The Supraorbital Endoscopic Approach for Aneurysms

Robert Reisch[1], Gerrit Fischer[2,3], Axel Stadie[4], Ralf Kockro[1], Evaldas Cesnulis[1], Nikolai Hopf[5]

Key words
- Intracranial aneurysms
- Keyhole neurosurgery
- Minimally invasive neurosurgery
- Supraorbital craniotomy
- Transcranial endoscope-assisted microneurosurgery

Abbreviations and Acronyms
ISAT: International Subarachnoid Aneurysm Trial
MCA: Middle cerebral artery
mRS: Modified Rankin scale
TEAM: Transcranial endoscope-assisted microneurosurgery

From the [1]Centre for Endoscopic and Minimally Invasive Neurosurgery, Zurich, Switzerland; [2]Department of Neurosurgery, Johannes Gutenberg-University Mainz, Mainz, Germany; [3]Department of Neurosurgery, University of Saarland, Homburg, Germany; [4]Department of Neurosurgery, University Hospital Mannheim, Mannheim, Germany; and [5]Department of Neurosurgery, Katharinenhospital, Stuttgart, Germany

To whom correspondence should be addressed: Robert Reisch, M.D., Ph.D.
[E-mail: robert.reisch@hirslanden.ch]

Citation: World Neurosurg. (2014) 82, 6S:S130-S137.
http://dx.doi.org/10.1016/j.wneu.2014.07.038

Journal homepage: www.WORLDNEUROSURGERY.org

Available online: www.sciencedirect.com

1878-8750/$ - see front matter

OBJECTIVE: To review our surgical experience in minimally invasive transcranial endoscope-assisted microsurgical treatment of intracranial aneurysms, using the supraorbital keyhole craniotomy.

METHODS: The supraorbital keyhole approach was performed through an eyebrow skin incision in 793 cases for treatment of 989 intracranial aneurysms. Of patients, 474 were operated on after subarachnoid hemorrhage, and 319 were operated on under elective conditions. After lateral frontobasal burr hole trephination, a limited subfrontal craniotomy was created. To achieve adequate intraoperative exposure through the limited approach, endoscopes were used routinely. Surgical outcome was assessed using the modified Rankin scale.

RESULTS: The transcranial endoscope-assisted microneurosurgery technique was used routinely via a supraorbital approach. In 152 operations (19.1%), the endoscope provided important visual information in the vicinity of the aneurysm, revealing subsequent clip repositioning. The results of incidental aneurysms were excellent with a modified Rankin scale score ≤2 in 96.52%. The overall outcome of ruptured aneurysms was good with a modified Rankin scale score ≤2 in 72.2% of patients. There were no approach-related intraoperative or postoperative complications.

CONCLUSIONS: The minimally invasive supraorbital keyhole approach allowed safe surgical treatment of intracranial aneurysms, including after subarachnoid hemorrhage. The markedly improved endoscopic visualization increased the assessment of clip placement with ideal control of surrounding vessels including perforators for identification of incorrect clip position.

INTRODUCTION

The initial data from the International Subarachnoid Aneurysm Trial (ISAT) published in 2002 showed a significant superiority of endovascular coiling compared with surgical clipping as defined by the proportion of patients dead or disabled at 1 year in a carefully selected group of patients deemed suitable for either therapy (31). The results of this randomized, prospective, international controlled trial represented a landmark and radical change in the treatment of intracranial aneurysms (6, 9, 10, 28, 32, 33, 48).

This significant superiority of interventional therapy is difficult to comprehend from a surgical point of view, particularly after comparison of both methods. Using surgical exposure, operative removal of blood clots with rinsing and cleaning of the subarachnoid spaces may decrease the risk of cerebral vasospasm and chronic hydrocephalus (14, 17, 20-22, 24, 29, 43, 46, 47, 53). With an additional opening of the lamina terminalis, the intracranial cerebrospinal fluid circulation also can be effectively improved (3, 27, 45). An operative approach allows adequate optical exposure of the individual anatomy of the aneurysm, with safe assessment of perforators and neighboring neurovascular structures (29, 33). In the case of rerupture of the aneurysm, immediate control of bleeding is possible (19). In addition, surgical clipping of the aneurysm offers a high reconstructive capacity of the vessel and high reliability of the occlusion resulting in minimal risk of postoperative rebleeding (39). Interventional therapy cannot offer careful exploration of the subarachnoid spaces or the aneurysm. Several cases of insufficient aneurysm occlusion and postinterventional aneurysm recanalization were reported associated with increased risk of rebleeding (8, 33, 44, 49).

Nevertheless, operative therapy requires a surgical approach involving manipulation and retraction of the cortical surface and functionally relevant neurovascular structures. Almost all neurosurgical centers included in ISAT used standard microneurosurgical approaches to treat the ruptured aneurysm (31). We hypothesize that the reason for the significant superiority of endovascular coiling compared with surgical therapy in ISAT was the surgical morbidity and mortality of "standard," large surgical approaches that were usually employed in this study (12). We believe that operative clipping as treatment of intracranial aneurysms can be improved if surgeons are able to reduce its approach-related complications allowing minimally invasive and maximally effective aneurysm closure. The most effective solution for reducing intraoperative manipulation and retraction is the use of minimally invasive keyhole approaches in neurosurgery (7, 11, 23, 30, 35-38, 41, 49). However, marked reduction of the craniotomy size may result in different shortcomings during the procedure (39).

Because of the predefined direction of the operative exposure, the surgical corridor cannot be changed intraoperatively. Preoperative planning of the approach, including 1) thorough evaluation of preoperative diagnostic imaging of the lesion with respect to the individual anatomy of the patient, 2) definition of the size and site of the tailored craniotomy, 3) positioning of the patient according to the planned surgical corridor, and 4) skin-to-skin performance of the exact approach, is of particular importance in keyhole surgery of intracranial aneurysms (11, 12, 37, 46). An additional problem is the application and maneuverability of conventional instruments; the use of such instruments becomes limited if the size of the craniotomy is <15 mm (**Figure 1**). The application of special keyhole-adapted slender microsurgical instruments (e.g., clip appliers, scissors, suction devices) can effectively resolve this shortcoming (13, 35-37, 39, 42).

The most important disadvantage of small, less invasive keyhole approaches is the loss of intraoperative light and sight causing significantly reduced optical control during surgery (39). For the purpose of bringing light into the surgical field, the optical properties of surgical microscopes can be effectively supplemented by the intraoperative use of endoscopes (5, 7, 11-13, 15, 19, 23, 30, 37-39, 49). The main advantages of endoscopes are the increased light intensity, broadening of the viewing angles, enlarged focus range, and clear depiction of pathoanatomic details in close-up positions (**Figure 2**).

Figure 2. Transcranial endoscope-assisted microneurosurgery—TEAM-work between microscope and endoscope.

MATERIALS AND METHODS

We retrospectively evaluated 793 consecutive cases of intracranial aneurysms operated through a supraorbital keyhole craniotomy. There were 269 male patients and 524 female patients; patient age ranged from 14—82 years (mean age, 51.8 years). Of procedures, 474 were performed following an acute subarachnoid hemorrhage, and 319 were performed on patients with aneurysms that were found incidentally.

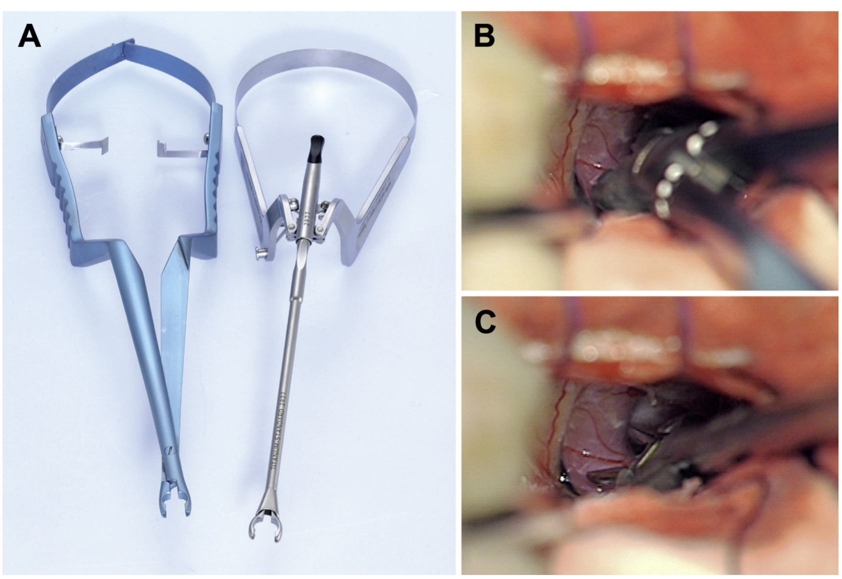

Figure 1. (**A**) Photograph comparing a conventional (*left*) and slender-type clip applier (Aesculap AG, Tuttlingen, Germany). (**B**) When used in keyhole conditions, the conventional instrument cannot be maneuvered, and placement of the clip is not controllable. (**C**) The tube shaft applier can be used within the narrow corridor; the jaws of the clip are well seen allowing safe aneurysm closure.

After interdisciplinary discussion with the interventional neuroradiologist, surgical treatment was chosen when endovascular coiling was deemed technically not feasible. In every case, the surgical approach was determined after careful preoperative study of diagnostic images to determine the least traumatic access to the lesion taking into consideration the individual anatomy of the patient. To improve intraoperative visualization and optical control during surgical manipulation, we routinely used the technique of transcranial endoscope-assisted microneurosurgery (TEAM). The endoscopic imaging was evaluated with respect to the different routes that are available for the endoscope (e.g., the space between the eloquent neurovascular structures). The endoscopes were used for 1) intraoperative anatomic orientation, 2) assessment of the individual anatomy of the aneurysm including small perforators, and 3) control of clip position including the evaluation of neck occlusion or reconstructive capacity of the clip.

Supraorbital Keyhole Technique

After positioning the patient supine, anatomic landmarks of the frontal area, such as the supraorbital foramen, temporal line, level of the frontal cranial base, impression of the sylvian fissure, and zygomatic arch, are determined. Based on this careful anatomic surface orientation, the borders of the craniotomy and placement of the individual skin incision are defined.

After facultative use of neuromonitoring, neuronavigation, and intraoperative imaging, the skin incision is started laterally from the supraorbital incisura within the eyebrow. To achieve an optimal cosmetic result, the incision should follow the orbital rim. To avoid frontal numbness, the skin incision should not extend medially to the supraorbital nerve. The subcutaneous dissection is continued in the frontal direction to achieve optimal exposure of the frontolateral region. The frontal muscle is cut with a monopolar knife parallel to the orbital rim in a medial-to-lateral direction (Figure 3A). As the temporal line is reached with the monopolar knife, the blade is turned 90 degrees. The incision follows the temporal line in a basal direction to the zygomatic process of the frontal bone. The temporalis muscle is dissected laterally; muscular mobilization is restricted to a necessary minimum (Figure 3B), The frontal and temporal muscles are retracted with sutures and hooks. A single frontobasal burr hole is made using a high-speed drill, avoiding penetration of the orbit (Figure 3C). After minimal enlargement of the hole with a thin Kerrison punch, a straight line is cut with a high-speed craniotome parallel to the orbital rim in a lateral-to-medial direction. The craniotomy is completed with a C-shaped incision. A limited craniotomy approximately 2 cm × 1.5 cm is created (Figure 3D). A critical stage of the craniotomy after removal of the bone flap is high-speed drilling of the inner edge of the bone above the orbital rim under protection of the dura mater (Figure 3E). Careful removal of this inner bone edge can significantly increase the angle for visualization and manipulation. Small osseous extensions of the superficial orbital roof, termed juga cerebralia, should also be drilled extradurally to obtain optimal intradural visualization. The dura mater is opened in a simple C-shaped form and retracted in a basal direction, with minimal exploration of the brain surface (Figure 3F).

RESULTS

Using the supraorbital keyhole approach, 989 aneurysms in 793 patients were treated. There were 38 giant aneurysms, and 53 patients had space-occupying hematomas. Incomplete clipping was achieved in 19 cases (3.3%) with complex aneurysm anatomy, making additional interventional treatment necessary. The overall outcome of the acute cases on follow-up examination was good (modified Rankin scale [mRS] score $\leq$2) in 72.2% and poor (mRS score $\geq$3) in 27.8%. There were 319 operations performed on incidentally found aneurysms or as scheduled elective procedures. The surgical results were good (mRS score $\leq$2) in 96.6% and poor (mRS score $\geq$3) in 3.4% of the cases. The TEAM technique was

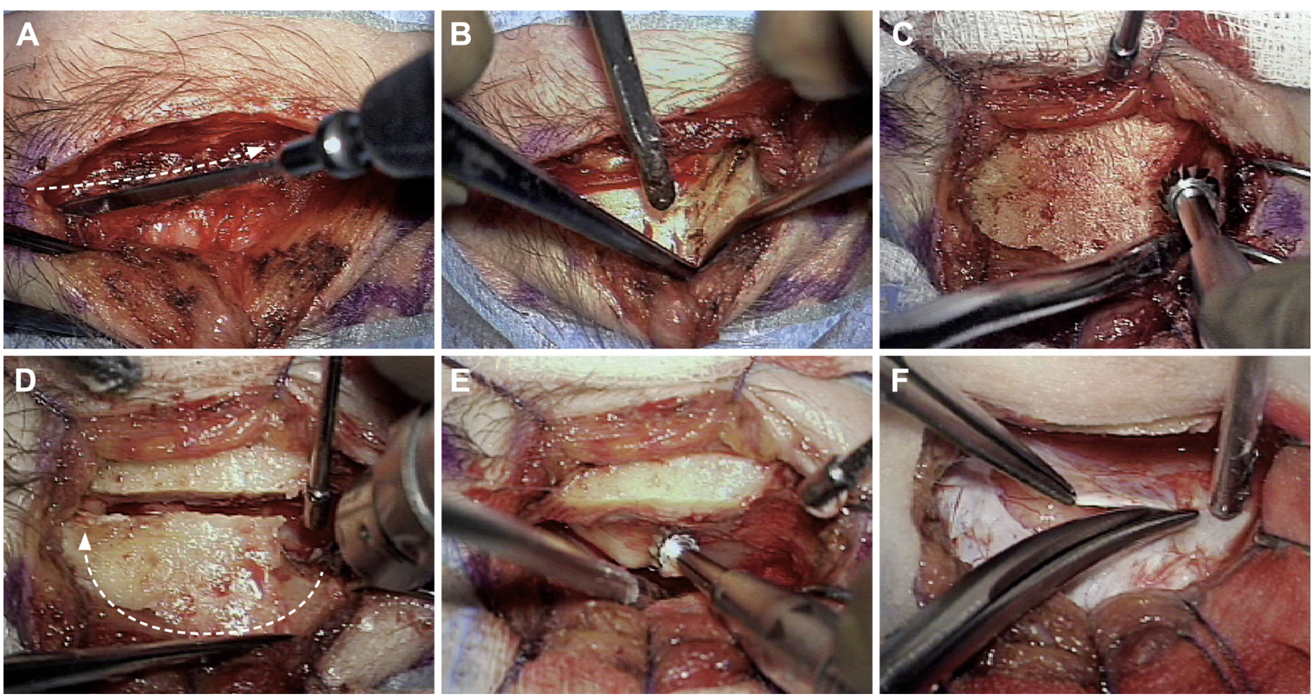

Figure 3. (**A**) After skin incision within the eyebrow, the frontal muscle is cut with a monopolar knife parallel to the orbital rim in a medial-to-lateral direction. (**B**) The temporalis muscle is dissected laterally; muscular mobilization is restricted to a necessary minimum. (**C**) The frontal and temporal muscles are retracted with sutures and hooks, and a lateral frontobasal burr hole is made using a high-speed drill. (**D**) After mobilization of the dura mater, a straight line is cut in a lateral-to-medial direction, and the craniotomy is then completed with a C-shaped incision. (**E**) An essential step of the approach is drilling of the inner edge of the bone above the orbital rim, increasing the angle for visualization and manipulation. (**F**) The dura mater is opened simply in a curved way and retracted in a basal direction, with minimal exploration of the brain surface.

used routinely. Endoscopes were used mainly to visualize the target area before and after clipping and rarely for actual endoscope-controlled clipping procedures. In 152 operations (19.1%), endoscopy revealed suboptimal or incorrect clip position with 1) residual neck, 2) narrowed vessel, or 3) occluded perforator, which was poorly seen or not seen at all with the microscope. In all cases, clip position was subsequently corrected; the markedly improved endoscopic visualization increased the likelihood of controlling ideal aneurysmal closure.

Illustrative Case

A 33-year-old woman whose sister had experienced severe subarachnoid hemorrhage underwent neurologic examination that included magnetic resonance imaging of the brain. Imaging detected bilateral aneurysms of the middle cerebral artery (MCA). There were no signs of subarachnoid hemorrhage.

Because of an irregular aneurysm surface, the family history, and the patient's anxiety, the decision was made to treat the aneurysms. After performing digital subtraction angiography and an interdisciplinary discussion with the interventional neuroradiologists concerning the treatment modality, surgical treatment was chosen. Factors favoring surgery were the small size of the left-sided aneurysm, the unfavorable aspect ratio of the dome and neck of the right-sided aneurysm, and the patient's request for surgical therapy (Figure 4A). Evaluation of magnetic resonance imaging and angiographic studies including three-dimensional planning software demonstrated that the left-sided aneurysm was proximally located near the early temporal branch. The right-sided aneurysm originated more distally at the MCA bifurcation (Figure 5). A right-sided supraorbital subfrontal exposure was chosen, treating both aneurysms through a single minimally invasive approach.

After performing the supraorbital keyhole approach (Figure 3), the suprasellar cisterns were opened, and the contralateral internal carotid artery was approached (Figure 6A). Gentle retraction was used; the elevator was placed between the frontal lobe and olfactory nerve, avoiding stretching the fila olfactoria. The contralateral sylvian fissure was opened, approaching the left-sided aneurysm. Endoscopic inspection verified the aneurysm neck and its relationship to the early temporal branch (Figure 6B). A straight bayonet-shaped clip was placed under microscopic control, immediately closing the aneurysm. The use of a tube-shaft clip applier in the narrow corridor was crucial (Figure 6C). Complete aneurysm closure

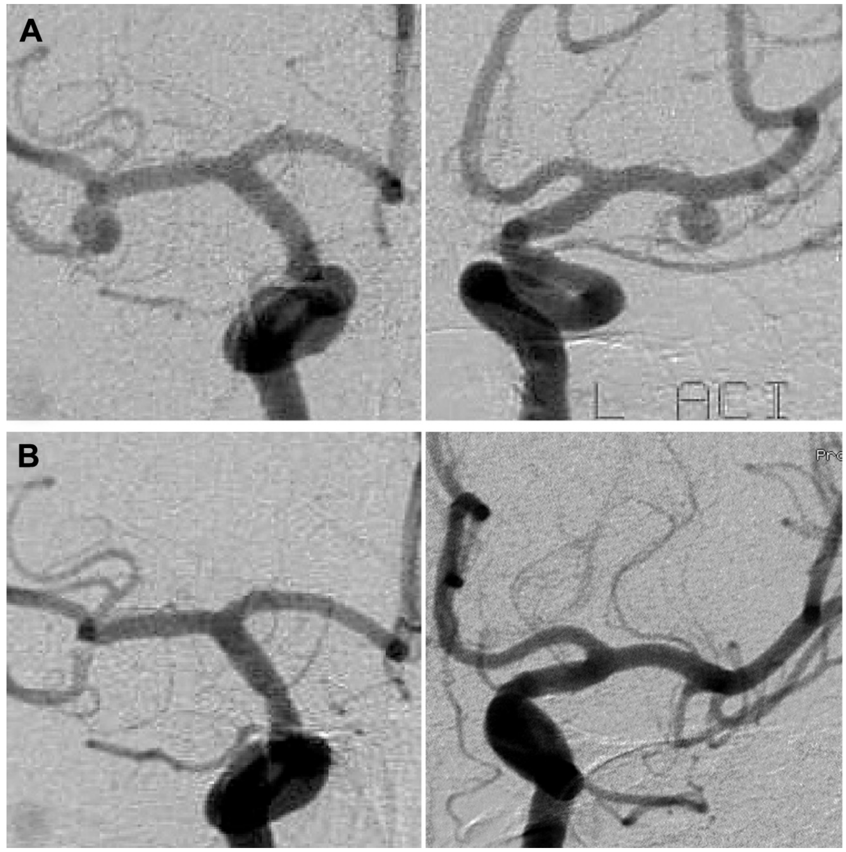

Figure 4. (**A**) Preoperative angiography showing nonruptured bilateral aneurysms. The left-sided middle cerebral artery aneurysm originates near the early temporal branch, and the right-sided aneurysm originates at the middle cerebral artery bifurcation. (**B**) After surgery, digital subtraction angiography reveals no residual aneurysm.

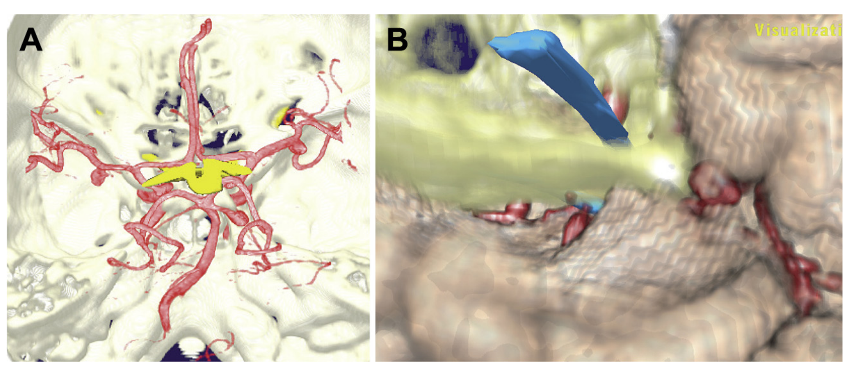

Figure 5. (**A**) Three-dimensional observation of bilateral aneurysms demonstrating the relationship of the optic nerve and arterial vessels to the bony skull base structures allowing precise and comprehensive surgical planning. (**B**) Virtual inspection through the right-sided keyhole craniotomy reveals that both aneurysms are safely approachable (Dextroscope; Volume Interactions, Singapore).

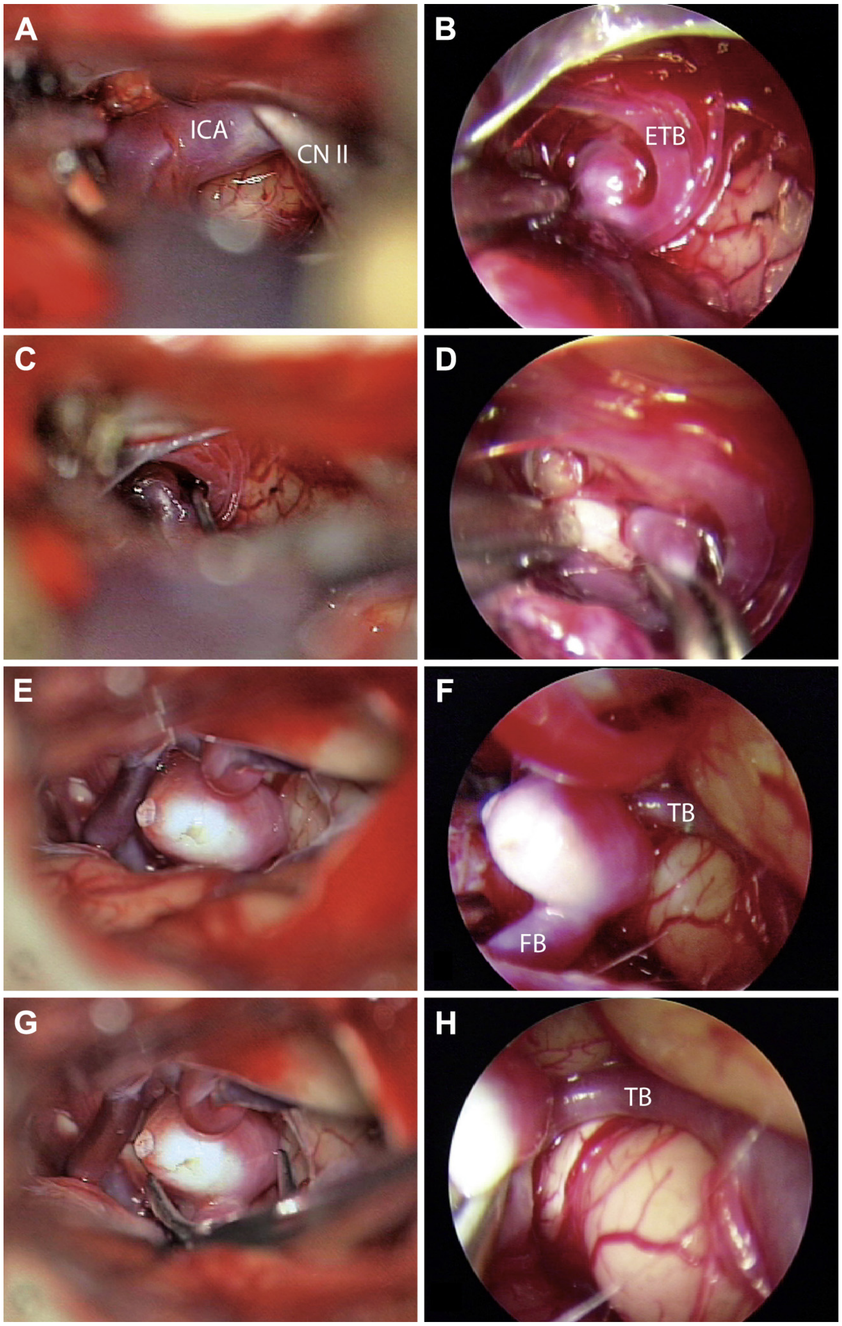

Figure 6. Intraoperative photographs showing critical steps of the procedure. (**A**) First, the opposite internal carotid artery was approached, and the sylvian fissure was exposed. (**B**) The anatomy of the left-sided aneurysm was investigated with the endoscope. After clipping with a tube-shaft instrument, secured by safe proximal control (**C**), endoscopic control revealed complete occlusion without narrowing of the parent vessels (**D**). (**E**) Next, the right middle cerebral artery was approached, but the temporal branch could not be seen behind the aneurysm dome and sphenoid wing. With the endoscope, this hidden part could optimally be visualized (**F**), allowing safe clip application (**G**). (**H**) The last endoscopic investigation showed complete closure without tightening the middle cerebral artery bifurcation. ICA, internal carotid artery; CN II, optic nerve; ETB, early temporal branch; FB, frontal branch; TB, temporal branch.

was controlled with the help of the endoscope (Figure 6D). The right sylvian fissure was opened without using the brain retractor. With microscopic visualization, the temporal branch of the MCA could not be visualized behind the dome of the aneurysm (Figure 6E); however, this hidden part of the field was ideally managed with endoscopic assistance (Figure 6F). After successful clipping without the use of a retractor (Figure 6G), the clip position was endoscopically controlled, confirming reliable aneurysm closure without narrowing the MCA bifurcation surrounding the perforators (Figure 6H). Patency of the MCA branches was confirmed with Doppler sonography and indocyanine green angiography. Using the TEAM technique, both aneurysms could be completely closed through the one-sided limited keyhole approach.

The patient had an uneventful recovery. Postoperative examination revealed no neurologic symptoms. computed tomography scan showed no intracranial complications and optimal repositioning of the bone flap. Cerebral angiography showed complete closure of both aneurysms (Figure 4B). The patient was able to return to her previous employment, and the cosmetic result was excellent.

DISCUSSION

Since the beginning of neurosurgery, it has been widely accepted that exposure of brain tissue for several hours during surgery using extended craniotomies results in injury of the cortical surface by nonphysiologic surroundings, including room air, irrigation, cover material, and spatula pressure (51). In addition, it has been shown in many experimental and clinical studies that brain retraction causes significant intraoperative trauma to brain tissue and may lead to permanent neurologic deficits (1, 2, 4, 25, 52). To minimize brain retraction, various methods have been proposed (e.g., application of special anesthetic techniques to achieve brain relaxation, individual brain retractor systems, unusual positioning techniques of patient) (12, 13, 16, 18, 50). However, the best retraction is no retraction. Careful choice of an adequate, least invasive surgical approach with minimal brain exploration and dissection without the use of a retractor may result in a significant reduction of trauma to intracranial structures (25, 37, 38).

With the excellent diagnostic capabilities of digital subtraction angiography, three-dimensional angiography, computed tomography, and MRI currently available, one can demonstrate and clarify the individual spatial anatomy of a patient including the smallest details. Anatomically suitable corridors for surgical dissection can be described and discussed in a meticulous preoperative planning procedure. With the knowledge of the individual anatomic details of a specific patient, it is possible to perform a tailored surgical procedure reducing the size of the skin incision, the craniotomy, and the extent of retraction and trauma to the brain surface to a minimum. In recent years, the ability to plan specific approaches has been improved further by using three-dimensional graphic tools of radiologic image processing consoles or planning software of surgical navigation systems. We have also worked extensively with virtual reality environments, allowing precise and comprehensive surgical planning with multimodality, patient-specific three-dimensional objects displayed in a spatial working environment (26, 43).

The advantages of keyhole microsurgery may contribute to improved postoperative results, including shorter hospitalization time because of reduction of the risk for complications, such as bleeding or rebleeding with neurologic deterioration, leakage of cerebrospinal fluid, infection, scarification, and cosmetic disturbances (37, 38). However, limited keyhole approaches cause a significant loss of optical control, especially in the deep-seated surgical field. The first neurosurgeons who realized the limitations of surgical microscopes and the advantages of endoscopic views during microsurgical procedures were Prott in 1974 (40), when he performed endoscopic cisternoscopy of the cerebellopontine angle; Apuzzo et al. in 1977 (5), when they introduced the so-called side-viewing telescope; and Oppel in 1981 (34), when he applied intraoperative endoscopy during microvascular trigeminal decompression. All of these descriptions can be regarded as the initiation of endoscope-assisted microneurosurgery, which, along with other neuroendoscopic techniques, experienced an enormous revival in the 1990s (11-13, 15, 19, 37, 39, 42). At this time, Perneczky developed and refined the concept of endoscopic and endoscope-assisted neurosurgery using limited keyhole approaches in transcranial neurosurgery. As pioneer in minimal invasive techniques, Perneczky became the teacher of countless residents and international fellows in the Neurosurgical Department of the University Mainz, Germany.

The TEAM technique enables neurosurgeons to approach deep-seated regions through narrow anatomic windows, without excessive retraction of sensitive neurovascular structures. The endoscopic pictures allow illumination and inspection of angles in hidden parts of the surgical field and, owing to the enormous optical depth of field of modern endoscopes, provide an almost three-dimensional aspect of anatomic structures. Frequent training of spatial eye-hand coordination, which is necessary for all endoscope-assisted microsurgical procedures, enables neurosurgeons to perform minimally invasive, maximally effective procedures.

Rigid lens scopes are recommended for endoscope-assisted microsurgery because only the position of instruments with rigid shafts can be controlled precisely and because, at the present time, only lens scopes offer acceptable image quality. In addition, modern video and image processing technology with high-definition visualization is essential to achieve full benefit of endoscope-assisted microsurgery (15, 42).

CONCLUSIONS

This article has provided a brief review of our experience with the endoscope-assisted supraorbital keyhole approach in surgical treatment of intracranial aneurysms. This method allowed safe intraoperative control of clipping of ruptured and incidental intracranial aneurysms. Because the limited approach-related trauma to the brain, postoperative results were favorable compared with the results of interventional treatment. Essential prerequisites of keyhole aneurysm surgery are 1) careful selection of cases, 2) accurate preoperative planning, 3) tailored placement of the craniotomy, and 4) use of TEAM techniques. Intraoperative application of endoscopes is mandatory for adequate visualization, especially for control of clip placement and assessment of surrounding perforators. In 19.1% of our cases, endoscopy revealed suboptimal clip position with residual neck, narrowed parent vessel, or occluded peforator that was not clearly detected with the microscope. Endoscopic visualization increased markedly the likelihood of controlling optimal aneurysmal closure and consequently achieving better surgical results.

ACKNOWLEDGMENTS

TEAM technique involves real teamwork. We express our gratitude to our colleagues in the Clinic Hirslanden Zurich; in the University Hospitals Mainz, Homburg, and Mannheim; and in the Katharinenhospital Stuttgart. Supraorbital craniotomy for intracranial aneurysms was first used and described by our late teacher and mentor, Axel Perneczky. This article is dedicated to him with deep grief and infinite respect.

REFERENCES

1. Albin MS, Bunegin L, Dujovny M: Brain retraction pressure during intracranial procedures. Surg Forum 26:499-500, 1975.
2. Albin MS, Bunegin L, Bennett MH: Clinical and experimental brain retraction pressure monitoring. Acta Neurol Scand 65:522-523, 1977.
3. Andaluz N, Zuccarello M: Fenestration of the lamina terminalis as a valuable adjunct in aneurysm surgery. Neurosurgery 55:1050-1059, 2004.
4. Andrews RJ, Bringas JR: A review of brain retraction and recommendations for minimizing intraoperative brain injury. Neurosurgery 33: 1052-1064, 1993.
5. Apuzzo ML, Heifetz MD, Weiss MH, Kurze T: Neurosurgical endoscopy using the side-viewing telescope. Technical note. J Neurosurg 46: 398-400, 1977.
6. Ausman JI: ISAT study: is coiling better then clipping? Surg Neurol 59:162-165, 2003.
7. Cohen AR, Perneczky A, Rodziewicz GS, Gingold SI: Endoscope-assisted craniotomy: approach to the rostral brain stem. Neurosurgery 36:1128-1129, 1995.
8. Conrad MD, Pelissou-Guyotat I, Moral 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) 144:419-426, 2002.
9. Diringer MN: To clip or to coil acutely ruptured intracranial aneurysms: update on the debate. Curr Opin Crit Care 11:121-125, 2005.

10. Flett LM, Chandler CS, Giddings D, Gholkar A: Aneurysmal subarachnoid hemorrhage: management strategies and clinical outcomes in a regional neuroscience center. AJNR Am J Neuroradiol 26:367-372, 2005.

11. Fischer G, Stadie A, Reisch R, Hopf NJ, Fries G, Böcher-Schwarz H, van Lindert E, Ungersböck K, Knosp E, Oertel J, Perneczky A: The keyhole concept in aneurysm surgery: results of the past 20 years. Neurosurgery 68:45-51, 2011.

12. Fries G, Perneczky A: Endoscope-assisted brain surgery. Part 2—analysis of 380 procedures. Neurosurgery 42:226-232, 1998.

13. Fries G, Reisch R: Biportal neuroendoscopic microsurgical approaches to the subarachnoid cisterns: a cadaver study. Minim Invasive Neurosurg 39:99-104, 1996.

14. Gorski R, Zabek M, Jarmuzek P: Influence of intraoperative using of rt-PA on development of cerebral angiospasm after subarachnoid hemorrhage in patients with ruptures intracranial aneurysms. Neurol Neurochir Pol 34:41-47, 2000.

15. Grotenhuis JA: Endoscope-Assisted Microneurosurgery. Nijmegen, The Netherlands: Machaon; 1998.

16. Hasegawa T, Yamano K, Miyamori T: A micromanipulator for precise control of brain retractor. Technical note. J Neurosurg 74: 1009-1010, 1991.

17. Hirashima Y, Hamada H, Hayashi N, Kuwayama N, Origasa H, Endo S: Independent predictors of late hydrocephalus in patients with aneurysmal subarachnoid hemorrhage—analysis by multivariate logistic regression model. Cerebrovasc Dis 16:205-210, 2003.

18. Hongo K, Kobayashi S, Yokoh A: Monitoring retraction pressure on the brain. An experimental and clinical study. J Neurosurg 66: 270-275, 1987.

19. Hopf NJ, Stadie A, Reisch R: Surgical management of bilateral middle cerebral artery aneurysms via a unilateral supraorbital key-hole craniotomy. Minim Invasive Neurosurg 52: 126-131, 2009.

20. Hosoda K, Fujita S, Kawaguchi T, Shose Y, Hamano S, Iwakura M: Effect of clot removal and surgical manipulation on regional cerebral blood flow and delayed vasospasm in early aneurysm surgery for subarachnoidal hemorrhage. Surg Neurol 51:81-88, 1999.

21. Inagawa T, Ohbayashi N, Kumano K: Effect of rapid spontaneous diminution of subarachnoid hemorrhage on cerebral vasopasm. Surg Neurol 43:25-30, 1995.

22. Inagawa T, Yamamoto M, Kamiya K: Effect of clot removal on cerebral vasopasm. J Neurosurg 72: 224-230, 1990.

23. Kalavakonda C, Sekhar LN, Ramachandran P, Hechl P: Endoscope-assisted microneurosurgery for intracranial aneurysms. Neurosurgery 51: 1119-1126, 2002.

24. Kasuya H, Shimizu T, Kagawa M: The effect of continuous drainage of cerebrospinal fluid in patients with subarachnoid hemorrhage: a retrospective analysis of 108 patients. Neurosurgery 18: 56-59, 1991.

25. Kivisaari RP, Salonen O, Ohman J: Basal brain injury in aneurysm surgery. Neurosurgery 46: 1070-1074, 2000.

26. Kockro RA, Stadie A, Schwandt E, Reisch R, Charalampaki C, Ng I, Yeo TT, Hwang P, Serra L, Perneczky A: A collaborative virtual reality environment for neurosurgical planning and training. Neurosurgery 61:379-391, 2007.

27. Komotar RJ, Olivi A, Rigamonti D, Tamargo RJ: Microsurgical fenestration of the lamina terminalis reduces the incidence of shunt-dependent hydrocephalus after aneurysmal subarachnoid hemorrhage. Neurosurgery 51:1403-1412, 2002.

28. Lindsay KW: The impact of the International Subarachnoid Aneurysm Trial (ISAT) on neurosurgical practice. Acta Neurochir (Wien) 145: 97-99, 2003.

29. MacDonald RL, Wallace MC, Coyne TJ: The effect of surgery on severity of vasospasm. J Neurosurg 80: 433-439, 1994.

30. Menovsky T, Grotenhuis JA, de Vries J, Bartels RH: Endoscope-assisted supraorbital craniotomy for lesions of the interpeduncular fossa. Neurosurgery 44:106-110, 1999.

31. Molyneux A, Kerr R, Stratton I, Sanderock P, Clarke M, Shrimpton J, Holman R; ISAT Collaborative Group: International Subarachnoid Aneurysm Trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomized trial. Lancet 360:1267-1274, 2002.

32. Niemela M, Koivisto T, Kivipelto L, Ishii K, Rinne J, Ronkainen A, Kivisaari R, Shen H, Karatas A, Lehecka M, Frosen J, Piippo A, Jaaskelainen J, Hernesniemi J: Microsurgical clipping of cerebral aneurysms after the ISAT study. Acta Neurochir Suppl 94:3-6, 2005.

33. Ogilvy CS, Hoh BL, Singer RJ, Putman CM: Clinical and radiographic outcome in the management of posterior circulation aneurysms by use of direct surgical or endovascular techniques. Neurosurgery 51:14-21, 2002.

34. Oppel F: Indications and operative technique for endoscopy of the cerebellopontine angle. In: Samii M, Jannetta P, eds. The Cranial Nerves. Berlin: Springer; 1981:429-437.

35. Perneczky A: Planning strategies for the suprasellar region. Neurosurgeons 11:343-348, 1992.

36. Perneczky A, Fries G: Use of a new aneurysm clip with inverted-spring mechanism to facilitate visual control during clip application. Technical note. J Neurosurg 82:898-899, 1995.

37. Perneczky A, Fries G: Endoscope-assisted brain surgery. Part 1—evolution, basic concept and current technique. Neurosurgery 42:219-225, 1998.

38. Perneczky A, Müller-Forell W, van Lindert E, Fries G: Keyhole Concept in Neurosurgery. Stuttgart: Thieme Verlag; 1998.

39. Perneczky A, Reisch R: Key Hole Approaches in Neurosurgery. Volume I, Concept and Surgical Technique. Vienna: Springer Verlag; 2008.

40. Prott W: Cisternoscopy-endoscopy of the cerebellopontine angle. Acta Neurochir 1:105-113, 1974.

41. Reisch R, Fries G, Patonay L, Perneczky A: Biportal neuroendoscopy of the prepontine cisterns [in Hungarian]. Ideggyogy Sz 56:76-81, 2003.

42. Reisch R, Stadie A, Kockro R, Gawish I, Schwandt E, Hopf N: The minimally invasive supraorbital subfrontal key-hole approach for surgical treatment of temporomesial lesions of the dominant hemisphere. Minim Invasive Neurosurg 52:163-169, 2009.

43. Stoodley M, MacDonald RL, Weir B, Marton LS, Johns L, Du Zhang Z, Kowalczuk A: Subarachnoid hemorrhage as a cause of an adaptive response in cerebral arteries. J Neurosurg 93: 463-470, 2000.

44. Stadie AT, Kockro RA, Reisch R, Tropine A, Boor S, Stoeter P, Perneczky A: Virtual reality system for planning minimally invasive neurosurgery. Technical note. J Neurosurg 108:382-394, 2008.

45. Tomasello F, d'Avella D, de Divitiis O: Does lamina terminalis fenestration reduce the incidence of chronic hydrocephalus after subarachnoid hemorrhage? Neurosurgery 45:827-831, 1999.

46. Tomasello F, d'Avella D: Intracisternal rt-PA during early surgery for aneurismal subarachnoid hemorrhage: an Italian report. J Neurosurg Sci 37: 71-75, 1993.

47. Tsuji T, Cook DA, Weir BK, Handa Y: Effect of clot removal on cerebrovascular contraction after subarachnoid hemorrhage in the monkey: pharmacological study. Heat Vessels 11:69-79, 1996.

48. Van den Berg R, Rinkel GJ, Vandertop WP: Treatment of ruptured intracranial aneurysms: implications of the ISAT in clipping versus coiling. Eur J Radiol 46:172-177, 2003.

49. Van Lindert E, Perneczky A, Fries G, Pierangeli E: The supraorbital keyhole approach to supratentorial aneurysms. Concept and technique. Surg Neurol 49:481-490, 1999.

50. Waring AJ, Housworth CM, Voorhies RM: A prototype retractor system designed to minimize ischemic brain retractor injury. An experimental study. J Neurosurg 58:139-143, 1990.

51. Wilson DH: Limited exposure in cerebral neurosurgery. Technical note. J Neurosurg 34:102-106, 1971.

52. Yokoh A, Sugita K, Kobayashi S: Clinical study of brain retraction in different approaches and diseases. Acta Neurochir 87:134-139, 1987.

53. Zhang ZD, Yamini B, Komuro T, Ono S, Johns L, Marton LS, Weir B, MacDonald RL: Vasospasm in monkeys resolves because of loss of and encasement of subarachnoid blood clot. Stroke 32: 1868-1874, 2001.

Conflict of interest statement: The authors declare that the article content was composed in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received 19 September 2013; accepted 25 July 2014

Citation: World Neurosurg. (2014) 82, 6S:S130-S137.
http://dx.doi.org/10.1016/j.wneu.2014.07.038

*Journal homepage: **www.WORLDNEUROSURGERY.org***

*Available online: **www.sciencedirect.com***