inferomedial to the optic nerve. It penetrates the optic nerve from an average distance of 11.2 – 11.3 mm posterior to the sclera. Moreover, in only two cases of the total 20, has the central retinal artery been found to be located on the inferolateral side of the optic nerve. The deep apical infraoptic region is well visualized. However, exposure of the superolateral portion of the optic nerve is limited because the lateral rectus muscle blocks the line of view.

The medial central approach

If it is necessary to obtain proximal exposure of the optic nerve or to gain access to the deep medial portion of the muscle cone, additional bone must be removed from the ethmoid bone with a high-speed drill and small angled rongeurs. After total removal of the fragile cell septa of the ethmoid labyrinth including the entire mucosa, the posterior plate of the ethmoid sinus is removed. When the bone is removed, the periorbita, fascia and retrobulbar content become visible. The medial rectus muscle is disinserted and retracted (Fig. **4**). It provides excellent exposure of the structures of the medial part of the orbit and the optic nerve. There are no structures blocking the access to the two-third anterior optic nerve and medial surface of the globe. It is easy to expose the optic nerve medial to the fibrous hammock. The superior division of the oculomotor nerve to superior rectus muscle, medial and inferior rectus muscle, apsidal vein, optic nerve and posterior long and short medial ciliary arteries, central retinal artery, and the inferior division of the oculomotor nerve to inferior rectus muscle are well visualized.

Table **1** Measurement of anatomic structures encountered through the medial orbital approach

Measurements sites	*Right (mm)*		*Left (mm)*	
	Mean	*Range*	*Mean*	*Range*
Distance between the entrance of central retinal artery to the optic nerve and ocular bulb	11.3	8.9 – 14.6	11.2	6.9 – 14.9
Diameter of central retinal artery	0.46	0.35 – 0.55	0.46	0.44 – 0.55
Entrance point of central retinal artery to the optic nerve	Inferomedial in 18 eyes, inferolateral in two eyes			
Medial rectus muscle measurement	**Mean (mm)**		**Mean (mm)**	
Medial rectus muscle thickness	2.90 ± 0.50		2.60 ± 0.80	
Medial rectus muscle width	9.00 ± 1.50		8.70 ± 1.45	
Medial rectus muscle length (except tendon)	37.10 ± 3.40		38.00 ± 3.90	

For reconstructing a bony defect, non-absorbable alloplastic implants such as the Medpor porous polyethylene Flexblock implant (Medpor surgical implant; Porex Surgical, Inc., Newnan, GA) or Silastic sheet are suitable. This implant is readily available, easy to handle through a small incision and stable in the long term.

Discussion

The orbital walls have seven bones. The orbital opening is somewhat quadrangular; its supraorbital margin formed entirely by the frontal bone. The lateral margin is largely the frontal process of the zygomatic bone; the infraorbital margin is the zygomatic bone laterally and the maxilla medially. The medial margin is formed above by the frontal bone, below by the lacrimal crest of the maxillary frontal process [11].

The medial wall of the orbit is almost rectangular and very thin, forming the lateral walls to the ethmoidal sinuses. The medial wall has anterior and posterior ethmoidal foramina transmitting their vessels and nerves.

A medial microorbitotomy provides excellent exposure of the superior, medial and inferior intraconal compartments. This approach is not suitable for resection of optic nerve gliomas or for lesions which extend into the optic canal, superior orbital fissure, cavernous sinus or intracranial structures. The transcranial approach to the orbit is ideal for lesions that involve both the superior orbital fissure and the cavernous sinus [12].

The medial superior approach exposes the superomedial aspect of the optic nerve. The medial and supraoptic regions are well visualized. However, access to the inferomedial portion of the optic nerve is limited because the medial rectus muscle blocks the line of view. This approach has a risk of damaging the posterior medial ciliary arteries.

The medial inferior approach exposes the inferomedial aspect of the optic nerve. The deep apical and infraoptic regions are well visualized. However, access to the superomedial portion of the optic nerve is limited because the medial rectus muscle blocks the line of view. In 18 of the 20 orbits the central retinal artery passed inferomedially to the optic nerve. In these cases, it is risky to approach the deep inferior area because the central retinal artery is likely to be damaged. The medial inferior approach is well suited for lesions located inferior and medial to the optic nerve.

It was thought that either the ciliary nerves or the ciliary arteries were damaged during surgery. The posterior short ciliary arteries separate into 10 – 20 parts and insert the sclera around the optic nerve. The posterior long ciliary arteries insert the sclera as two branches, and then go along forward between the choroid. The cause of anterior and posterior ischemic optic neuropathy has been poorly understood until now. This entity has been thought to result from ciliary occlusion, and similar pathological changes could be shown experimentally to occur after ligation of these arteries in monkeys; other investigations could not reliably reproduce these experiments [13].

The medial central approach provides a wider working space than the superior or inferior approach. There are no structures blocking access to the medial orbital area. This approach has a low risk of damaging vascular and neural structures in the medial orbital area. The central approach should be preferred for lesions located in the mid-portion and anterior of the intraorbital segment of the optic nerve or in cases where there is a need to expose the optic nerve from the muscle cone to the globe.

Posterior medial lesions are suitable for the central approach. Although the medial central approach provides a wide exposure, decompression of the medial wall may cause ocular motility dysfunction and consequently diplopia. Several studies revealed that a medial wall fracture plays a major role in a traumatic enophthalmos [14 – 17]. Therefore, this approach is not recommended unless it is obligatory. Bony defects must be repaired and reconstructed with non-absorbable alloplastic implants.

Various surgical approaches have been used to explore the orbital medial wall. A medial canthal incision [18 – 20], open sky incision [21], medial brow incision [22], ethmoidal approach through the antrum [23], incisions above and below the medial canthal ligament [24,25], subciliary incision [26], inferior transconjunctival incision [26,27] and coronal incision [28] are suggested.

The evolution of surgical approaches to the medial and inferior orbit has been driven by the need to achieve a safe, versatile, and direct access, while minimizing unwanted structural changes and scarring. Although early surgical approaches achieved direct access, most incorporated cutaneous incisions [29,30]. Lynch [31] popularized the medial transcutaneous approach to the medial orbit in 1921, and the infracilliary approach to the inferior orbit has been used for decades. Although surgical approaches to the lateral and inferior orbit have advanced significantly during the past 70 years, the Lynch approach remains the major approach to the medial orbit. Although the Lynch approach offers excellent exposure, it has inherent cosmetic limitations. The Lynch approach also carries a risk of lacrimal system injury. Leone et al. [32] recommended lacrimal system irrigation before closing the medial transcutaneous incision and immediate silicone intubation in cases of lacrimal system injury.

The Lynch incision courses midway between the medial canthus and the bridge of the nose in an area prone to scarring and web formation. Several modifications have been proposed, including Z-plasty [33]. Although these modifications decrease the occurrence of web formation, postoperative scarring remains a problem [34 – 37]. Similarly, transcutaneous approaches to the inferior orbit carry the associated risks of scarring and lid retraction [38].

The transconjunctival approach to the orbital floor decreases the occurrence of postoperative scarring; however, it does not provide adequate exposure of the entire medial orbit [39 – 42].

The transcaruncular approach has completely replaced the Lynch approach. This versatile approach offers excellent and safe exposure of the medial orbital wall, ethmoid sinus, and orbital apex,

while avoiding cutaneous scarring caused by the Lynch approach [43].

The bicoronal approach can avoid facial scarring and provide an excellent surgical field while obtaining calvarian bone, as a reconstructive material, through the same incision [44]. However, the disadvantages of this approach are that it is time-consuming, there is much blood loss, and complications such as damage to the supraorbital nerve, facial nerve branches, and alopesia can result [44]. Orbital wall approaches are not always satisfactory because they may leave noticeable scars or provide a limited overview of the medial wall.

Various surgical approaches have been developed to the orbit. However, the approach to the posterior and medial intraconal lesions is still difficult. However, Missori et al. [45] have highlighted the significant morbidity associated with the removal of these tumors when they are close to the apex. In such cases, a pterional approach to the contralateral orbit has been advocated [46], which seems an extreme procedure for an orbital lesion.

Any lateral approach seems inappropriate, since the operative route would be obstructed not only by the optic nerve, but also intraorbital vessels and cranial nerves. Subfrontal or pterional approaches also make it difficult to maintain the functional integrity.

In view of this excellent functional result, the authors advocate the transnasal endoscopic approach in rare cases of inferomedial and posterior intraconal lesions as an alternative and addition to the standard techniques of orbital surgery [47].

The transconjunctival endoscopic-assisted technique provides an excellent full view on the most posterior and superior aspects of the fracture boundary with minimal effort, and visualizes clearly the anatomic relevance between the defect and the locations of the anterior and the posterior ethmoidal vessels.

The endoscopically-assisted medial transconjunctival approach is an excellent adjunct for the full exposure of the fracture area, and provides accurate reduction of the herniated orbital contents and placement of the bone grafts with minimal morbidity [48].

A standard transciliary or inferior transconjunctival incision has been used with success in gaining access to the inferior and inferomedial orbit. However, this approach makes it difficult to access the superomedial orbit and the medial subperiosteal space. Moreover, for maximal exposure, it may cause damage to the inferior oblique muscle [49]. Therefore, in cases of combined medial and inferior wall fracture, the combined transcaruncular approach provides a proper surgical field and working space.

Conclusion

A comprehensive knowledge of microanatomy will contribute to the effective use of the medial orbital approach. The assessment of relations between the significant vascular and neural structures will facilitate the surgical process. During an operation, the identification of orbital arteries, veins and nerves can be difficult because deep-lying structures must be dissected as little as possible to avoid unnecessary injury. Therefore, a detailed knowledge of the microanatomy of the orbit is of great importance and facilitates the procedure.

References

[1] Maroon JC, Kenerdell LS. Surgical approaches to the orbit. Indications and techniques. J Neurosurg 1984; 60: 1226 – 1235
[2] Al-Mefty O, Fox JL. Superolateral orbital exposure and reconstruction. Surg Neurol 1985; 23: 609 – 613
[3] Hamby WB. Pterional approach to the orbits for decompression or tumor removal. J Neurosurg 1964; 21: 15 – 18
[4] Housepian EM. Surgical treatment of unilateral optic nerve gliomas. J Neurosurg 1969; 31: 604 – 607
[5] Jane JA, Park TS, Poberskin LM, Winn HR, Butter AB. The supraorbital approach; technical note. Neurosurgery 1982; 11: 537 – 542
[6] Maccarty CS, Brown DN. Orbital tumors in children. Clin Neurosurg 1994; 11: 76 – 93
[7] Brihaye J. Neurosurgical approach to orbital tumors. In: Krayenbühl M (ed). Advances and Technical Standards in Neurosurgery. Wien, New York: Springer Verlag, 1976
[8] Cooper WC, Harris GJ. Orbital Surgery. In: Jones IS, Jakobiec FA (eds), Diseases of the Orbit. New York: Harper & Row Publishers Inc, 1979
[9] Kenerdell JS, Maroon JC. Microsurgical approach to intraorbital tumors. Technique and instrumentation. Arc Ophthalmol 1976; 94: 1333 – 1336
[10] Kim SJ, Lew H, Chung S-H, Kook KH, Juan Y, Lee SY. Repair of medial orbital wall fracture; transcaruncular approach. Orbit 2005; 24: 1 – 9
[11] Soames RW. Skeletal system. In: Williams PL (ed). Gray's Anatomy, 38th edn. London: ELBS, 1995: 425 – 736
[12] Natori Y, Rhoton AL. Transcranial approach to the orbit: Microsurgical anatomy. J Neurosurg 1994; 81: 78 – 86
[13] Anderson DR, Davis EB. Retina and optic nerve after posterior ciliary artery occlusion. Arch Ophthalmol 1974; 92: 422 – 426
[14] Nolasco FP, Matlog RH. Medial orbital wall fractures: Classification and clinical profile. Head and Neck Surg 1995; 112: 549 – 556
[15] Forbes GS, Gehring BS, Gorman CA et al. Volume measurement of normal orbit by computed tomographic analysis. Am J Neuroradiol 1985; 6: 419 – 424
[16] Charterside DG, Chan CH, Whitehouse RW, Noble JL. Orbital volume measurement of pure blow-out fractures of the orbital floor. Br J Ophthalmol 1993; 77: 100 – 102
[17] Yab K, Tajima S, Ohba S. Displacement of eyeball in orbital blowout fractures. Plast Reconst Surg 1997; 100: 1409 – 1417
[18] Leone Jr CR, Lloyd III WC, Rylander G. Surgical repair of medial wall fractures. Am J Ophthalmol 1984; 97: 349 – 356
[19] Edwards WC, Ridley RW. Blow-out fracture of medial orbital wall. Am J Ophthalmol 1968; 65: 248 – 249
[20] Rauch SD. Medial orbital blow-out fracture with entrapment. Arch Otolaryngol 1985; 111: 53 – 55
[21] Converse JM, Hogan VM. Open-sky approach for reduction of naso-orbital fractures. Plast Reconstr Surg 1970; 63: 396 – 398
[22] Rumelt MB, Ernst JT. Isolated blow-out fracture of the medial orbital wall with medial rectus muscle entrapment. Am J Ophthalmol 1972; 73: 451 – 453
[23] Domarus H von. A technique for reconstruction of blow-out fractures of the medial orbital wall-case report. J Maxillofac Surg 1974; 2: 55 – 57
[24] Davidson TM, Olsen RM, Nahum AM. Medial orbital wall fracture with rectus entrapment. Arch Otolaryngol 1975; 101: 33 – 35
[25] Thering HR, Bogart JN. Blow-out fracture of the medial wall, with entrapment of the medial rectus muscle. Plast Reconst Surg 1979; 63: 848 – 852
[26] Bartkowski SB, Krzystkowa KM. Blow-out fracture of the orbit. Diagnostic and therapeutic consideration, and results in 90 patients treated. J Maxillofac Surg 1982; 10: 155 – 164
[27] Magnus WW, Castner DV, Schonder AA et al. A conjunctival approach to repair of the medial wall of the orbit. J Oral Surg 1971; 29: 664 – 671
[28] de Visscher GAM, Wal KGH van der. Medial orbital wall fracture with enophthalmos. J Craniomaxillofac Surg 1988; 16: 55 – 59

[29] Anderson RL, Linberg JV. Transorbital approach to decompression in Graves' disease. Arch Ophthalmol 1981; 99: 120 – 124
[30] Naffziger HC. Exophthalmos. Some surgical principles of surgical management from the neurosurgical aspect. Ann J Surg 1948; 75: 25 – 41
[31] Lynch RC. The technique of a radical frontal sinus operation which has given me the best results. Laryngoscope 1921; 31: 1 – 5
[32] Leone Jr CR, Piest KL, Newman RJ. Medial and lateral wall decompression for tyroid ophthalmopathy. Am J Ophthalmol 1989; 108: 160 – 166
[33] Esclamado RM, Cummings CW. Z-plasty modification of the Lynch incision. Laryngoscope 1989; 99: 986 – 987
[34] Osguthorpe JD, Sounders RA, Adkins WY. Evaluation of and access to posterior orbital tumors. Laryngoscope 1983; 93: 766 – 771
[35] Lillie HI, Williams HL. The external fronto-ethmo-sphenoid operation: a critical review of the literature and details of the technique in use at the Mayo Clinic. Minnesota Med 1935; 18: 786 – 789
[36] Neel III HB, McDonald TJ, Facer GW. Modified Lynch procedure for chronic frontal sinus diseases: rational, technique, and long-term results. Laryngoscope 1987; 97: 1274 – 1279
[37] Harrison DF. Surgical approach to the medial orbital wall. Ann Otol Rhinol Laryngol 1981; 90: 415 – 419
[38] Shorr NS. "Madame Butterfly" procedure: total lower eyelid reconstruction in 3 layers utilizing a hard palate graft. Management of the unhappy post-blepharoplasty patient with round eye and scleral show. Int J Aesth Restor Surg 1995; 3: 3 – 26
[39] Tenzel RR, Miller GR. Orbital blow-out fracture repair, conjunctival approach. Am J Ophthalmol 1971; 71: 1141 – 1142
[40] McCord Jr CD, Mosses JL. Exposure of the inferior orbit with fornix incision and lateral canthotomy. Ophthalmic Surg 1979; 10: 53 – 63
[41] McCord Jr CD. Orbital decompression for Graves' disease. Exposure through lateral canthal and inferior fornix incisions. Ophthalmology 1981; 88: 533 – 541
[42] Goldberg RA, Lessner AM, Shorr N, Baylis HI. The transconjunctival approach to the orbital floor and orbital fat. A prospective study. Ophthalmic Plast Reconstr Surg 1990; 6: 241 – 246
[43] Shorr N, Baylis HI, Goldberg RA, Perry JD. Transcaruncular approach to the medial orbit and orbital apex. Ophthalmology 2000; 107: 1459 – 1463
[44] McCord Jr CD, Tanenbaum M, Nunery WR. Oculoplastic surgery, 3rd edn. New York: Raven Press, 1995: 537 – 538
[45] Missori P, Tarantino R, Delfini R, Lunardi P, Cantore G. Surgical management of orbital cavernous angiomas: prognosis for visual function after removal. Neurosurgery 1994; 35: 34 – 37
[46] Hassler WE, Meyer B, Rohde V, Unsöld R. Pterional approach to the contralateral orbit. Neurosurgery 1994; 34: 552 – 554
[47] Herman P, Lot G, Portier F et al. Transnasal endoscopic removal of an orbital cavernoma. Ann Otol Rhinol Laryngol 1999; 108: 147 – 150
[48] Mun GH, Song YH, Bang SI. Endoscopically assisted transorbital approach in orbital medial wall fractures. Ann Plast Surg 2002; 49: 337 – 343
[49] Garcia HG, Goldberg RA, Shorr N. The transcaruncular approach in repair of orbital fracture: A retrospective study. J Cranio-maxillofacial Trauma 1984; 4: 7 – 12

CyberKnife Stereotactic Radiotherapy for Patients with Malignant Glioma

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Abstract

Objective: The CyberKnife is a new frameless image-guided radiosurgical modality. The authors report on their experience using the CyberKnife in 25 patients with malignant gliomas. **Methods:** Twenty-five patients with histologically proven malignant gliomas (18 glioblastoma: GB, 7 anaplastic astrocytoma: AA) were treated with the CyberKnife at Konan St. Hill Hospital between June 1998 and November 2002. CyberKnife therapy was performed on 44 lesions (31 GB lesions, 13 AA lesions) in the 25 patients. The median target volume was 19.1 mL (range: 0.3 – 90.2). The median prescribed dose was 20.3 Gy (range: 13.9 – 26.4). Patient-, tumor-, and treatment-related variables were analyzed by univariate analysis, and survival curves were generated by the Kaplan-Meier product limit. **Results:** In the 18 GB patients, the median survival after diagnosis was 20.7 months (82.6 weeks) with a mean follow-up of 85.7 weeks. Of the 7 AA patients, 6 were alive at the time of analysis with follow-up periods ranging from 11.4 to 52.8 months. Patients younger than 70 years had a median survival after diagnosis of 37.1 months, compared to 12.4 months for older patients ($p = 0.003$). Similarly, patients with well-controlled lesions had a median survival after diagnosis of 39.8 months compared to 16.0 months for those with uncontrolled lesions ($p = 0.031$). Late delayed radiation necrosis was seen in 1 GB patient. No other patient suffered acute or delayed neurological morbidity after CyberKnife therapy. **Conclusion:** This is the first report of CyberKnife stereotactic radiotherapy applied to the treatment of malignant gliomas. The frameless and painless CyberKnife stereotactic radiotherapy has the potential to be as useful for treatment of malignant glioma as other radiosurgical modalities.

Key words

CyberKnife · malignant glioma · stereotactic radiotherapy · fractionated radiosurgery

Introduction

While the use of radiosurgical treatment for extra-axial localized brain tumors that grow non-invasively, such as neurinoma and meningioma, has reached consensus, radiosurgical treatment of malignant glioma, which grows intra-axially, invasively and in irregular shapes, remains controversial. However, some reports have indicated that radiosurgical treatment of malignant glioma can succeed in preventing tumor growth locally and can prolong the survival time of malignant glioma patients [1 – 5].

The CyberKnife (Accuray, Calfornia, USA) is a powerful device mounted on a highly maneuverable robotic manipulator, which eliminates the need for skeletal fixation or rigid immobilization of the target through its use of real-time image guidance (image-based stereotaxis) [6 – 8]. This frameless radiosurgical instrument has several distinct advantages over frame-based stereotaxis, including improved patient comfort, and the increased freedom and flexibility needed for fractionated irradiation of large and non-spherical lesions. These characteristics are advantageous in the treatment of malignant glioma.

To our knowledge, no previous report has quantified the use of the CyberKnife in the treatment of malignant glioma. Here, we

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Bibliography
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describe our initial results using the CyberKnife in patients of malignant glioma.

Patients and Methods

Patient population

The twenty-five adult subjects with malignant glioma included in the study were treated with CyberKnife stereotactic radiotherapy at Konan St. Hill Hospital between June 1998 and November 2002. All patients harbored supratentorial tumors and had a proven histological diagnosis of glioblastoma (GB) or anaplastic astrocytoma (AA) by previous surgery. Of the 25 patients, 18 (median age: 61.6 years; range: 48 – 78) were diagnosed with GB, while 7 (median age: 46.1 years; range: 28 – 71) had AA. Patients were enrolled on the basis of the most recent pre-enrollment pathological specimens. A summary of patient characteristics is shown in Table **1**.

CyberKnife stereotactic radiotherapy

CyberKnife stereotactic radiotherapy was used to address 44 lesions in the 25 patients (31 lesions in 18 GB patients, 13 lesions in 7 AA patients). Of the 25 patients:

- Fifteen patients had a single lesion (15 lesions), while 10 had multiple ones comprised of multifocal glioma (2 lesions in 1 patient) or several residual lesions around a resection cavity (27 lesion in 8 patients).
- Twenty patients (13 GB patients, 11 AA patients) received CyberKnife therapy just once in their follow-up periods (single CyberKnife therapy). The remaining 5 patients (3 GB patients, 2 AA patients) received CyberKnife therapy for each incident of recurrence (repeated CyberKnife therapy).

Table **1** Patient characteristics

Characteristic	*Glioblastoma (n = 18)*	*Anaplastic astrocytoma (n = 7)*
Age [years]		
– median	61.6	46.1
– range	48 – 78	28 – 71
Gender		
– male	10	3
– female	8	4
Karnofsky performance status		
– median	68.9	85.7
– range	30 – 90	70 – 90
Treatment before CyberKnife therapy		
Craniotomy		
– total resection	2	1
– subtotal resection	8	4
– partial resection	7	2
– biopsy	1	0
Conventional radiotherapy		
– Yes	9	5
– median [Gy]	44.5	56.3
– range [Gy]	20 – 66	50 – 60
– No	9	2
Chemotherapy		
– Yes	10	4
– No	8	3

The target area of CyberKnife therapy was defined by the gadolinium (Gd)-enhanced area in the pre-treatment magnetic resonance imaging (MRI). Fractionation was used positively in the case of large lesions. The prescribed marginal dose was defined as that delivered at an isodose surface surrounding 90% of the entire volume of each target. In planning the CyberKnife therapy, we used various planning types, including single-isocenter planning, multi-isocenter planning, and conformal planning, depending on the shape of the lesion.

Analysis of local response

Post-radiotherapeutic states were assessed by serial MRI scans every 3 months or more often if indicated for the analysis of local control. The therapeutic response was classified as follows: complete response (CR: Gd-enhanced area disappears and no regrowth is recognized for at least four weeks after treatment), partial response (PR: Gd-enhanced area is reduced by more than 50% and maintains this state for at least four weeks after treatment), no change (NC: less than 50% reduction or less than 25% growth of Gd-enhanced area, maintained for at least four weeks after treatment), and progressive disease (PD: more than 25% growth of Gd-enhanced area). The effectiveness and control rates were calculated by CR + PR/CR + PR + NC + PD and CR + PR + NC/CR + PR + NC + PD, respectively. To assess the therapeutic response of CyberKnife therapy fairly, classification and calculation of effectiveness and control rates were performed using only cases receiving no other adjuvant therapy such as chemotherapy after CyberKnife therapy.

Analysis of recurrence

We investigated the recurrence in regard to rate, location and interval from CyberKnife therapy to recurrence. All lesions receiving CyberKnife therapy were included for this analysis, whether or not the patients received adjuvant therapy such as chemotherapy.

Analysis of complication

We investigated complications on serial MRI scans every 3 months or more often if indicated. We also performed thallium-201 single photon emission computed tomography to estimate whether there was recurrence or radiation necrosis, if necessary.

Survival analysis

The actuarial median survival and survival rates at 1, 2 and 3 years after each diagnosis and initial CyberKnife therapy were calculated using the Kaplan-Meier method. Since 6 of the 7 AA patients are alive at present and calculations of median survival and survival rate of AA patients are inaccurate, this analysis was performed only in GB patients.

Univariate comparisons of survival between patient's factors were performed using Kaplan-Meier actuarial analysis and a log-rank technique. The factors included age, gender, Karnofsky performance scale score, previous conventional radiotherapy, frequency of CyberKnife therapy (single vs. repeated CyberKnife therapy), and local response (CR or PR vs. NC or PD). Multivariate

Table **2** Local response

	CR	*PR*	*NC*	*PD*	*Effectiveness rate*	*Control rate*
GB (No. of lesions = 22)	1 (4.5%)	5 (22.7%)	8 (36.4%)	8 (36.4%)	27.2%	63.6%
AA (No. of lesions = 11)	0 (0%)	2 (18.2%)	3 (27.3%)	6 (54.5%)	18.2%	45.5%

GB = glioblastoma, AA = anaplastic astrocytoma, CR = complete response, PR = partial response, NC = no change, PD = progressive disease.

Table **3** Recurrence

	Initial response	*No. of lesions*	*Appearance of new lesion*	*No. of lesions*	*Location of recurrence*	*No. of lesions*
GB (no. of lesions = 31)	controlled[a]	19	yes	18	beside[c]	12
	uncontrolled[b]	12	no	1	remote[d]	6
AA (no. of lesions = 13)	controlled	7	yes	5	beside	3
	uncontrolled	6	no	2	remote	2

[a] Controlled: complete response (CR), partial response (PR), or no change (NC) state after CyberKnife therapy.
[b] Uncontrolled: progressive disease (PD) state after CyberKnife therapy.
[c] Lesion located beside or inside the prescribed marginal isodose line of previous CyberKnife therapy.
[d] Lesion located remote from the prescribed marginal isodose line of previous CyberKnife therapy.

analysis was not performed since the number of patients included in this study was too small for accurate analysis.

Results

Treatment parameters

The median target volume was 19.1 mL (range: 0.3 – 90.2). The numbers of fractionations were 1/2/3/4/5 in 9/12/12/4/7 lesions. Lesion planning resulted in 6 single-isocenter, 7 multi-isocenter, and 31 conformal planning types. The median prescribed dose, calculated by a linear-quadratic formula using the LQ model (alpha/beta = 2) [9] in cases of fractionated irradiation, was 20.3 Gy (range: 13.9 – 26.4).

Analysis of local response

Our results are summarized in Table **2**. Twenty-two lesions of 11 GB patients and 11 lesions of 5 AA patients received no adjuvant therapy after CyberKnife treatment. Of the 22 GB lesions, those resulting in CR were 1 lesion (4.5%); PR, 5 (22.7%); NC, 8 (36.4%); and PD, 8 (36.4%). The effectiveness and control rates in GB patients were 27.2% and 63.6%, respectively. Of the 11 AA lesions, those resulting in CR were 0 lesions (0%); PR, 2 (18.2%); NC, 3 (27.3%); and PD, 6 (54.5%). The effectiveness and control rates in AA patients were 18.2% and 45.5%, respectively.

Analysis of recurrence

These results are summarized in Table **3**. Of 31 GB lesions, 19 were recognized to be controlled (i.e., CR, PR, NC) after treatment. Of the 19 controlled lesions, new lesions were seen in 18 cases (94.7%) within a mean follow-up of 20.7 weeks. Of the 18 new lesions, 12 (63.2%) were located beside or inside the prescribed marginal isodose line of the previous CyberKnife therapy. The remaining 6 lesions were recognized in areas remote from the radiation field of previous CyberKnife therapy or as dissemination. The interval from CyberKnife therapy to recurrence was 130 days on average.

Of the 13 AA lesions, 7 were recognized as controlled after treatment. Of the 7 controlled lesions, new lesions were seen in 5 cases (71.4%) within a mean follow-up of 27.3 weeks. Of the 5 new lesions, 3 (42.9%) were located beside or inside of the prescribed marginal isodose line of the previous CyberKnife therapy. The remaining 2 lesions were recognized in areas remote from the radiation field of previous CyberKnife therapy. The interval from CyberKnife therapy to recurrence was 281 days on average.

Analysis of complication

A complication was seen in only one case (1/25 = 4%). It was late delayed radiation necrosis in a GB patient, diagnosed pathologically in a craniotomy 10 months after Cyberknife therapy. No patient suffered acute neurological morbidity after CyberKnife therapy while maintaining stable doses of corticosteroid medication that were slowly tapered as tolerated.

Survival analysis

In 18 GB patients, the actuarial median survival after diagnosis was 20.7 months (82.6 weeks) with a mean follow-up of 85.7 weeks (Fig. **1a**). The survival rates at 1, 2 and 3 years after diagnosis were 68%, 42% and 27%. Of 7 AA patients, 6 were alive at the time of analysis with follow-up periods ranging from 11.4 to 52.8 months.

For patients treated with the CyberKnife, age and local response were significantly predictive of survival outcome both after diagnosis and after CyberKnife therapy on univariate analysis. Patients younger than 70 years had an actual median survival after diagnosis of 37.1 months (Fig. **1b**). This was compared with 12.4

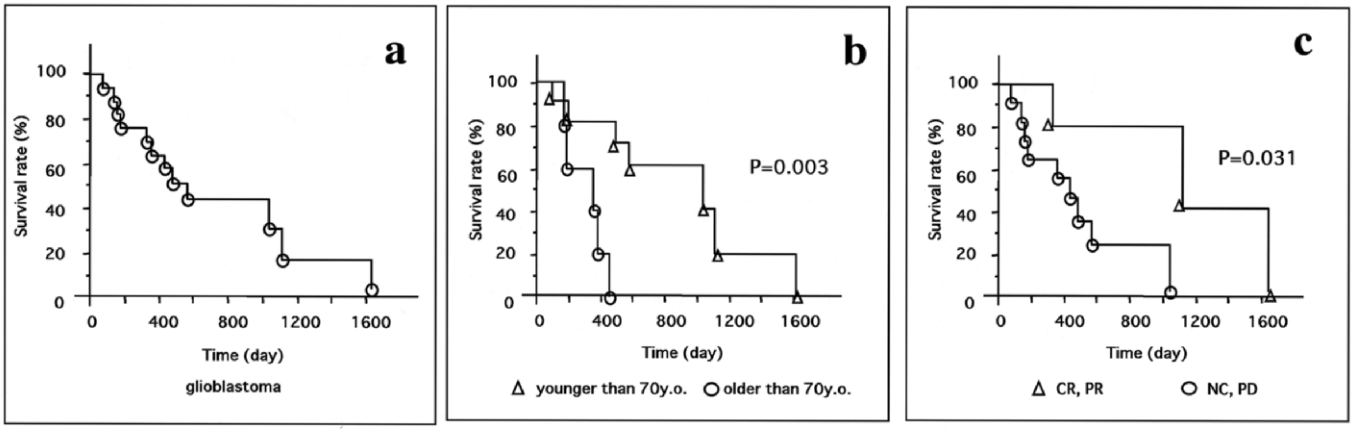

Fig. **1** **a** Kaplan-Meier plots displaying actuarial survival time after diagnosis in 18 patients with glioblastoma treated with CyberKnife. **b** Kaplan-Meier plots showing the statistically significant difference in survival time after diagnosis in patients younger or older than 70 years. **c** Kaplan-Meier plots showing the statistically significant difference in survival time after diagnosis in patients with lesions resulting in CR/PR or NC/PD. CR = complete response, PR = partial response, NC = no change, PD = progressive disease.

months for older patients (p = 0.003). Similarly, patients with well-controlled lesions such as CR/PR had an actual median survival after diagnosis was 39.8 months (Fig. **1c**), compared with 16.0 months for those with NC/ PD (p = 0.031). Patients receiving repeated CyberKnife therapy tended to have a longer median survival after diagnosis compared with those receiving single CyberKnife therapy, but the difference was not significant (p = 0.065). The other factors were not predictive of survival outcome.

Illustrative case

This 74-year-old woman suffered from dementia beginning in December 1997. Her symptoms gradually worsened and a malignant glioma in the left frontal base extending to the basal ganglia was diagnosed. She underwent craniotomy for partial resection of the tumor, and the histological diagnosis with surgical specimens was glioblastoma. She was referred to Konan St. Hill Hospital for the purpose of a CyberKnife boost therapy against the residual tumor in the basal ganglia in May 1998 after conventional external beam radiotherapy (Fig. **2a**). The first CyberKnife therapy was performed on June 14 – 15, 1998 with a total dose of 20.7 Gy in two fractions. The marginal dose was 15 Gy recalculated by the linear-quadratic formula using the LQ model (alpha/beta = 2 Gy). MRI revealed that the lesion was controlled in the NC state for a year after treatment (Fig. **2b**). Her first recurrence occurred a year after the first CyberKnife therapy (Fig. **2c**), and a second CyberKnife therapy with a total dose of 24.9 Gy in two fractions was performed on May 14 – 15, 1999. The marginal dose was 18 Gy, recalculated by the same method. She was stable in the NC state again (Fig. **2d**) and MRI revealed that the lesion vanished gradually as if it had been gouged out by a knife (Fig. **2e**). Her second recurrence occurred a year and 8 months after the second CyberKnife (Fig. **2f**), and a third CyberKnife therapy with a total dose of 23.3 G y in two fractions was performed on January 23 – 24, 2001. The marginal dose was 16.8 Gy recalculated by same method. Although the lesion shrank initially after the third treatment (Fig. **2g**), it began to grow 6 months later. The patient died of pneumonia on August 17, 2001. The survival periods after diagnosis and first CyberKnife treatment were 1234 days (3 years and 4 months) and 1144 days (3 years and 1 month).

Discussion

The standard treatment for malignant glioma is established as a combination of radical surgery, conventional external beam radiotherapy and intravenous chemotherapy using agents such as nitrosourea and interferon [10 – 12]. However, the prognosis of malignant glioma, particularly glioblastoma, remains dismal. A summary of survival analyses in the treatment of malignant glioma by conventional radiotherapy and radiosurgery is shown in Table **4**. The median survival for glioblastoma with postoperative treatment using conventional external beam radiotherapy ranges from 10 to 13 months, even in recent reports [8,13,14]. Dose escalation for treatment of malignant glioma using stereotactic radiotherapy or radiosurgery with the linear accelerator and gamma knife has been tried in recent decades with hopeful results [1 – 5].

The CyberKnife is a new radiosurgical modality that mounts a linear accelerator on a highly maneuverable robotic manipulator and eliminates the need for skeletal fixation or rigid immobilization of the target through its use of real-time imaging. The accuracy of the CyberKnife is comparable to published localization errors in current frame-based radiosurgical modalities [15]. This frameless and precise radiosurgical modality improves patient comfort and increases the degree of freedom and flexibility needed for fractionated irradiation. However, its therapeutic effect is insufficiently known. Although some therapeutic studies using the CyberKnife to treat brain tumors have been reported [8,16], none of these has quantified the use of CyberKnife in the treatment of malignant glioma. In our series, the median survival after diagnosis was 20.7 months, which compares favorably to other radiosurgical modalities (Table **4**). It is worthy of special mention that although the target volume in our series (19.1 mL, equivalent to 33 mm diameter) was fairly large, the risk of late radiation injury was minimized.

The first advantage of the CyberKnife in treating malignant glioma is its frameless stereotaxis [15,17]. We performed fractionated irradiation for safer treatment of large lesions. The target volume, or the Gd-enhanced area, is liable to be large in malig-

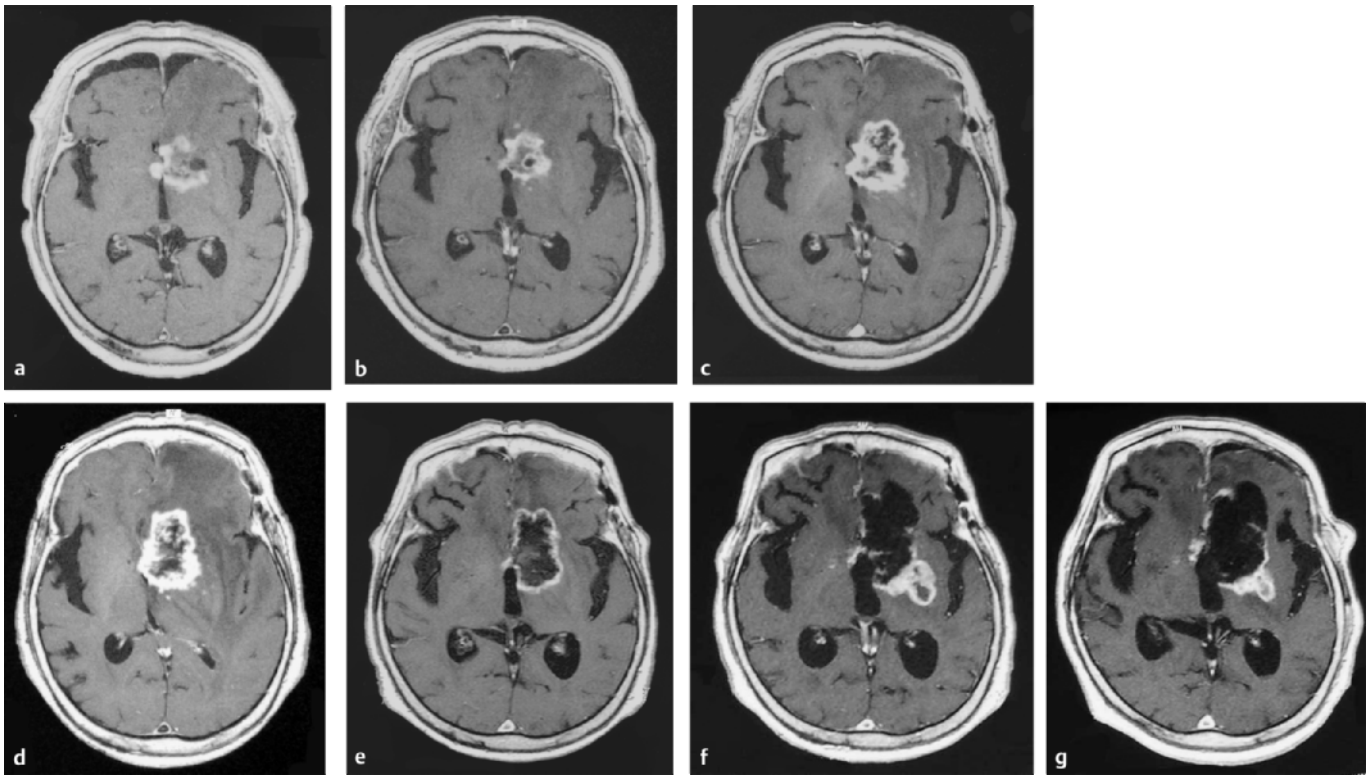

Fig. **2** Axial Gd-enhanced MRI obtained in a 74-year-old woman with glioblastoma who underwent repeated CyberKnife therapy (3 times). **a** Before CyberKnife therapy. **b** Seven months after first CyberKnife therapy. Tumor was controlled in the NC state. **c** Regrowth at one year after first CyberKnife therapy, prior to second CyberKnife therapy. **d** After second CyberKnife therapy. **e** Ten months after second CyberKnife therapy. **f** Regrowth at one and half years after second CyberKnife therapy, prior to third CyberKnife therapy. **g** Partially reduced tumor following third CyberKnife therapy.

nant glioma. In our series, 35 of 44 lesions (79.5%) were treated with fractionated irradiation. We could increase the number of fractions without hesitation since the CyberKnife realizes frameless stereotaxis and is therefore able to undertake fractionation without causing the patient the pain that normally arises from frame fixation with head-pins. The larger the number of fractions, the broader can the radiation field be. It becomes possible to cover an adequate area and also to include a safety margin in case the Gd-enhanced area is small. We think that it might be necessary to further increase the number of fractions for safer treatment in the future. In addition, repeated CyberKnife therapy at each time of recurrence might prolong survival time, as illustrated by the case above; the fact that it is painless is an important advantage in that regard.

The second advantage of the CyberKnife in treatment of malignant glioma, especially irregular, non-spherical lesions, is its flexibility of approach [18]. In the CyberKnife planning, the radiation field shape is constructed not only by a combination of ellipsoids but also by conformal planning that has no isocenter. In our series, the treatment of 31 of 44 lesions (70.5%) adopted conformal planning. Adaptability to irregular shapes is advantageous since malignant glioma grows invasively and tends to assume irregular shapes.

The most serious problem in the treatment of malignant glioma using radiosurgery is its failure to control recurrence outside the central field of therapy. It is known that the majority of recurrences in malignant glioma are located within 2 cm of the enhancing edge of the original tumor [19]. Unfortunately, in our series as well, tumor recurrence occurred in spite of a high local control rate. We coped with recurrent lesions by repeated CyberKnife therapy whenever possible. We think that adequate and thorough local control is important for prolonging survival time on the basis of the result that good local control was significantly predictive of survival outcome in our study. Although repeated CyberKnife therapy in the same or nearby locations increases the risk of radiation necrosis, no patient undergoing repeated CyberKnife therapy suffered from radiation necrosis in our series. Surgical resection of the recurrent lesion might be safer than repeated CyberKnife therapy to avoid the risk of radiation necrosis. However, "minimally invasive," repeated CyberKnife therapy is a valuable option for treating patients with a seriously compromised daily life or patients harboring unresectable lesions such as deep-seated glioma.

Conclusion

CyberKnife stereotactic radiotherapy was applied in the treatment of malignant glioma. The frameless, painless CyberKnife stereotactic radiotherapy has as much potential to prolong the survival time of patients with malignant glioma as other radiosurgical modalities. The definitive role of CyberKnife therapy for patients with malignant glioma awaits the results of a larger case series, case control and randomized trials.

Table **4** Summary of survival analysis in conventional and radiosurgical treatment of malignant glioma

Group	*Author, year*	*No. of patients*	*Radiosurgical modality*	*Study design*	*Median target volume (mL)*	*Late complication (%)*	*Median survival after diagnosis (months)*	*1-year SR after diagnosis (%)*	*2-year SR after diagnosis (%)*	*3-year SR after diagnosis (%)*
Radiosurgery	Masciopinto, 1995 [3]	GB 31	LINAC	CS	16.4	–	9.5	45	28	13.5
	Gannett, 1995	MG 30	LINAC	CS	24.0	0	13.9	57	25	20
	Kondziolka, 1997 [1]	GB 64	gamma knife	CS	6.5	1.6	26	–	51	30
	Shrieve, 1999 [5]	GB 78	LINAC	CS	–	(25.6)[a]	19.9	88.5	35.9	23
	Larson, 2002 [2]	GB 39	gamma knife	CS	13.6	–	–	–	–	–
	Nwokedi, 2002 [4]	GB 31	gamma knife	CCS	25.0	7.0	25	92	48	43
	Prisco, 2002	MG 15	gamma knife	CCS	15.0	(20.0)[a]	21.4	61	43	43
	our series, 2004	GB 18	CyberKnife	CS	19.1	4.0	20.7	68	42	27
EBRT	Curran, 1993 [13]	MG 1578	x	x	x	x	11.3	–	–	–
	Nwokedi, 2002 [4]	GB 33	x	x	x	x	13	58	40	22
	Prisco, 2002	MG 17	x	x	x	x	11.6	43	16	0
	Laws, 2003 [14]	GB 413	x	x	x	x	10.2	–	–	–

GB = glioblastoma; MG = malignant glioma; SR = survival rate; CS = case series; CCS = case-control study; LINAC = linear accelerator; – = data not shown; EBRT = external beam radiotherapy; [a] The rates of cases, not mentioned as complications, but requiring reoperation after radiosurgical treatment and diagnosed radiation necrosis by surgical specimen.

References

[1] Kondziolka D, Flickinger JC, Bissonette DJ, Bozik M, Lunsford LD. Survival benefit of stereotactic radiosurgery for patients with malignant glial neoplasms. Neurosurgery 1997; 41: 776 – 785

[2] Larson DA, Prados M, Lamborn KR, Smith V, Sneed PK, Chang S, Nicholas KM, Wara WM, Devriendt D, Kunwar S, Berger M, McDermott MW. Phase II study of high central dose gamma knife radiosurgery and marimastat in patients with recurrent malignant glioma. Int J Radiat Oncol Biol Phys 2002; 54: 1397 – 1404

[3] Masciopinto JE, Levin AB, Mehta MP, Rhode BS. Stereotactic radiosurgery for glioblastoma: a final report of 31 patients. J Neurosurg 1995; 82: 530 – 535

[4] Nwokedi EC, DiBiase SJ, Jabbour S, Herman J, Amin P, Chin LS. Gamma knife stereotactic radiosurgery for patients with glioblastoma multiforme. Neurosurgery 2002; 50: 41 – 47

[5] Shrieve DC, Alexander E, Black PM, Wen PY, Fine HA, Kooy HM, Loeffler JS. Treatment of patients with primary glioblastoma multiforme with standard postoperative radiotherapy and radiosurgical boost: prognostic factors and long-term outcome. J Neurosurg 1999; 90: 72 – 77

[6] Adler JR, Chang SD, Murphy MJ, Doty J, Geris P, Hancock SL. The Cyberknife: a frameless robotic system for radiosurgery. Stereotact Funct Neurosurg 1997; 69: 124 – 128

[7] Chang SD, Adler JR. Robotic and radiosurgery – the cyberknife. Stereotact Funct Neurosurg 2001; 76: 204 – 208

[8] Chang SD, Murphy M, Geis P, Martin DP, Hancock SL, Doty JR, Adler JR. Clinical experience with image-guided robotic radiosurgery (the Cyberknife) in the treatment of brain and spinal cord tumors. Neurol Med Chir (Tokyo) 1998; 38: 780 – 783

[9] Fowler JF. The linear-quadratic formula and progress in fractionated radiotherapy. Br J Radiol 1989; 62: 679 – 694

[10] Fine HA, Dear KBG, Loeffler JS, Black PM, Canellos GP. Meta-analysis of radiation therapy with and without adjuvant chemotherapy for malignant gliomas in adults. Cancer 1993; 71: 2585 – 2597

[11] Kelly PJ, Hunt C. The limited value of cytoreductive surgery in elderly patients with malignant gliomas. Neurosurgery 1994; 34: 62 – 67

[12] Shapiro WR, Green SB, Burger PC, Mahaley MS, Selker RC, VanGilder JC, Robertson JT, Ransohoff J, Mealey J, Strike TA, Pistenmaa DA. Randomized trial of three chemotherapy regimens and two radiotherapy regimens in postoperative treatment of malignant glioma. Brain Tumor Cooperative Group Trial 8001. J Neurosurg 1989; 71: 1 – 9

[13] Curran WJ, Scott CB, Horton J, Nelson JS, Weinstein AS, Fischback AJ, Chang CH, Rotman M, Asbell SO, Krisch RE, Nelson DF. Recursive partitioning analysis of prognostic factors in three Radiation Therapy Oncology Group malignant glioma trials. J Natl Cancer Inst 1993; 85: 704 – 710

[14] Laws ER, Parney IF, Huang W, Anderson F, Morris AM, Asher A, Lillehei KO, Bernstein M, Brem H, Sloan A, Berger MS, Chang S. Survival following surgery and prognostic factors for recently diagnosed malignant glioma: data from the Glioma Outcomes Project. J Neurosurg 2003; 99: 467 – 473

[15] Chang SD, Main W, Martin DP, Gibbs IC, Heilbrun MP. An analysis of the accuracy of the CyberKnife: a robotic frameless stereotactic radiosurgical system. Neurosurgery 2003; 52: 140 – 146

[16] Shimamoto S, Inoue T, Shiomi H, Sumida I, Yamada Y, Tanaka E, Inoue T. CyberKnife stereotactic irradiation for metastatic brain tumors. Radiat Med 2002; 20: 299 – 304

[17] Stieber VW, Bourland JD, Tome WA, Mehta MP. Gentlemen (and ladies), choose your weapons: Gamma knife vs. linear accelerator radiosurgery. Technol Cancer Res Treat 2003; 2: 79 – 86

[18] Yu C, Jozsef G, Appuzzo ML, Petrovich Z. Dosimetric comparison of CyberKnife with other radiosurgical modalities for an ellipsoidal target. Neurosurgery 2003; 53: 1155 – 1162

[19] Wara WM, Bauman GS, Sneed PK, Larson DA, Karlsson UL. Brain, brain stem and cerebellum. In: Perez CA, Brady LW (eds). Principles and Practice of Radiation Oncology. 3rd edn. Philadelphia: Lippincott-Raven, 1998: 777 – 828

Management of Intracranial Germ Cell Tumors Presenting with Rapid Deterioration of Consciousness

H. Nishioka
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T. Miki

Original Article

Abstract

Objectives: The value of surgical intervention in the management of intracranial germ cell tumors remains controversial. **Patients:** We report three patients who presented with rapid deterioration of consciousness but resulted in complete remission of the tumor after emergency surgery for both diagnostic (biopsy) and therapeutic (for hydrocephalus) purposes followed by prompt initiation of radiochemotherapy. **Conclusion:** For management of these rapidly deteriorating patients, immediate histological verification and avoidance of delay in the induction of radiochemotherapy are essential. Thus, emergency surgery with a less invasive procedure is the first choice of treatment, i.e., endoscopic surgery for pineal region tumor and CT-guided biopsy for basal ganglia tumor.

Key words

Germ cell tumor · hydrocephalus · endoscopic surgery · biopsy

Introduction

Although rare, intracranial germ cell tumors (GCTs) have attracted much attention due to their characteristic clinical features: tumor location, tumor markers and histology, as well as the distinctive therapeutic strategies that are quite different from those for other brain tumors. At present, many therapeutic protocols, e.g., combined chemotherapy and radiation therapy for GCTs other than mature teratomas, have been proposed. In Japan, most patients are treated in accordance with a protocol of the Japanese Pediatric Brain Tumor Study Group [1] with satisfactory results. Although histological information is necessary for the definitive diagnosis and decision on the therapeutic strategy, the significance of surgical intervention, including biopsies, remains controversial [2–11]. In addition, the management of patients who present with rapidly deteriorating symptoms has rarely been reported. We report three patients who presented with a rapid deterioration of consciousness. Diagnostic and therapeutic strategies for these patients are discussed.

Case Reports

Case 1 (Fig. 1)

A 10-year-old boy presented with progressive headache and vomiting. On the day he was referred to our hospital with a diagnosis of pineal region tumor with obstructive hydrocephalus, 5 days after onset, his consciousness had deteriorated to lethargy and showed general convulsions. He underwent emergency endoscopic biopsy and third ventriculostomy that yielded a histological diagnosis of yolk sac tumor and immediate recovery of consciousness. However, 4 days after the surgery, bilateral ptosis, downward ocular deviation, hearing disturbance, and the Parinaud's sign manifested. He developed mildly disturbed consciousness again. His serum AFP titer was 388.0 ng/mL on admission but his AFP titers in the serum and CSF had increased to 2192.1 and 1253.2 ng/mL, respectively, when these symptoms developed. Enlargement of the tumor without hydrocephalus was noted on CT. Thus chemotherapy (CARB-VP: carboplatin and etoposide) was hastily initiated, beginning from 7 days after surgery. Since his consciousness continuously deteriorated, ra-

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Bibliography
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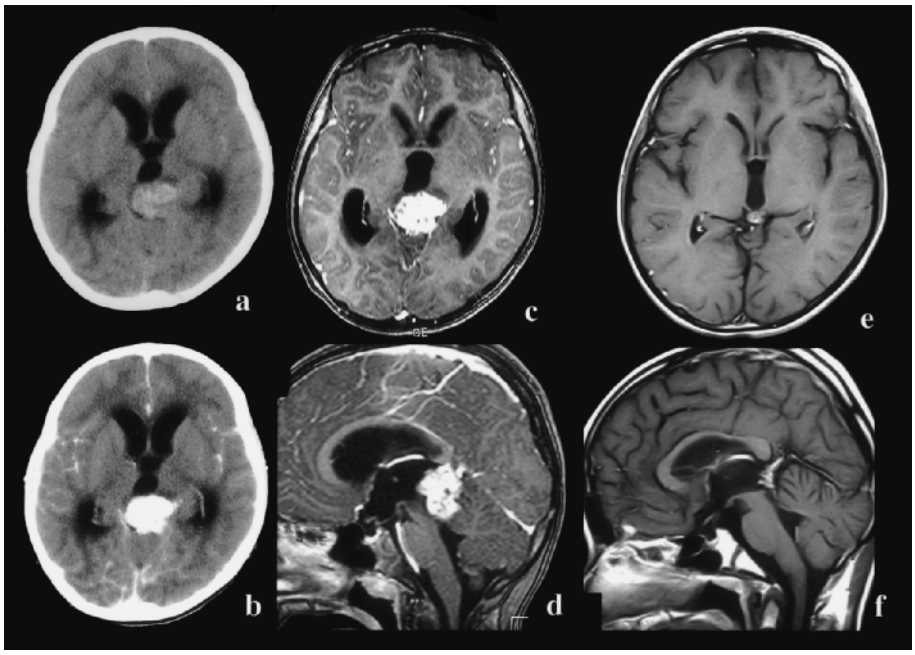

Fig. **1** Case 1: A pineal region tumor that was irregular in margins and enhancement (axial: **a**; sagittal: **b**) with obstructive hydrocephalus was noted on a T_1-weighted Gd-enhanced study. The T_1-weighted Gd-enhanced image after radiation therapy and one course of chemotherapy showed prominent shrinkage of the tumor (**c**).

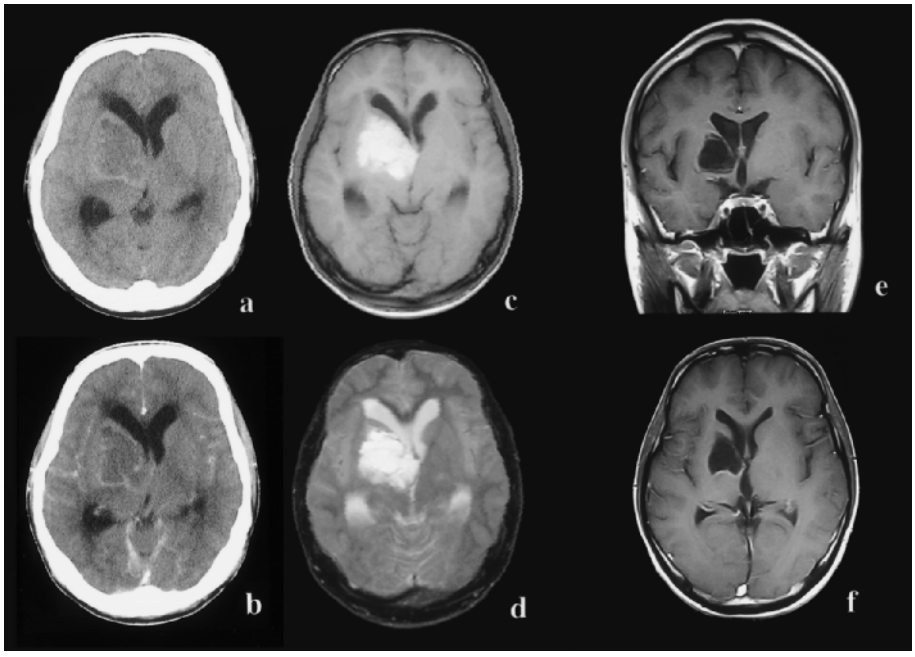

Fig. **2** Case 2: A mass lesion was noted in the right basal ganglia with mild marginal enhancement on CT (**a**). The lesion showed high signals on both T_1- and T_2-weighted images (T_1 axial: β; T2 axial: **c**). The T_1-weighted Gd-enhanced image after radiochemotherapy demonstrated complete remission of the tumor (**d**).

diation therapy was commenced 10 days after the surgery with doses of 30 Gy for whole-brain, 30 Gy for the local region and 24 Gy for the whole spine. His condition improved rapidly during these treatments and he became symptom-free with negative AFP in both serum and CSF. He received the same chemotherapy a total of 7 times every 3 to 4 months. He is now in good health without any neurological deficit at 42 months since onset.

Case 2 (Fig. 2)

A 20-year-old man who presented with progressive headache and vomiting was referred to our hospital 8 days after onset. On admission, he had mild hemiparesis in addition to symptoms of intracranial hypertension. CT/MRI demonstrated a hematomatous lesion in the right basal ganglia associated with obstructive hydrocephalus. Two days later, he suddenly suffered coma with signs of uncal herniation. Ventricular drainage and CT-guided aspiration/biopsy were performed on an emergency basis and improved his condition dramatically. Although the histological diagnosis was germinoma with hemorrhage and no syncytiotrophoblastic elements were found, titers of HCG of the serum, CSF, and hematoma fluid were 15, 45, and 78,000 mIU/mL, respectively, and HCG-beta titers in the serum, CSF, and hematoma fluid were 0.1, 0.3, and 810 ng/mL, respectively. After a course of chemotherapy (CARB-VP) on the basis of a diagnosis of an HCG-producing germinoma, radiation with doses of 30.6 Gy for the extended local region and additional 20 Gy for the local region was delivered, resulting in complete remission of the tumor. He received the same chemotherapy a total of 8 times every 3 to 4 months. He is now in good health without any neurological deficit at 74 months since onset.

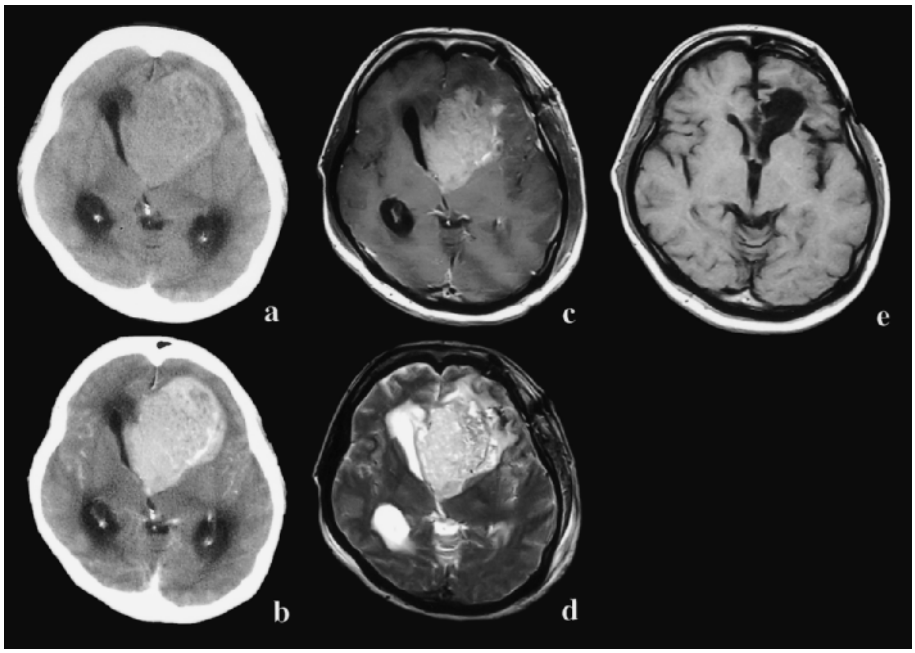

Fig. **3** Case 3: A huge tumor with homogeneous enhancement was noted in the left frontal lobe (**a**). MRI obtained after one course of chemotherapy demonstrated slight shrinkage of the tumor that showed homogeneous Gd-enhancement (**b**) and high-signal intensity in the T_2-weighted image (**c**). The T_1-weighted image after radiochemotherapy showed complete remission of the tumor (**d**).

Case 3 (Fig. 3)

A 40-year-old man, who had a past history of testicular seminoma 10 years previously, presented with headache and frontal signs: short memory disturbance and moria. Disorientation was detected when he was referred to our hospital, 10 days after onset, with a diagnosis of a left frontal tumor. His consciousness rapidly deteriorated to stupor or semicoma within 4 days. Open biopsy and ventricular drainage were performed on an emergency basis and a diagnosis of metastatic seminoma was obtained. HCG-beta titers in serum and CSF were 0.4 and 13 ng/mL, respectively. On the day after surgery, a course of chemotherapy (CARP-VP) followed by radiotherapy with a dose of 30 Gy for the extended local region was commenced. The treatment resulted in complete remission of the tumor. He received the same chemotherapy for a total of 3 times every 3 to 4 months. He is now in good health with no neurological deficit and no further metastasis at 80 months since onset.

Discussion

At present, intracranial GCTs are diagnosed by radiological findings, tumor marker analyses in serum and CSF, histological examination, and, in a few institutes, by diagnostic radiotherapy and chemotherapy [8]. Although MRI is useful in defining the precise location and speculating on the diagnosis [12], a definitive diagnosis cannot be achieved by CT and/or MRI alone [2–4,6]. Matsutani et al. [2] have reported the risk of misdiagnosis to be nearly 20% in patients with germinomas. Similar to neuroimaging, tumor markers alone do not yield a definitive diagnosis [2,3,6], particularly when negative. It may be harmful to sample CSF from a patient with intracranial hypertension. In addition, a survey of tumor markers usually takes time: half a day and 3 to 5 days for AFP and HCG-beta, respectively, in our institute. Thus tumor marker analysis was not beneficial in the present 3 patients who urgently needed a diagnosis. Furthermore, we considered that the induction of radiotherapy in these patients with presumed GCTs could be hazardous.

The significance of histological verification in the management of GCTs remains controversial [2–11]. Surgical removal, particularly of lesions in the pineal region, has been a challenging task for neurosurgeons and is still potentially dangerous [6,11]. Clinical features and the aforementioned radiological and tumor marker studies can achieve a tentative diagnosis. In addition, all GCTs other than mature teratomas are, to some degree, radiosensitive and most are chemosensitive, whereas the value of extensive surgical resections is unproven [3–5,7,10]. In the present 3 patients, immediate diagnosis and avoidance of surgical risks as well as delay in induction of radiochemotherapy were necessary. Thus we selected the less invasive approach of biopsy according to the tumor location: endoscopic biopsy for the pineal region, CT-guided biopsy for the basal ganglia, and open biopsy for the frontal lobe. On the other hand, biopsy alone may not be helpful in obtaining the diagnosis of subtypes because GCTs are frequently heterogeneous tumors consisting of a mixture of subtype components. Small biopsy specimens may therefore not represent the entire lesion and may cause sampling error [2,3,7,10]. Diagnosis of subtypes and precise therapeutic strategies could be made later based on the results of the tumor marker analyses together with the biopsy findings.

Endoscopic surgery is now the becoming first-line treatment for pineal region tumors [6,11,13,14]. Not only yielding several biopsy specimens, this procedure can also treat an accompanying hydrocephalus by third ventriculostomy and sample CSF for the tumor markers analysis with safety and accuracy [6,11]. Since this procedure is minimally invasive, it also has great advantages in shortening the time interval from the diagnosis to further treatment. This is important for patients with rapid deterioration, in order to hasten the induction of radiochemotherapy. Meanwhile, GCTs frequently show CSF dissemination and there is a possibility that endoscopic biopsy may cause seeding of the

tumor cells. At present, this complication has not been reported [6,9,11,14] and we have seen no such dissemination after endoscopic biopsy, including cases of GCTs and periventricular gliomas [13]. To minimize the risk of this complication, however, coagulation of the residual tumor after the biopsy, extensive irrigation of CSF during the procedure [11], and early induction of radiochemotherapy should be considered.

References

[1] Matsutani M, Ushio Y, Abe H, Yamashita J, Shibui S, Fujimaki T, Takakura K, Nomura K, Tanaka R, Fukui M, Yoshimoto T, Hayakawa T, Nagashima T, Kurisu K, Kayama T. Combined chemotherapy and radiation therapy for central nervous system germ cell tumors: preliminary results of a phase II study of the Japanese Pediatric Brain Tumor Study Group. Neurosurg Focus 1998; 5: article 7

[2] Matsutani M. [Germ cell tumor.] In: Takakura K, Yamaura A (eds). New Lecture 3. Noushuyo, 2nd edn. Tokyo: Shinohara, 1996: 281 – 303

[3] Matsutani M, Sano K, Takakura K, Fujimaki T, Nakamura O, Funata N, Seto T. Primary intracranial germ cell tumors: a clinical analysis of 153 histologically verified cases. J Neurosurg 1997; 86: 446 – 455

[4] Packer RJ, Cohen BH, Coney K. Intracranial germ cell tumors. Oncologist 2000; 5: 312 – 320

[5] Balmaceda C, Heller G, Rosenblum M, Diez B, Villabranca JG, Kellie S, Maher P, Vlamis V, Walker RW, Leibel S, Finlay JL. Chemotherapy without irradiation – a novel approach for newly diagnosed CNS germ cell tumors: results of an international cooperative trial. J Clin Oncol 1996; 14: 2908 – 2915

[6] Ferrer E, Santamarta D, Garcia-Fructuoso G, Caral L, Rumia J. Neuroendoscopic management of pineal region tumours. Acta Neurochir (Wien) 1997; 139: 12 – 21

[7] Jaing T-H, Wang H-S, Hung I-J, Tseng C-K, Yang C-P, Hung P-C, Lui T-N. Intracranial germ cell tumors: a retrospective study of 44 children. Pediatr Neurol 2002; 26: 369 – 373

[8] Janmohamed S, Grossman AB, Metcalfe K, Lowe DG, Wood DF, Chew SL, Monson JP, Besser GM, Plowman PN. Suprasellar germ cell tumours: specific problems and the evolution of optimal management with a combined chemoradiotherapy regimen. Clin Endocrinol 2002; 57: 487 – 500

[9] Linstadt D, Wara WM, Edwards MSB, Hudgins RJ, Sheline GE. Radiotherapy of primary intracranial germinomas: the case against routine craniospinal irradiation. Int J Radiat Oncol Biol Phys 1998; 15: 291 – 297

[10] Nishizaki T, Kajiwara K, Adachi N, Tsuha M, Nakayama H, Ohshita N, Ikeda N, Iwamoto N, Ito H, Suzuki M. Detection of craniospinal dissemination of intracranial germ cell tumours based on serum and cerebrospinal fluid levels of tumour markers. J Clin Neurosci 2001; 8: 27 – 39

[11] Oi S, Shibata M, Tominaga J, Honda Y, Shinoda M, Takei F, Tsugane R, Matsuzawa K, Sato O. Efficacy of neuroendoscopic procedures in minimally invasive preferential management of pineal region tumors: a prospectively study. J Neurosurg 2000; 93: 245 – 253

[12] Liang L, Korogi Y, Sugahara T, Ikushima I, Shigematsu Y, Okuda T, Takahashi M, Kochi M, Ushio Y. MRI of intracranial germ-cell tumours. Neuroradiol 2002; 44: 382 – 388

[13] Miki T, Ito H, Wada J, Hashimoto T. [Neuroendoscopic treatment of pineal region tumors.] Nerv Sys Child 1998; 23: 323 – 331

[14] Pople IK, Athanasiou TC, Sandeman DR, Coakham HB. The role of endoscopic biopsy and third ventriculostomy in the management of pineal region tumours. Br J Neurosurg 2001; 15: 305 – 311

Modified Surgical Technique for the Treatment of Idiopathic Spinal Cord Herniation

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Technical Note

Abstract

Objective and Importance: Spinal cord herniation is not a common disease and only 80 cases have been reported to the best of our knowledge. The treatment of this lesion is thought to be difficult and a better surgical technique has not been established. **Clinical Presentation:** A 57-year-old man presented with gradually worsening spastic gait and hypoesthesia in the bilateral lower extremities suspected to be due to Brown-Séquard syndrome. Magnetic resonance imaging showed a thoracic spinal cord herniation into the anterior hiatus at T2 – 3. **Intervention:** A modified technique of closure of the hiatus in front of the herniation was performed. A surgical artificial dural membrane was introduced between the herniated portion of the thoracic cord and the dural hiatus and was placed to cover the whole dural defect in order to minimize the operative procedure at the ventral side of the spinal cord. On subsequent magnetic resonance imaging, the herniation was remarkably improved and patient's symptoms were abolished. **Conclusion:** The direct widening of the dural defect has been reported to be the only treatment providing a good outcome. We suggest that our modified technique for its closure can be as safe and effective as the direct widening method.

Key words

Cord herniation · thoracic spine · surgery

Introduction

Spinal cord herniation is a rare disease and only 80 cases have been reported. An anterior kink of the spinal cord is a characteristic finding on MRI. A better technique for the surgical treatment of spinal cord herniation is controversial and has not been established. We report on a patient with Brown-Séquard syndrome, who was effectively treated by a modified dural closure of the hiatus at the ventral side of the spinal cord in order to minimize the anterior procedure of the spinal cord. Here we report our modified surgical technique for this disease and review previous reports of its treatment.

Case Report

A 57-year-old man had a history back to 1990, when he developed hypoesthesia with decreased temperature sensation in the right lower extremity, apparent to him when he took a bath. He also had felt weakness in the left lower extremity since June in 2003. The weakness in the left leg had gradually deteriorated and he also presented with weakness in the right extremity. His gait has been pointed to change since February 2004 and he continued to have progressive deterioration with difficulty in walking, increased spasticity and weakness of the both lower extremities. He was admitted to our hospital on July 2004 because the vesicorectal disturbance that presented in addition to the weakness of his legs. He had no history of previous trauma, spinal surgery and other spinal disorders.

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Bibliography
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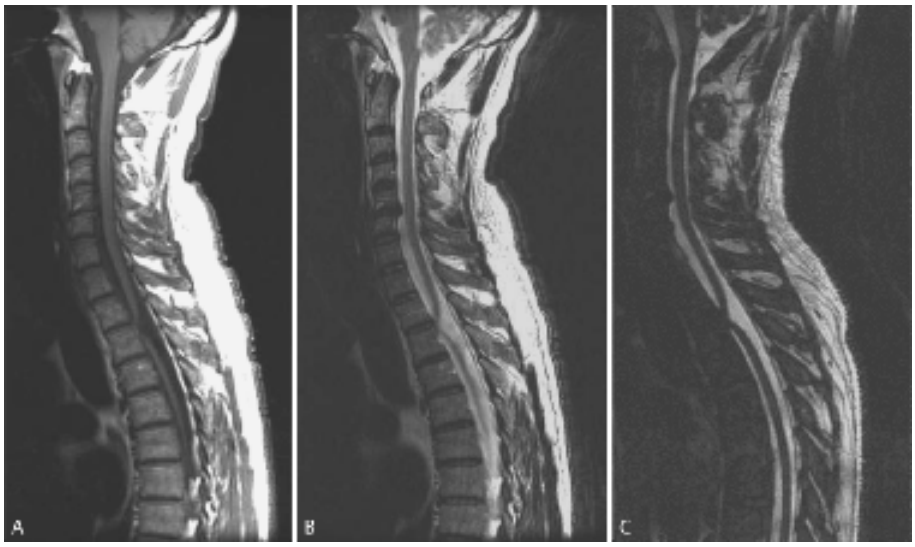

Fig. **1** **A** Preoperative sagittal T_1-weighted (left panel) and T_2-weighted (right panel) images of the thoracic spine. The spinal cord herniates ventrally in a C-shaped fashion at the T2/T3 level. **B** Preoperative sagittal T_2-weighted image of the thoracic spine. The spinal cord herniates into the ventral dural cavity. **C** Sagittal T_2-weighted CISS MR image of the thoracic spine. Arachnoid cysts were not observed at the dorsal side of the herniation.

On examination the patient was found to have a Brown-Séquard syndrome below L1, with decreased pain and temperature sensations, 4/5 weakness of the left lower extremity. He demonstrated a positive Babinski sign and hyperreflexia of deep tendon reflexes on the left. He also had 4 – 5/5 weakness of the right lower extremity in addition to Brown-Séquard syndrome. An MRI revealed an anterior kink of the thoracic spinal cord at T2 – T3, with anterior herniation of the partial spinal cord into the space of the cerebrospinal fluid (CSF) collection, which existed in the ventral side of the vertebral canal (Fig. **1**). The CISS images of MRI revealed no complication of arachnoid cysts on the dorsal side of the spinal cord herniation (Fig. **1**). The preoperative diagnosis was idiopathic spinal cord herniation at the T2-T3 level.

A partial laminectomy of T1 and T4, and osteoplastic laminotomy from T2 to T3 were performed on June 20, 2004. The dura mater was opened at the midline from the T2 to T3 level. The arachnoid membrane and CSF pulsation on the dorsal side were normal and neither arachnoid cysts nor thickness of the arachnoid membrane was observed. The thoracic spinal cord was displaced ventrally at this level. Retraction of the spinal cord by lifting the dentate ligament at T2 – 3 showed that the hiatus of approximately 1 cm × 1 cm in diameter covered with dura matter existed on the ventral side of the vertebral canal. A duplication of dura mater was observed and the dural hiatus seemed to consist of the partial defect of the inner membrane of the duplicated dura mater and the outer dural membrane. The thoracic spinal cord was herniated into this dural hiatus and there was no adhesion between the ventral side of the herniated spinal cord and the dural hiatus and no chronic inflammation (Fig. **2A**).

The spinal cord was carefully returned to the dural hiatus. The herniated portion of the thoracic cord exhibited a yellowish and edematous round-shaped projection. Dural plasticity of the dural duplication was performed to prevent herniation of the thoracic cord into the dural hiatus because both primary suture of the margin of the dural defect and the enlargement of the margin were impossible. A surgical artificial dura [Gore-tex] was introduced between the herniated portion of the thoracic cord and the dural hiatus and was placed to cover the whole defect of the inner dural membrane. The artificial dura was attached with stay-sutures to the lateral side of the dural sac and the herniated thoracic cord was dislocated from the ventral dural hiatus and was covered with the artificial dura (Fig. **2B**). Lastly, a laminoplasty was performed. The postoperative diagnosis was idiopathic spinal cord herniation with the ventral dural hiatus consisting of the dural duplication. At 3 days after surgery, the patient experienced a rapid improvement in the spasticity and weakness of the bilateral lower extremities. An MRI 7 days after surgery revealed that the spinal cord herniation was improved and C-shaped fashion of the thoracic cord had disappeared (Fig. **3**). On 11 days after surgery, the positive sign of Babinski on his left leg turned to negative and his symptoms continued to improve. He discharged on foot 17 days after surgery.

Discussion

Spinal cord herniation can be classified into idiopathic, traumatic, and iatrogenic [1]. The idiopathic type is reported in 80 cases including our case, in 60 women and 20 men aged from 22 to 71 years (mean: 50 years) to our knowledge [2]. There is a female preponderance with a ratio of 5 : 3. The most common clinical presentation was that of a Brown-Séquard syndrome, which slowly progresses, as seen in our case. Idiopathic or spontaneous herniation of the spinal cord occurred in the thoracic spine was reported in all the cases [2 – 4]. The herniation was located either ventral or ventro-lateral through an oval dural defect [2]. MRI findings are typical showing on the sagittal scan an anterior C-shaped kink of the spinal cord and secondary enlargement of the dorsal subarachnoid space [2, 5]. In this present case, MRI images were good enough to diagnose this disease, however, we could not estimate its pathogenesis because the patient had no history of the spinal injury or other diseases and no complication of arachnoid cysts on MRI findings. We thus considered it as an idiopathic case of the thoracic spinal cord herniation. The clinical features of this case were based on the epidemiology of the 80 cases in previous reports. He had a slowly progressive Brown-Séquard syndrome and the MRI findings revealed the ventral herniation of the thoracic spinal cord into the dural defect at the level of T2-3.

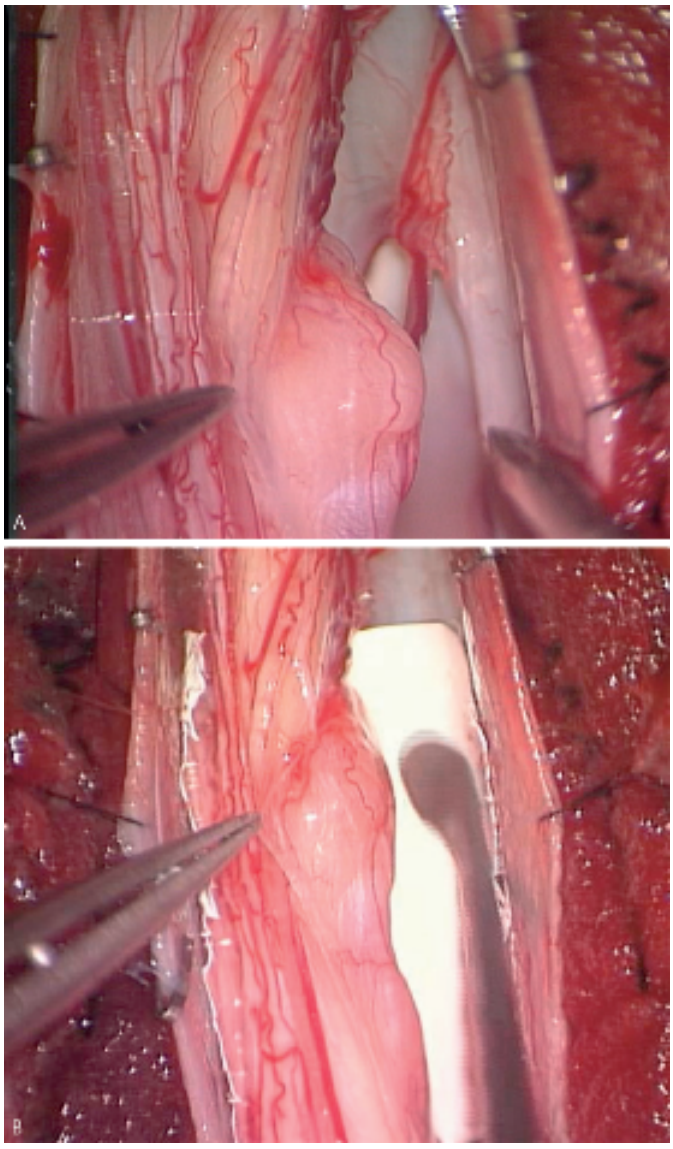

Fig. **2** **A** Intraoperative photographs (lower side of the figure: cephalic direction, upper side of the figure: caudal direction) demonstrating the herniated cord with a yellowish edematous projection, the dural cavity is composed of the duplicated dura mater. **B** Intraoperative photographs of the dural plasty with a surgical artificial dura (Gore-tex). A surgical dura covered the dural hiatus and was sutured by stay-sutures at the lateral side of the spine.

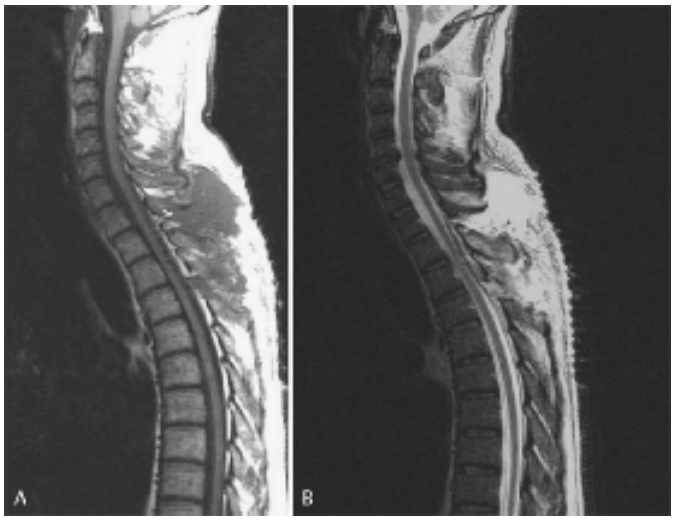

Fig. **3** **A** Postoperative sagittal T_1-weighted (left panel) and T_2-weighted (right panel) images of the kink of the thoracic spinal cord. **B** Postoperative axial T_2-weighted image of the thoracic spine. The ventral spinal cord herniation was improved and the spinal cord is located in the midportion of the spinal canal.

The goals of treatment are to reduce the herniation, return the spinal cord to the normal position, and prevent the recurrence of herniation. A variety of surgical managements have been reported in this field and classified with two main treatment strategies. One is closure of the dural defect such as direct closure of the hiatus in front of the herniation, patch closure of the hiatus with artificial dura and sealing with fibrin glue into the hiatus. The other is simply widening the aperture to prevent strangulation of the cord such as direct widening of the size of the hiatus. 65 surgical cases of idiopathic spinal cord herniation were reported to our knowledge (direct widening: 22; patch closure: 19; direct suture: 11; graft: 9; arachnoid cyst removal: 2; laminectomy: 2) [2,6]. In all 80% of the surgical cases were performed at the ventral side of the spinal cord. However, the ventral operative space of the thoracic spine seems not to be wide enough for the safe surgical procedure. These operative techniques have been associated with the danger of anterior spinal cord injury because of the limited operative field at the ventral side of the spinal cord. In the previous reports, postoperative cases whose symptoms worsened or did not change after the surgery of the direct widening of the ventral dural defect described twice (9%) and improvements were seen in 20 cases (91%). As for patch closure, worsened or same status was seen in 8 cases (42%) and improvements were documented in 11 cases (58%). In direct closure, worsened or same status was reported postoperatively in 4 cases (36%) and 7 cases (64%) were improved (Table **1**). In previous reports, most operative cases brought about good results. Widening the dural aperture was the surgical technique associated with the best outcome in the series reported in the literature. Less manipulation of the already compromised spinal cord is one possible explanation [2]. Complicated procedures at the ventral side of the spinal cord, such as patch closure and direct closure, were not always done safely and effectively. Surely, widening of the dural defect involves less manipulation compared with the patch closure and direct closure. However, when widening the dural defect, it is not easy to decide on the width to incise the inner layer and surgeon cannot select this technique in cases where the outer layer of the dural hiatus is not intact to

Table **1** Summary of reported operative cases of spinal cord herniation

Procedure	*Cases*	*Worsened*	*Improved*	*Same*
direct widening	22	1	20	1
patch closure	19	4	11	4
direct suture	11	2	7	2
graft	9	1	3	5
laminectomy	2		1	1
resection of arachnoid	1	1		
Fill in with material	1			

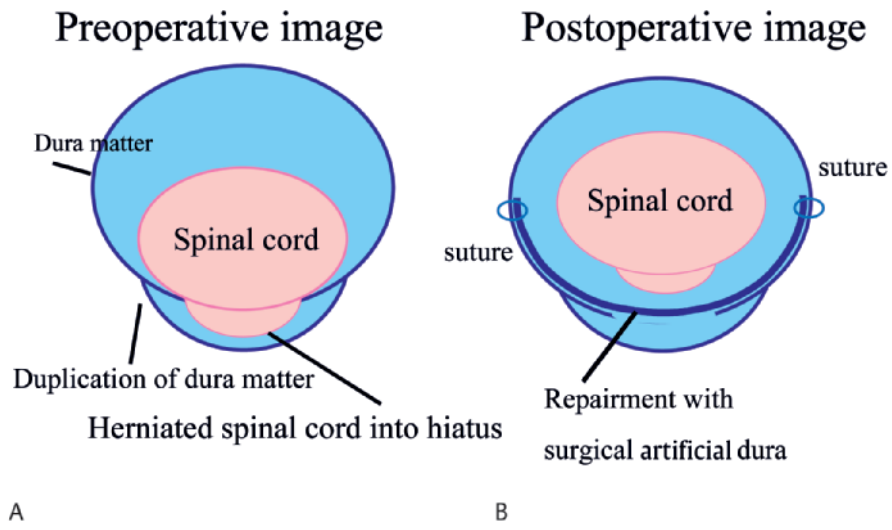

Fig. **4** Scheme of preoperative (**A**) and postoperative (**B**) images of the spinal cord herniation. The spinal cord herniates into the hiatus composed by dural duplication in the preoperative scheme (**A**). The dural defect was covered with an artificial dura which was sutured at the lateral side of the dual sac (**B**). The herniated spinal cord was repaired with less manipulation of the ventral side of the spinal cord.

prevent the leakage of cerebrospinal fluid. The technique of widening the dural defect requires an anterior procedure to observe these points prior to the incision of the inner dura mater. Surgical procedures anterior to the spinal cord always have a risk of spinal cord injuries. More safe and effective methods are required to be developed in order to minimize the risks of the anterior procedure. In the present case, we tried to decrease the risk of spinal damage caused by the anterior surgical procedure. We only sheeted the artificial dural membrane and covered over the dural defect with this membrane (Fig. **4**). The procedure of suturing in the narrow operative field has a higher risk of spinal cord damages. We sutured the artificial dural membrane with dura mater at the lateral side of the spinal cord to cover the anterior half of the spinal cord. We could easily observe the suturing line in the open field and safely completed its suturing. The herniated portion of the spinal cord was completely dissociated with the dural hiatus and the symptoms improved during the early period after the surgery. This newly introduced procedure of the covering the anterior side of the spinal cord is recommended in the cases of spinal cord herniation without severe adhesion to the dural defect. In such cases, it is difficult to select any of the surgical methods that have been reported. This will be the next target for surgeon and require further experience and study to solve this problem.

Conclusion

A modified new technique for the treatment of spinal cord herniation, which requires less manipulation anterior to the spinal cord, is described. This procedure is easier and safer than the conventional repair of the dural defect with patch closure and direct closure, providing satisfactory clinical results.

References

[1] Sagiuchi F, Iida H, Tachibana S, Utsuki S, Tanaka R, Fujii K. Idiopathic spinal cord herniation associated with calcified thoracic disc extrusion. Neurol Med Chir (Tokyo) 2003; 43: 364 – 368

[2] Najjar MW, Baeesa SS, Lingawi SS. Idiopathic spinal cord herniation: A new theory of pathogenesis. Surg Neurol 2004; 62: 161 – 171

[3] Barbagallo GMV, Marshman LAG, Hardwidge C, Gullan RW. Thoracic idiopathic spinal cord herniation at the vertebral body level: a subgroup with a poor prognosis? J Neurosurg 2002; 97: 369 – 374

[4] Ewald CM, Kuhne D, Hassler WE. Progressive spontaneous herniation of the thoracic spinal cord: case report. Neurosurgery 2000; 46: 493 – 496

[5] Brugieres P, Malapert D, Adle-Biasssette H, Fuerxer F, Djindjian M, Gaston A. Idiopathic spinal cord herniation: value of MR phase-contrast imaging. AJNR Am J Neuroradiol 1999; 20: 935 – 939

[6] Watanabe M, Chiba K, Matsumoto M, Maruiwa H, Fujimura Y, Toyama Y. Surgical management of idiopathic spinal cord herniation: a review of nine cases treated by the enlargement of the dural defect. J Neurosurg (Spine 2) 2001; 95: 169 – 172

Endoscopic Aqueductoplasty with and without Stent

Y. Erşahin

Sir,

I read with interest the article on endoscopic aqueductoplasty (EAP) by Miki et al. [1]. They performed EAP in 6 patients with aqueduct stenosis (AS) by using a flexible neuroendoscope. They have achieved good results in all patients and have not encountered restenosis. However they did not mention the follow-up period. In 1999, Schroeder and Gaab [2] reported that EAP is an effective alternative to third ventriculostomy for the treatment of hydrocephalus caused by a short AS. In 2004, Schroeder et al. [3] reported the long-term results of their patients in whom EAP had been performed. Their patients' mean follow-up period was 40 months. EAP was performed in 39 patients and endoscopic third ventriculostomy (ETV) was also performed simultaneously in 13 patients. They observed restenosis of the aqueduct in 7 patients, after an average of 25 months, ranging from 14 days to 97 months.

Fritsch et al. [4] retrospectively analyzed the outcome of 27 patients who underwent EAP or interventriculostomy with or without stent placement. They concluded that in patients with membranous distal AS, EAP alone is sufficient enough at 2 years follow-up to provide clinical and radiographic sufficiency and in patients with tumor-associated AS, EAP alone will not suffice. If there is an indication for EAP, a stent needs to be placed. In patients with isolated fourth ventricle and a history positive for intraventricular haemorrhage or meningitis, it is very unlikely that an EAP alone will stay open. The high revision rate in this group has led to a change in treatment strategy toward initial stent placement [4].

We have performed aqueductoplasty only in 8, aqueductoplasty with ETV in 11, aqueductoplasty with stent in 5 and aqueductoplasty with stent and ETV in 7 patients. It is not possible to figure out which procedure would be effective when aqueductoplasty and ETV are done simultaneously. Therefore aqueductoplasties with or without stent should be analyzed to find out the need of stenting the aqueduct. Of the 6 adult patients with primary AS, only one needed a second endoscopic procedure following EAP. Restenosis developed 5 months after the first EAP. The patient's symptoms and signs completely improved after ETV. Aqueductoplasty failed in 2 children. A 7-month-old boy with AS and shunt infection underwent EAP at the time of shunt malfunction. He was shunted one week after aqueductoplasty. The other patient was a 5-year-old boy with isolated fourth ventricle. Unfortunately isolated fourth ventricle on MRI and ataxia and dysphagia persisted in the follow-up. MRI in the constructive, steady-state sequences disclosed a web in the aqueduct (Table **1**). Of the 6 patients in whom aqueductoplasty with stent had been performed, 4 patients had primary AS, one patient had a tectal glioma and one had a pineal tumor. In two patients with secondary AS, the brain stem was pushed toward the clivus and there was no space between the brain stem and clivus for a safe ETV. This is why EAP and stenting of the aqueduct were done in both patients. Endoscopic subtotal tumor removal was done prior to EAP with stent in the patient with a pineal tumor. The stent migrated into the third ventricle 3 months later. Aqueductoplasty with stent was performed again and he has been symptom-free for one year. Bilateral subdural fluid collection developed following aqueductoplasty with stent in two infants with marked hydrocepha-

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Bibliography
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Table **1** Summary of the patients who underwent endoscopic aqueductoplasty

Patients	*Gender*	*Age*	*Diagnosis*	*Endoscopic procedure*	*Complications*	*Outcome and final procedure*	*Follow-up (months)*
1	male	7 months	primary AS and shunt infection	EAP		failure – VP shunt	57
2	male	10 years	primary AS	EAP		good	52
3	male	5 years	isolated fourth ventricle	EAP	permanent dysconjugate gaze	failure	47
4	female	7 years	primary AS	EAP		good	47
5	male	19 years	primary AS	EAP		good	42
6	female	53 years	primary AS	EAP	transient diplopia	good	40
7	female	33 years	primary AS	EAP	vertigo and vomiting transient dysconjugate gaze	failure – ETV	24
8	male	14 years	primary AS and shunt malfunction	EAP		good	24

AS = aqueduct stenosis, EAP = endoscopic aqueductoplasty, ETV = endoscopic third ventriculostomy.

Table **2** Summary of the patients who underwent endoscopic aqueductoplasty with stent

Patients	*Gender*	*Age*	*Diagnosis*	*Endoscopic procedure*	*Complications*	*Outcome and final procedure*	*Follow-up (months)*
1	female	10 years	tectal glioma	EAP with stent		good	34
2	female	3 months	primary AS	EAP with stent	bilateral subdural fluid collection	good	29
3	male	3 months	primary AS	EAP with stent	bilateral subdural fluid collection	good	27
4	male	33 years	pineal tumor	EAP with stent and tumor resection	transient diplopia and stent migration	failure – EAP with stent	12
5	female	22 years	primary AS	EAP with stent	transient vertigo	good	12
6	male	23 years	primary AS	EAP with stent		good	6

EAP = endoscopic aqueductoplasty, AS = aqueduct stenosis.

lus. A subdural-peritoneal shunt was implanted in both patients (Table **2**).

EAP should be performed in short-segment primary and secondary AS when ETV is not feasible. In isolated fourth ventricle, aqueductoplasty should always be preferred to fourth ventricular shunting. Stenting of the aqueduct will prevent restenosis particularly in secondary AS and isolated fourth ventricle. As stated by Schroeder et al. [3] more experience and longer follow-up periods are necessary to determine the place of EAP in the treatment of aqueductal stenosis.

References

[1] Miki T, Nakajima N, Wada J, Haraoka J. Indications for neuroendoscopic aqueductoplasty without stenting for obstructive hydrocephalus due to aqueductal stenosis. Minim Invas Neurosurg 2005; 48: 136 – 141

[2] Schroeder HW, Gaab MR. Endoscopic aqueductoplasty: technique and results. Neurosurgery 1999; 45: 508 – 515

[3] Schroeder HW, Oertel J, Gaab MR. Endoscopic aqueductoplasty in the treatment of aqueductal stenosis. Child's Nerv Syst 2004; 20: 821 – 827

[4] Fritsch MJ, Kienke S, Mehdorn HM. Endoscopic aqueductoplasty: stent or not to stent? Child's Nerv Syst 2004; 20: 137 – 142