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ORIGINAL PAPER

The Mini-Spheno-Supraorbital Craniotomy for Treatment of Ruptured Anterior Circulation Aneurysms

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ABSTRACT

Objectives: *Yasargil introduced the pterional approach mainly for clipping of anterior circulation (AC) aneurysms. We implemented the mini-spheno-supraorbital (MSS) craniotomy, changing the shape and reducing the size of the classical pterional craniotomy. The literature on clipping ruptured AC aneurysms through reduced-in-size craniotomies is sparse. This study aims to describe the technique and present our experience in clipping ruptured AC aneurysms through the MSS approach.*

Materials and methods: *The MSS craniotomy was used in 114 cases of clipping ruptured AC aneurysms. A single burr hole was placed at the "keyhole" and an ellipsoid bone flap in the spheno-supraorbital region was raised. The tabula interna was thinned circumferentially, the roof of the orbit was flattened. Among aneurysm clipping, the lamina terminalis and the subarachnoid basal cisterns were opened. The imaging modality, the severity of the subarachnoid hemorrhage (SAH) according to Hunt & Hess (H&H), the size of the bone flap, the surgery duration and the aneurysm obliteration rate seen at the postoperative DSA were examined.*

Results: *Out of all patients in the study, 71% had exclusively CT-angiogram as initial imaging and suffered low-grade (H&H I°) SAH (71%). The mean size of the bone flap was 1.6 x 4.5 cm (1.3 x 4.3 – 2 x 8.5 cm).*

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The approach allowed adequate 360°-dissection, sufficient proximal and distal control, brain relaxation though laminoterminotomy and opening of the basal cisterns. The mean duration from skin incision to clip application was 130 minutes (64-236 mins). Total obliteration rate was 97.3%.

Conclusion: *The MSS craniotomy is feasible in terms of safety and speed for clipping of ruptured AC aneurysms especially in lower-grade SAH.*

Keywords: mini-pterional craniotomy, anterior circulation aneurysms, pterional craniotomy, mini-spheno-supraorbital craniotomy.

INTRODUCTION

At the end of the 60s, Yasargil introduced the pterional approach mainly for the treatment of aneurysms of the AC of the circle of Willis. The development of this craniotomy began with the application of microsurgical techniques to approach skull base neoplasias and it was later used in intracranial aneurysms (1). From a historical perspective, four different basic approaches were developed to clip aneurysms of the AC: a) the subfrontal approach suggested by Dott in 1933 (2); b) the interhemispheric approach, which was used from Tönnis in 1936 (3); c) the frontotemporal approach, which was proposed by Dandy in 1942 (4); and finally d) the interhemispheric subfrontal approach, which was established by Pool in 1961 (5). However, the approaches proposed by Dott, Tönnis and Pool were mainly utilized to treat aneurysms arising from the anterior communicating artery itself as well as for aneurysms of the A1- and A2-segment of the anterior cerebral artery, whereas the frontotemporal approach of Dandy has been used for all the aneurysms of the AC but can be also utilized for aneurysms of the tip of the basilar artery, as it was proposed by Yasargil (6). In our institution, the classic pterional approach is also used to clip ruptured and unruptured aneurysms of the AC, but since 2005 we modified this approach, reducing the size and slightly changing the shape of the bone flap, generating a small, roughly oval shaped spheno-supraobital craniotomy. Despite numerous published works on keyhole approaches for unruptured AC aneurysms, the literature on the use of reduced-in-size craniotomy for ruptured AC aneurysms is not extensive. In this paper we describe our technique and surgical results of 114 ruptured AC aneurysms approached through a MSS craniotomy. To our knowledge, this is one of the largest studies reported with the use of reduced-in-size approach solely for ruptured AC aneurysms. ❑

MATERIALS AND METHODS

We retrospectively analyzed all patients who underwent microsurgical clipping for ruptured AC aneurysms in our department between March 2005 and March 2015. A total of 114 patients with single ruptured AC aneurysms were operated using the MSS approach. Patients who underwent a classical pterional craniotomy as well as those requiring a decompressive hemicraniectomy were excluded from this study. Further exclusion criteria for the application of MSS craniotomy were clinical and radiographical signs of cerebral herniation and a large sized frontal sinus extending more than 2 to 3 cm from the lateral orbital rim. The imaging modalities with which the aneurysms were diagnosed, the grade of the subarachnoid haemorrhage (SAH) according to Hunt and Hess grading system, the size of the MSS bone flap as well as the operation duration in minutes from skin incision to clip application were recorded. All operations were performed from the senior author (TB). A postoperative digital subtraction angiography (DSA) was performed in all patients to examine the aneurysm obliteration rate of our cohort. We also studied the intraoperative and postoperative complications.

Surgical technique

After the initial imaging diagnostic and the decision for microsurgical clipping of the AC aneurysm, the patients received general anaesthesia. An external ventricular drainage was placed in all cases through the Kocher point. Patients were then placed in supine position, the head was fixed *via* a three-point fixation skull clamp (Mayfield, Integra LifeSciences Corporation, Cincinnati) with the head being slightly elevated, extended backwards and rotated approximately 30° towards the contralateral side of the aneurysm. After shaving of the hair, the subcutaneous tissue was infiltrated with a mixture of xylocaine and 1%-adrenaline to limit bleeding during the skin incision and reduce postoperative pain. A typical curvilinear fronto-temporal skin incision beginning slightly anterior to tragus and reaching the widow´s peak at the midline was performed. To protect the frontal branch of the facial nerve subfascial preparation of the deep temporal fat pad and subperiosteal exposure of the supraorbital frontal bone, medial to superior temporal line, was utilized. Subsequently, in contrast with the classical pterional approach, only the anterior 1/3 to 1/4 of the temporalis muscle was cut and reflected antero-basally with the skin-galea-periostal flap which was previously raised. Care was taken to preserve the superficial temporal artery not to compromise wound healing and to be able to harvest it as a donor artery in case a bypass would be needed. A single burr-hole was placed at the "keyhole" as described in the standard pterional craniotomy by Yasargil (6-8); just below the anterior end of the superior temporal line, above the frontozygomatic suture and behind the upmost part of the posterior edge of the zygomatic process of the frontal bone. Using the pneumatic craniotome, ellipsoid shaped, bone flap with its long axis being in coronal and its short axis in anteroposterior plane was elevated in the shpeno-supraorbital region (Figures 1 and 2). The sphenoid ridge was drilled away and, if necessary, the lesser sphenoid wing was also drilled up to meningo-orbital band, which was then coagulated and incised. The tabula interna of the frontal bone at the superior, dorsal and frontal edge of the craniotomy was drilled and the bony protrusions of the orbital roof were meticulously flattened extradurally, using the craniotome without the footplate to increase the working angle without increasing the size of the trepanation. Removal of the orbital roof was not necessary. The dura was opened in a curvilinear fashion and retracted frontobasally with a tack-up suture. Two suctions were available at all times; one for microsurgical manoeuvres with 6G or 7G diameter connected to suction regulator (Aesculap Cerullo Suction Regulator, B. Braun, Tuttlingen, Germany) to fine tune the suction power without the help of the running nurse and one bigger suction 10G or 5G ready to be employed in case of intraoperative rupture. Parallel to the standard microsurgical steps of aneurysm clipping, each operation included the opening of the lamina terminalis as well as the meticulous opening of the arachnoid of the subarachnoid cisterns of the anterior fossa, which are comprehensively delineated by Yasargil *et al* (9). This procedure included the fenestration of the Liliequist's membrane. Utmost blood clot removal from the subarachnoid cisterns was undertaken. The aforementioned steps promote CSF release and circulation thus allowing the surgeon to operate around "relaxed" brain. After closure of the dura, the bone flap was fixed to the skull with microplates and microscrews. The temporalis muscle was sutured back to the rest of the muscle along

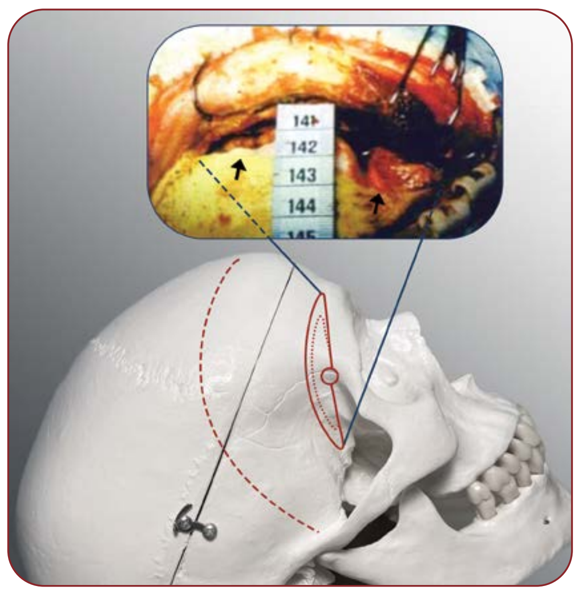

FIGURE 1. Schematic illustration of the skin incision (dashed line) and the MSS craniotomy on a skull with an intraoperative image of the exposure (the black arrows indicate the dorsal margin of the craniotomy). The red dotted line represents that the sphenoidal and the supraorbital extension of the craniotomy can be varied according to the aneurysm localization and its morphology

FIGURE 2. The ellipsoid shaped mini-spheno-supraorbital bone flap from the craniotomy shown in Figure 1

its posterior aspect and to the thin myofascial cuff at the superior temporal line. Subcutaneous tissue and the skin were closed in standard fashion. ❑

OUTCOMES

From total of 114 patients with SAH, 81 (71%) presented with H&H Grade 1, 22 (19.3%) with H&H Grade 2, eight (7%) with H&H Grade 3 and three with H&H Grade 4. The preoperative diagnostic imaging modality consisted of only CT-angiogram (CTA) in 81 (71%) patients, CTA and MR-angiogram (MRA) in three (2.6%) patients, CTA and DSA in 21 (18.4%) patients, and CTA, MRA and a DSA in nine (7.9%) patients. Compared to the cases operated through the classical pterional craniotomy, dynamic retraction with the suction augmented with cottonoids was sufficient most of the time, with very little or almost no use of fixed retractors. The mean size of the bone flap was 1.6 x 4.5 cm (range: minimum 1.3 x 4.3 cm, maximum 2 x 8.5 cm). The approach allowed sufficient space a) to perform a 360° dissection of the aneurysm with adequate length of the afferent and efferent arteries exposed to secure proximal and distal control (Figure 3); and b) to comfortably perform fenestration of the lamina terminalis as well as opening the arachnoid of the basal cisterns. Temporal clipping was utilized in 63 (55.2%) cases. The temporary clips were placed as close as possible to the aneurysm. There were seven (6%) cases of intraoperative aneurysm ruptures upon the placing a temporary clip. In all instances with intraoperative rupture, craniotomy allowed more than enough space to apply temporary clips and to deploy the second large suction in the operating field. Adenosine was administered in all cases of intraoperative ruptures. Four out of seven intraoperative ruptures (57.1%) were successfully treated with temporary clips and subsequent application of the final clip. These patients did not show any neurological worsening and the postoperative DSA documented a complete aneurysm occlusion. In one case (14.2%), final-clip application after placement of temporary clips was possible, but postoperative DSA showed narrowing of the parent artery, resulting in an ischemia and a moderate hemiparesis. At the time period of this retrospective analysis, an intraoperative ICG-videoangiography or micro-doppler was not available in our department due to limited financial resources. The aforementioned patient had initially suffered a SAH H&H grade 4, but finally had a relatively favourable outcome of mRS 3 at one-year follow up after rehabilitation. In the last two cases of intraoperative rupture (28.6%), in which both patients had presented with a SAH H&H Grade 4, the outcome was fatal due to sudden and massive increase of brain oedema. Administration of adenosine, application of temporary clips and enlargement of the craniotomy did not affect the outcome. The mean time in minutes elapsed from skin incision to the application of the final clip was 130 (range: 64–236). Postoperative DSA showed a complete occlusion of the aneurysm in 111 (97.3%) cases. Opening of the sinus frontalis was not encountered. Although the superior temporal artery was prophylactically harvested at some cases at the begin of the operation, extra- to intracranial bypass was not necessary in any of the operated cases. During in-hospital postoperative period, three patients with superficial wound infections received conservative treatment with antibiotics and local antiseptic emulsions. Two patients presented subcutaneous CSF collections, which we retrospectively associated with premature removal of the external ventricular drainage; those patients were successfully treated with sterile puncture of the collection, injection of 2 to 3 mL of "autologous blood patch" drawn in sterile fashion, application of compression bandage on the head for 48 hours and lumbar drainage for 96 hours. None of the surviving patients required permanent CSF shunting during the one-year follow-up.

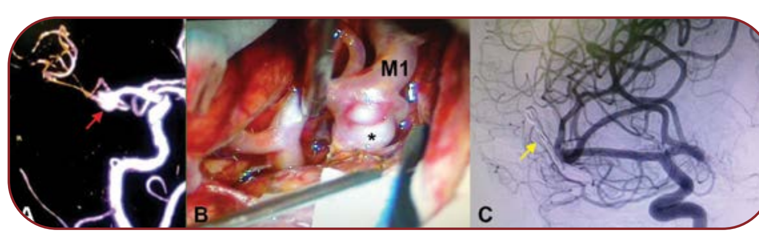

FIGURE 3. Ruptured aneurysm of right medial cerebral artery bifurcation clipped through the craniotomy shown in Figure 1.
(A) Preoperative 3D reconstruction of the aneurysm (red arrow) from CT-angiogram. (B) Intraoperative image of the aneurysm (asterisk). Note that the craniotomy allows adequate exposure of the afferent/parent and the efferent arteries providing proximal and distal control as well as space for deployment of various microsurgical instruments.
(C) Postoperative DSA showing complete occlusion of the aneurysm with a straight clip (yellow arrow)

After one-year follow-up, all patients with initial H&H grade 1-3 SAH had a favourable clinical outcome, with mRS 0-3 after neurological rehabilitation, and commonly encountered cosmetic issues after classical pterional craniotomy like temporal muscle atrophy or temporomandibular dysfunction (10) was not observed. ❑

DISCUSSION

Various keyhole approaches for microsurgical treatment of AC aneurysms are reported in the literature, with the classical pterional craniotomy still being the gold standard because of various safety reasons and the limitations of the minimalistic approaches (11). The recent literature demonstrates the safety, feasibility and outcome of keyhole approaches for ruptured AC aneurysms with comparable to the standard approaches in experienced hands and mindful patient selection (12-20). For anatomical purposes, we chose to describe our approach as mini-spheno-supraorbital, since the bone flap included both the region of the greater wing of the sphenoid bone and the supraorbital portion of the frontal bone in varying degrees each time, according to the aneurysm localization and morphology. Compared to the long-established variations of the minimal-invasive or keyhole variations of pterional craniotomy and fronto-lateral craniotomoies like the supraorbital keyhole approach (21), the lateral supraorbital approach (22) and the minipterional craniotomy (23), our approach can be placed from anatomical aspect somewhere where these overlap and provides the combination of their angle of attack (AoA) to various AC aneurysms. Some of the main variations of the pterional craniotomy with their respective advantages and possible limitations are presented in Table 1.

The mini-pterional approach is more suitable for middle cerebral artery aneurysms and for internal carotid artery (ICA) aneurysms that project posteriorly (13); the AoA provided though this approach is covered by the sphenoidal part of the MSS craniotomy and the supraorbital crani-

TABLE 1. Main variations of the pterional craniotomy with their respective advantages and possible limitations

Approach	Advantages	(Possible) Limitations
Supraorbital keyhole (van Lindert et al.) (21)	Shorter operation time Preserved vascular and nerve supply to temporalis and frontal muscles Better cosmetic outcomes Less retraction Reduced risk of accidental cortical injury	Limited intraoperative possibility of enlarging the craniotomy in case of unexpected events/findings Proximal control in cases of ICA-aneurysms or aneurysms of the ophthalmic artery may be inadequate
Lateral supraorbital (Hernesniemi et al.) (22)	Fast procedure Less traumatization of the temporal muscle Less risk of facial nerve injury Good cosmetic results Smaller bone flap reducing the risk of CSF-leak, post-op epidural hematoma and infection	Limited temporal exposure for approaching posteriorly projecting aneurysms of posterior communicating artery, laterally projecting large and giant MCA aneurysms and lower basilar tip aneurysms Limited exposure for ruptured MCA aneurysms with large temporo-parietal intracerebral hematoma
Minipterional craniotomy (Figueiredo et al.) (23)	Reduced tissue trauma Reduced length of surgery Better cosmetic outcomes Reduced bone removal Less retraction of the frontal lobe Less risk of accidental injury of the cortex	Limited subfrontal exposure Limited temporal exposure

otomy is more suitable for the aneurysms of the anterior communicating artery and ICA aneurysms that project laterally (13); the AoA provided by this craniotomy is covered by the supraorbital part of the MSS craniotomy. Reduced-in-size fronto-latero-basal approaches with smaller skin incision are described (24, 25). However, we preferred to perform the typical curvilinear frontotemporal incision of the pterional approach to allow the enlargement of the craniotomy, if necessary, just by cutting and reflecting the rest of the temporalis muscle dorsally without having to perform an extension of the skin incision additionally. Smaller skin incisions, like the eyebrow incision in the classical supraorbital craniotomy described by Dr. Perneczky (26), are faster to perform and cosmetically more favourable but as the frontal branch of the facial nerve travels through the epiperiostal areolar loose tissue, the senior author (TB) favours the classical skin incision which allows subfascial preparation of the fat pad to avoid any chances of frontal branch palsy. Nevertheless, the small size of the bone flap (12) and less manipulation of the temporalis muscle facilitate a favourable cosmesis compared to the classical pterional craniotomy (Figure 4). Owing to the supraorbital portion of our craniotomy almost flush with the anterior skull base and thorough flattening of the orbital roof, removing of the superior orbital rim or posterolateral orbitotomy was not needed to achieve less frontal lobe retraction employing the subfrontal route in comparison to the classical pterional approach (27). The limited exposure also accommodates less thermal damage to the cortex from the light of the surgical microscope. The supraorbital component of the MSS craniotomy provides an excellent straightforward trajectory to perform the fenestration of the lamina terminalis. The circumferential thinning of the tabula interna not only increases the working space and the visual field of the surgeon (26) but also provides a flat operative corridor decreasing the need for brain retraction. Drilling of the lesser sphenoid wing and incision of the meningo-orbital band "unlocks" the frontal lobe from the temporal lobe, facilitating exposure to the skull base and reducing the amount of possible retraction needed (28). Through the communication of the CSF between the cisterns and the brain parenchyma opening of the subarachnoid cisterns and removal of subarachnoid blood clots promote brain relaxation by reducing the cisternal pressure and consequently aiding the release of the CSF trapped in the brain parenchyma causing brain oedema, into the cisterns during the operation (29-31). As the membrane of Liliequist separates the infra- and supratentorial basal cisterns (32), its fenestration plays a key role promoting CSF flow towards the spinal subarachnoid space and reduces the intracranial pressure in the acute phase of the haemorrhage. The opening of the lamina terminalis not only functions complementary to the EVD in terms of achieving brain relaxation but, in combination with the fenestration of the Liliequist´s membrane, it alleviates the shunt-dependendent postheamorrhagic hydrocephalus, as Winkler *et al* reported in a large series of 663 patients (33). Temporary clips were implemented to a greater extent compared to operations where standard craniotomy was used, compensating in some manner any safety doubts when operating thorough small sized craniotomy. We prefer to apply the temporary clips as close as possible to the aneurysm sac to avoid ischemic complications ascribable to perfusions disturbances of small perforating vessels, which can occur when the temporary clip is placed very proximal on the parent vessel (34). Our work underscores the importance of aforementioned microsurgical manoeuvres of opening the arachnoid of the basal cisterns, fenestration of the lamina terminalis as well as applying the "unlocking" principals in keyhole approaches to achieve brain relaxation. Over-sized fontal sinus is a limiting factor for the MSS craniotomy. Although clip applicators for keyhole surgery are commercially available, they might not always be accessible in resource limited settings as in our department. The conventional clip applicators were somehow "bulky" for the MSS craniotomy, which, however, did not create any safety issue. The main limitation of our study was that the cohort mostly consisted of patients who had suffered a low-grade subarachnoid haemorrhage, so that firm conclusions on performing the MSS craniotomy in patients with high-grade SAH cannot be drawn. The technique of MSS craniotomy for clipping of ruptured AC aneurysms requires a shorter surgical time, better cosmesis, less brain exposure and retraction in comparison to the classical pterional approach, without compromising safety. These goals were achieved judging by our results, and the fear of inability to manage an intraoperative bleeding due to the small opening was not justified, as the approach provided sufficient exposure for proximal and distal control with 360° aneurysm dissection, without creating space problems when placing temporary clips and employing the second larger suction in case of intraoperative rupture. The fatal outcome in two out of seven cases of intraoperative rupture were attributable to the severity of the underlying initial haemorrhage as well as that of the re-bleeding and not the size of the craniotomy. Including the experience of the senior author (TB) in clipping ruptured aneurysms of anterior and posterior circulation causing poor grade SAH through conventional craniotomies, when a particular size of the craniotomy allows emergency manoeuvres (temporary clips, use of second suction, resection of adjacent brain parenchyma) to be performed adequately and comfortably, we assume that any additional increase of the size of the craniotomy is not translated into further advantage. Despite controversies on the optimal timing of treatment (interventional or surgical) for poor grade aneurysmal SAH, our institution embraces the ultra-early treatment as it enables to be able to keep the cerebral perfusion high against the increased risk of vasospasm without having to be concerned for re-bleeding from an unsecured aneurysm. The recent literature favours the early and ultra-early treatment of poor grade SAH for a better clinical outcome (35-38). The approach should always be tailored to the benefit of the patient; the surgeon must feel comfortable and have the proper experience not only to perform a keyhole craniotomy but also to carefully identify the cases which should be operated through the classical approach, as ultimately the principle of Al-Mefty "remove bone and leave the brain alone" (39) applies not only for meningiomas but for all neurosurgical pathologies. ❑

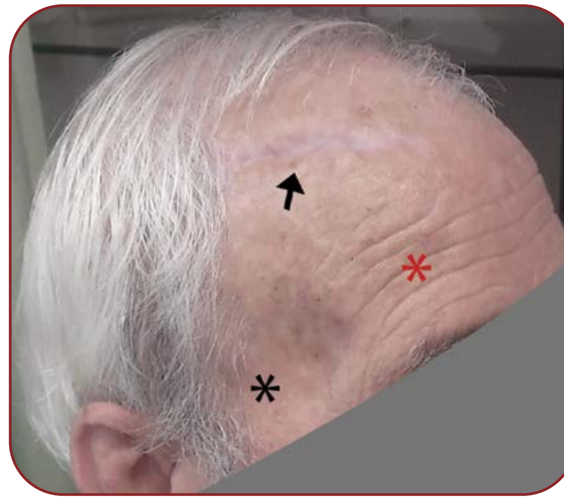

FIGURE 4. Image of the frontotemporal region of a patient at one-year follow-up who underwent aneurysm clipping through the MSS craniotomy. The black arrow points to the typical pterional skin incision. A hollowing of the temporal region is not seen (black asterisk). The function of the frontal branch of the facial nerve is intact (red asterisk)

CONCLUSION

The MSS craniotomy is a feasible approach in terms of speed and safety for clipping ruptured AC aneurysms, especially in cases of lower grade SAH, with good cosmetic results when microsurgical techniques intra- and extradurally to achieve flat operative corridors as well as brain relaxation are meticulously applied. Generous use of temporary clips as proximal as possible to the aneurysm is advisable. ❑

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