Video Article

Minimally Invasive Thumb-sized Pterional Craniotomy for Surgical Clip Ligation of Unruptured Anterior Circulation Aneurysms

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Abstract

Less invasive surgical approaches for intracranial aneurysm clipping may reduce length of hospital stay, surgical morbidity, treatment cost, and improve patient outcomes. We present our experience with a minimally invasive pterional approach for anterior circulation aneurysms performed in a major tertiary cerebrovascular center and compare the results with an aged matched dataset from the Nationwide Inpatient Sample (NIS). From August 2008 to December 2012, 22 elective aneurysm clippings on patients ≤55 years of age were performed by the same dual fellowship-trained cerebrovascular/endovascular neurosurgeon. One patient (4.5%) experienced transient post-operative complications. 18 of 22 patients returned for follow-up imaging and there were no recurrences through an average duration of 22 months. A search in the NIS database from 2008 to 2010, also for patients aged ≤55 years of age, yielded 1,341 hospitalizations for surgical clip ligation of unruptured cerebral aneurysms. Inpatient length of stay and hospital charges at our institution using the minimally invasive thumb-sized pterional technique were nearly half that of NIS (length of stay: 3.2 vs 5.7 days; hospital charges: $52,779 vs. $101,882). The minimally invasive thumb-sized pterional craniotomy allows good exposure of unruptured small and medium-sized supraclinoid anterior circulation aneurysms. Cerebrospinal fluid drainage from key subarachnoid cisterns and constant bimanual microsurgical techniques avoid the need for retractors which can cause contusions, localized venous infarctions, and post-operative cerebral edema at the retractor sites. Utilizing this set of techniques has afforded our patients with a shorter hospital stay at a lower cost compared to the national average.

Video Link

The video component of this article can be found at http://www.jove.com/video/51661/

Introduction

Surgical clip ligation had been the mainstay of treatment for intracranial aneurysms but has been recently supplanted mostly by less invasive endovascular techniques.[1,2] Clinical trials including the *International Study of Unruptured Intracranial Aneurysms (ISUIA-1 and ISUIA-2),* and the *International Subarachnoid Aneurysm Trial (ISAT*) have demonstrated lower morbidity and mortality, reduced length of hospital stay, and lower overall expense, with endovascular treatment compared to surgical clip ligation.[3–5] However, the higher aneurysm recurrence rate after endovascular therapy has led to the examination of the cumulative risk to the patients compared to surgical clip ligation.[3,4] Surgical treatment remains an important modality for aneurysm therapy, particularly for anterior circulation aneurysms that have morphologies that may be difficult to treat with endovascular means.

Unlike advancements in endovascular devices, few advances in surgical techniques have been made recently. Techniques to make surgical treatment less invasive have included the supraorbital craniotomy combined with the eyebrow incision for anterior circulation aneurysms and “retractorless surgery” to minimize surgical trauma to the brain during aneurysm clipping.[6–8] These less invasive surgical approaches may reduce length of hospital stay, surgical morbidity, treatment cost, and improve patient outcomes.[9]

Here, we present our experience with a minimally invasive approach to surgical clip ligation of unruptured intracranial aneurysms using a pterional approach for anterior circulation aneurysms performed in a major tertiary cerebrovascular center and compare the results with an age matched dataset from the Nationwide Inpatient Sample (NIS). The surgical technique will be reviewed, including patient preparation, brain relaxation, sylvian fissure dissection, and closure. Post-operative care and discharge requirements will also be outlined.

Protocol

NOTE: Prior to performing this procedure, obtain all required institutional approval and patient consent.

1. Surgical Technique

1. Induce patient with general anesthesia.
2. Place radial arterial line for blood pressure monitoring.
3. Place patient in the supine position on the operating room table.
4. After the head is clamped into the Mayfield Head holder using standard techniques for a pterional craniotomy, position the head 30°-45° with the ipsilateral side up towards the ceiling, except for anterior-communicating artery aneurysms in which the head is placed at 60º to allow for better visualization across the interhemispheric fissure.
5. Position the neck midline and translate anteriorly to maximize jugular venous drainage to prevent cerebral edema and then extend the head to position the ipsilateral zygoma at the highest point—this allows for frontal lobe relaxation and elevation from the orbital roof during dissection without the use of retractors.
6. Clip the hair in preparation for standard pterional scalp incision; use about a one to two inch strip behind the hairline.
7. Sterilely prep the skin and drape the surgical area according to standard of care.
8. Perform a standard curved scalp incision for a pterional approach extending from the midline of the scalp behind the hairline with a gentle curve posteriorly and inferiorly towards the tragus ending it about 3 mm anterior to the tragus and at the level of the superior edge of the zygoma. Perform this incision down to the skull above the superior temporal line and to the muscle fascia at the level of the temporalis muscle.
9. Use electrocautery for scalp hemostasis with the bipolar device.
10. Cut the temporalis muscle down to the skull using the bovie monopolar electrocautery device.
11. Raise a myocutaneous flap keeping the temporalis muscle attached to the undersurface of the scalp for now. Fish-hooks are used to evert the flap after the temporalis muscle is elevated from the skull using a combination of monopolar electrocautery and a periosteal elevator.
12. Perform an inverse subfascial dissection in the avascular plane from the undersurface of the myocutaneous flap using Metzenbaum scissors, keeping the fascia and subfacsial fat pad with the scalp to avoid injury to the facial nerve.
13. Secure the temporalis muscle posteriorly and inferiorly to expose the pterional region with “star” fishhooks.
14. Keep all components of the myocutaneous flap moist with wetted gauze.
15. Drill a single temporal 5 mm burr-hole at the posterior-most aspect of the planned craniotomy with a 2 mm cutting burr so that the foot plate of the side-cutting drill can be inserted into this hole and then use a side-cutting drill with a foot plate to remove the thumb-sized (approximately 3 x 4 cm) kidney-shaped craniotomy centered anteriorly around the pterion.
16. Using a No. 1 Penfield, separate the dura on all sides of the pterion and have an assistant gently retract the dura away from the bone surface that is being drilled to minimize risk of penetrating the dura and causing cortical injury.
17. Remove the pterion with a drill: anteriorly, until the superior and lateral aspects of the orbital roof are smooth and flattened down to the outer cortical table of bone, without entering the orbit, to maximize subfrontal exposure; medially, drill until the superior orbital fissure dura is exposed and remove any small pieces of bone that would interfere with medial exposure using either a drill bit or hand-held Lempert bone cutting device. Ensure that excellent hemostasis of all soft-tissue and bone surfaces has been obtained to avoid blood dripping into the intradural space during brain dissection and aneurysm exposure, using electrocautery and bone wax as needed, before opening the dura.
18. Gently elevate the dura and use a No. 11 scalpel to penetrate the dura and then use dural scissors to create a “C-shaped” opening in the dura with the base at the pterion. Secure the dura flat against the outer cortical bone of the orbit without having redundant dural leaflets that would otherwise obscure visualization of the proximal Sylvian Fissure and subfrontal region. This can be performed by using 4-0 Surgilons sutures to tack the dura to the scalp.

2. Brain Relaxation

1. Give 25-50 g of Mannitol at the time of bone flap removal to relax the brain if anesthesia agrees that the blood pressure will tolerate diuresis.
   NOTE: This will allow time for the diuresis to occur and ultimately will relax the brain to help maximize gravity dependent brain retraction during dissection.
2. Keep End-Tidal pCO_2 between 30-35 mm Hg to achieve slight hypercapnea. NOTE: This will safely allow for brain relaxation and maximize gravity dependent brain retraction during dissection.
3. Evacuate cerebrospinal fluid (CSF) to promote brain relaxation by opening the arachnoid cisterns in the interoptic, carotid-optic, and carotid-oculomotor cisterns and patiently suction CSF until the desired brain relaxation has been achieved.
   NOTE: This typically takes about 1 min; no lumbar drain is needed with this technique and it dramatically opens the surgical corridors.

3. Sylvian Fissure Dissection

1. Bring the intra-operative microscope with the mouthpiece into the field using sterile techniques. Also bring surgical chairs with arm support into the field sterilely to maximize bimanual dexterity and to prevent surgeon arm and hand fatigue.
   NOTE: The mouthpiece should be adjusted before draping so that the surgeon can move the microscope with the mouth while simultaneously looking through the ocular pieces.
2. Perform dissection.
   NOTE: For anterior communicating artery aneurysms, no Sylvian Fissure dissection is required and minimal (2-3 mm in extreme cases only, but this is a rare occurrence) to no gyrus rectus resection is needed using only subfrontal dissection; all other supraclinoid anterior circulation aneurysm locations (including posterior communicating artery) require <1 cm proximal Sylivan Fissure dissection to expose the supraclinoid internal carotid artery, its branches (posterior communicating and anterior choroidal arteries), the internal carotid artery terminus, the A1 and

M1 origins, and the proximal A2 and M2 segments distal to their respective bifurcations. Total Sylvian Fissure exposure was dime-size (1 cm x 1 cm) and no brain retractors were used for any of the cases reported. Gravity dependent brain relaxation was sufficient for excellent exposure of the soft tissue structures and vasculature needed to perform surgical clip ligation in the areas discussed above.

3. Using bimanual manipulation with surgical microinstruments gently open the arachnoid corridors, holding the brain tissue aside with the edge of the instrument handles or suction device as needed through this exposure.
   NOTE: The senior author's preference is to use a 4-French Fukishima suction tip in the non-dominant hand and in the dominant hand bipolar bayonettes for blunt dissection or microscissors for sharp dissection. Moistened Telfa strips are placed on the brain surface at the site of manipulation to prevent cortical injury. Cottonoids often stick to the brain surface and can't be easily advanced deeper as the dissection progresses, without causing mild cortical injury.
4. Use the mouthpiece on the operating microscope frequently to adjust the scope and focus length as needed while keeping both hands in the field.
5. Secure the aneurysm in standard fashion, using the suction most often in the non-dominant hand to maintain the surgical corridor and visualization free of CSF.
6. After clip placement, perform intra-operative Doppler of the aneurysm dome to confirm cessation of flow as well as the inflow and outflow vessels to confirm flow and carefully examine the aneurysm neck and parent vessels. We reserve intra-operative digital subtraction angiography (DSA) for anterior communicating artery aneurysms and those clipped aneurysms where inflow, outflow, or aneurysm neck cannot be visualized completely or there is a concern with intra-operative Doppler. Intra-operative DSA is preferred over indocyanine green (ICG) angiography because when multiple aneurysm clips are used to reconstruct the aneurysm neck, the clip can obstruct visualization.
   NOTE: Once the aneurysm has been securely clipped, the microscope is removed from the field and the brain irrigated with normal saline solution to minimize the amount of pneumocephalus after closure.
7. After inspecting the clip for aneurysm occlusion with the Doppler, the aneurysm dome is perforated with a 22 G needle attached to intravenous tubing and a 10 ml syringe and manually suction aspirated to confirm aneurysm occlusion.
8. Reapproximate the native dura with 4-0 surgilon and cover with a synthetic dural substitute if a watertight closure is not able to be obtained properly.
9. Secure bone plates with a metal plating system per standard of care.
10. Secure the frontal edge of the bone flap flush against the native bone to avoid space between the two which would not be cosmetically pleasing after the tissues heal.
11. Reapproximate the temporalis muscle fascia with interrupted 2-0 Vicryl sutures. Secure the top of the temporalis muscle with a 2-0 Vicryl stitch to the frontal metal plate to reapproximate it to the superior temporal line.
12. Reapproximate the galea using 3-0 Vicryl sutures and close the scalp in a standard fashion using either staples, nylon, or prolene. Dress with sterile bandages per surgeon preference.

4. Post-treatment Care

1. Admit patient to the intensive care unit after treatment and mobilize with the nursing staff as soon as sedation or general anesthesia has worn off enough to do so, typically within 6 hr of extubation.
2. Order physical and occupational therapy to begin post-operative day one in order to assess the patient for safe discharge to home if there were any concerns by the nursing staff.
3. Discharge the patient when criteria are met: pain controlled with only oral medications, voiding independently, ambulating independently, and tolerating oral food intake.

Representative Results

Currently, at our institution over 150 aneurysms are treated annually. From August 2008 to December 2012, 22 elective aneurysm clippings using this minimally invasive thumb-sized pterional craniotomy technique for supraclinoidal aneurysms on patient's ≤55 years of age were performed by the same dual fellowship-trained cerebrovascular/endovascular neurosurgeon that developed this technique (EMD) (**Table 1**). This age group was chosen as earlier trials have shown that surgical treatment of aneurysms in patients above this age result in worse outcomes than endovascular treatment and hence, few patients older than 55 are treated with surgical clip ligation at our institution.

Only one patient (4.5%) treated for a right MCA aneurysm experienced a post-operative complication. A head CT scan was obtained due to decreased left upper extremity movement and revealed ischemic changes in the distribution of a right MCA branch most consistent with a thromboembolic event during clip ligation or transient vasospasm. The patient improved with physical and occupational therapy and was at baseline at two-month follow-up. 18 of 22 patients returned for follow-up imaging and there were no recurrences through an average duration of 22 months.

To represent the national average, we utilized the Nationwide Inpatient Sample (NIS) from 2008 to 2010. The NIS is a hospital discharge database that represents approximately 20% of all inpatient admissions to nonfederal hospitals in the United States. We obtained the NIS database from the Agency for Healthcare Research and Quality's Healthcare Cost and Utilization Project (Rockville, MD). Detailed information on the design of the NIS is available at http://www.hcup-us.ahrq.gov.

Hospitalizations for clipping of unruptured cerebral aneurysms were collected from the NIS by cross-matching the International Classification of Diseases (ICD-9-CM) diagnosis code for an unruptured cerebral aneurysm (437.3) with the procedure code for clipping (39.51) of a cerebral aneurysm. The ICD-9-CM codes used for aneurysm clipping have been previously studied and validated.[10–16] Only patients under 55 years of age were included, as to age-match the cases with our internal dataset. We excluded patients with "subarachnoid hemorrhage" (ICD-9-CM 430) and "intracerebral hemorrhage" (ICD-9-CM 431). In comparing total hospital charges across the years we assumed a 3% annual inflation rate for each year and used the adjusted charges in the analyses.

1,341 hospitalizations for surgical clip ligation of unruptured cerebral aneurysms were identified. Inpatient length of stay and hospital charges at our institution using the minimally invasive thumb-sized pterional technique were compared to NIS using Mann-Whitney U tests. Both outcome measures were significantly reduced at our institution in comparison to the national average (**Table 2**).

Age, yrs	47.5 (44-52)
Male	4 (18%)
Aneurysm maximum dimension, mm	6.3 (5.6-9.0)
Location	
Internal carotid artery	4 (18%)
Middle cerebral artery	7 (32%)
Anterior cerebral artery	2 (9%)
Anterior communicating artery	6 (27%)
Posterior communicating artery	3 (14%)
Craniotomy size, mm^2	1,835 (1,370-2,133)
Postoperative complications	1 (4.5%)
Duration of follow-up, months	22 (14-28)
Recurrence	0 (0%*)
Continuous variables presented as median (intequartile range)	
Categorical variables presented as n (%)	
*4 patients were not available for follow-up imaging	

Table 1: Internal Dataset Patient Characteristics

	Internal dataset	NIS	P Value
Age, yrs	47.5 (44 - 52)	47 (42 - 52)	0.561
Length of stay, days	2 (1 - 3)	4 (3 - 6)	<.001
Hospital charges, $	49,040 (42,550 - 58,767)	77,178 (55,778 - 121,461)	<.001
Continuous variables presented as median (interquartile range)			

Table 2: Internal Dataset compared to Nationwide Inpatient Sample (NIS)

Discussion

Surgical clip ligation of intracranial aneurysms remains a relevant and important option in treating certain types of aneurysms, though this role has been diminishing over the past several years as endovascular technology becomes safer and more efficacious. Endovascular treatment has surpassed surgery for cerebral aneurysms, yet the higher recurrence rate after endovascular treatment, the occasional need for surgical treatment after aneurysm recurrence from failed endovascular treatment, specific morphologies making endovascular therapy higher risk requiring stent placement, and some recent literature reviewing the cumulative risk of endovascular treatment being higher than for surgical treatment, all keep surgical clip ligation relevant to aneurysm treatment.[17]

The subfrontal approach was first described as a unilateral approach by Krause in 1908, and then modified by Dandy and Heuer for lesions of the pituitary gland and optic canal.[18] In 1933, Dott used this approach for clipping an aneurysm.[19] Through this technique there is minimal brain exposure and wide access to the suprasellar region with minimal need for brain retractors. Dandy and later Yasargil modified and used this technique to clip anterior communicating artery aneurysms.[20,21] Many other neurosurgeons have modified this technique describing it by different terms and have used this approach not only to reach vascular, but also anterior skull base lesions. Al-Mefti and Fox modified the supraorbital approach to the supero-lateral orbital exposure.[22] This extends the supraorbital craniotomy to include the lateral and superior orbital wall. This approach was used for orbital and skull base tumors as well as for complex anterior circulation aneurysm clipping. The advances in neurosurgery have been reflecting the size of the craniotomy and exposure not only for the cosmetic advantage but also to avoid complications such as epidural hematomas, unintended cortical injury, brain retraction, and the time of exposure to room air.

Van Lindert *et al*. reported a series of 139 patients with a total of 197 aneurysms that were treated with clipping through the supraorbital keyhole approach.[18] In this study no complications related to the exposure were reported, and only four patients experienced aneurysmal rupture during clipping. The ruptures were attributed to aneurysm dissection or a result of clip application, and not due to brain retraction. The authors describe that multiple aneurysms can be safely clipped in the same procedure and that contralateral aneurysms can be safely reached. Petraglia *et al.* reported a series of 28 patients with anterior communicating artery aneurysms that were treated with clipping through the subfrontal approach.[8] They describe this technique as safe and with fewer complications compared to the traditional pterional approach.

Some of the limitations related to the keyhole supraorbital approach are: (1) the keyhole is not always performed in the same anatomical location. The small incision and craniotomy requires good preoperative planning with MRI and CT reconstructions that depict the aneurysm orientation and the bony structures. In this way the incision and craniotomy need to be individualized for each patient's anatomy. (2) The direction of the instruments and light must be in the same plane and may require special clips that allow better visualization of the target. (3) There is a higher risk of opening of the frontal sinus, which may negate any cosmetic advantages compared to the pterional approach.[23] (4) Requires a well trained vascular neurosurgeon.

At our institution, the senior author's (EMD) approach for clipping anterior intracranial aneurysms involves thumb-sized pterional craniotomies without brain retractors. It is important to use a mouthpiece on the operative microscope for continuous readjustment of focus and angle of view to maintain constant bimanual manipulation of the brain tissues without retractors. This is considered less invasive than the standard approach and prevents many post operative complications and provides a faster recovery. We believe this is reflected in the shorter post-operative length of stay and lower total hospital charges, in comparison to the national average from NIS.

It is important to note that the patients treated at our institution had supraclinoid aneurysms. We do not treat aneurysms below the communicating segment of the internal carotid artery using the described clipping technique because drilling of the anterior clinoid process would require a larger craniotomy and cervical carotid cut-down for proximal arterial control. Additionally, none of the aneurysms treated in this study were considered giant aneurysms (>20 mm). In our experience, these larger aneurysms typically require more extensive exposure to allow bypass and dissection to identify inflow and outflow zones and would not be treated well with a mini-craniotomy. Additionally, this smaller-sized craniotomy does readily allow for multiple clip placements when needed and provides adequate exposure for proximal and distal control of the parent arteries associated with supraclinoid aneurysms in preparation for possible aneurysm rupture during dissection or clip placement. It avoids using the standard sized craniotomy flap to minimize any unnecessary exposure of the cortical surface which can be damaged during the approach. It also minimizes potential space for fluid and blood collections to form in the subdural and epidural spaces.

It is important to recognize however, that this is a single-center, single surgeon, retrospective study with a relatively small sample size. Treatment was not randomized and this could be a potential for selection bias. We tried to minimize bias by matching the groups with only patients under 55 years of age; knowing that advanced age is a contraindication to clipping of an unruptured cerebral aneurysm.[3] However, due to limitations of the NIS, we could not control for important confounders such as aneurysm size and location, limiting the conclusions that can be drawn in our comparisons with the national average. The lower costs and shorter length of stay at our institution, in comparison to the national averages, can also be partially attributed to institutional resources. Centers handling a large volume of cases for aneurysm treatment likely have a dedicated staff and a standardized set of protocols. A prospective randomized multicenter trial that includes the cost of long-term follow-up, recurrence rates, and return to work will better address these limitations and expand the scope of the study.

Lastly, we emphasize that this technique is being reported for the surgical treatment of unruptured supraclinoid anterior circulation aneurysms measuring no larger than 20 mm. Larger or ruptured aneurysms, were not evaluated in this study because these aneurysms frequently require larger craniotomies for bypass and proper exposure and in the case of subarachnoid hemorrhage, larger craniotomies are required because of brain swelling, potential craniectomy, and access to lobar intraparenchymal hemorrhages. Though this exposure has been used in low Hunt-Hess grade subarachnoid hemorrhage patients with small and medium sized anterior circulation aneurysms in the locations described above, these data were not studied here and are not recommended until the surgeon has established a degree of comfort with surgical exposure first, with the unruptured aneurysms. The minimally invasive thumb-sized pterional craniotomy allows good exposure of small and medium-sized supraclinoid anterior circulation aneurysms. Additionally, minimal to no Sylvian Fissure dissection can be acquired with this craniotomy when approaching anterior communicating artery aneurysms. The senior author has found this approach to be very effective when approaching both ruptured and unruptured anterior communicating artery aneurysms, particularly those pointing inferiorly and anteriorly where the neck and inflow and outflow vessels could be readily identified. This thumb-sized craniotomy allows a subfrontal approach with minimal to no dissection of the Sylvian Fissure or resection of the Gyrus Rectus.

We recommend that neurosurgeons who do not routinely employ these surgical techniques, judiciously and progressively incorporate these minimally invasive and less tissue damaging maneuvers into their approach based upon comfort level. Cerebrospinal fluid drainage from key subarachnoid cisterns and constant bimanual microsurgical techniques avoid the need for retractors which can cause contusions, localized venous infarctions, and post-operative cerebral edema at the retractor sites. Utilizing this set of techniques has afforded our patients with a shorter hospital stay at a lower cost compared to the national average.

Disclosures

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