Minimally Invasive Microsurgery for Cerebral Aneurysms

Johnny Ho Yin Wong, PhD; Rachel Tymianski; Ivan Radovanovic, PhD; Michael Tymianski, MD, PhD

Intramural aneurysms arise in ≈2% of the population, and their rupture causes 3% of all strokes.1 Their treatment requires safely achieving complete aneurysm occlusion while preserving blood flow in the parent, branching, and perforating vessels. For decades, this task was achieved using classic open approaches, such as the pterional craniotomy (PTC) described by Yasargil and Fox in 1975, which afforded safe and effective exposure of the Circle of Willis through the Sylvian fissure with minimal retraction on the frontal and temporal lobes.2 Supported by the introduction of the operating microscope, this approach gained popularity for treating tumors and aneurysms of the anterior circulation and the basilar tip.3,4

However, the most significant advance in aneurysm treatment has been the advent of safe and effective endovascular techniques for the treatment of intracranial aneurysms, buoyed by clinical trials, such as International Subarachnoid Aneurysm Trial5 and Barrow Ruptured Aneurysm Trial (BRAT).6 Although both surgical and endovascular aneurysm occlusion technologies are effective for appropriately selected patients, endovascular treatment is also perceived to be less invasive as compared with classical open surgery. Indeed, technological developments in microsurgery, such as improved vascular imaging, intraoperative navigation, and fluorescence angiography,7 have focused on improving precision and effectiveness. However, more recently, the advent of endovascular techniques has spurred a shift of surgery to minimally invasive microsurgery (MIM) with keyhole or mini-craniotomies and the development of endoscope-assisted and purely endoscopic aneurysm surgery. These techniques are already well established in skull base neurosurgery, but are now being increasingly applied to aneurysm operations.

Classic Pterional Craniotomy

Aneurysm surgery requires exposure and adequate visualization of the circle of Willis at the skull base. Initially, surgeons used the frontolateral craniotomy as described by Dandy in 1938, involving extensive retraction of the frontal and temporal lobes to provide visualization of an aneurysm.9 With the advent of the improved illumination and magnification afforded by operating microscopes, Yasargil promoted the PTC involving less brain retraction but more bone removal of the sphenoid wing and dissection of the Sylvian fissure.2 This approach requires a long skin incision hidden behind the hairline, significant dissection and disruption of the temporalis muscle, and a craniotomy involving the frontal, squamous temporal, and greater wing of sphenoid bones with drilling of the sphenoid wing. The PTC gives access to the optic apparatus and the Circle of Willis once the Sylvian fissure is split.2,10 However, the extensive surgical manipulation and retraction of the temporalis muscle causes it delayed atrophy and scarring, producing facial asymmetry, discomfort with eyewear, and risks temporomandibular joint dysfunction, mastication pain, and injury to the frontal branch of the facial nerve.4 In addition, large areas of cerebral cortex are unnecessarily exposed. These factors contribute adversely to length of hospitalization and return to employment and activities of daily living.

Pterional Variations: Keyhole or Mini-Craniotomies

To address such drawbacks, several miniature versions, termed keyhole or mini-cranietomies, have been developed. These include supraorbital (SOC), lateral supraorbital (LSOC), mini-pterional (MPTC), and interhemispheric craniotomies (Figure 1). In essence, most are modeled on the PTC, but customize the opening location, trajectory, angle of approach, and extent of exposure to the exact position of the aneurysm, thereby minimizing unnecessary temporalis dissection and brain exposure (Table 1).

Supraorbital Craniotomy

The SOC was first described for aneurysms by Paladino et al and Van Lindert et al in 1998,11,12 An example is illustrated in Figure 2. It is a subfrontal approach to the anterior skull base giving access to both supratentorial and basilar aneurysms.13,15 It is performed either through an incision behind the hairline superficial to the temporalis fascia or an eyebrow

Received April 29, 2015; final revision received June 22, 2015; accepted June 25, 2015.

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Stroke. 2015;46:2699-2706. DOI: 10.1161/STROKEAHA.115.008221. © 2015 American Heart Association, Inc.

Stroke is available at http://stroke.ahajournals.org DOI: 10.1161/STROKEAHA.115.008221
or transciliary incision, preserving the supraorbital nerve and the nerve to frontalis. The craniotomy is as small as 25×15 mm, but gives an ample trajectory to the basal cisterns, lamina terminalis, and most midline and paramedian aneurysms. Specific risks include a frontal sinus breach with cerebrospinal fluid leakage and palsies of supraorbital and facial nerves with associated forehead numbness and weakness, respectively.

**Lateral Supraorbital Craniotomy**

Hernesniemi et al development the LSOC approach through which he performed thousands of operations for anterior circulation aneurysms and tumors of the anterior fossa and sellar regions. Compared with SOC, it is a more posteriorly located skull opening with a less subfrontal angle involving a comparatively shorter incision behind the hairline and minimal temporalis dissection. It is typically ≈3×3cm in size, much smaller than the PTC, but gives access to the Sylvian fissure, basal cisterns, lamina terminalis, and the circle of Willis.

**Mini-Pterional Craniotomy**

This approach was originally termed the sphenoid ridge keyhole craniotomy by Nathal et al, but Figueiredo et al later termed the technique mini-pterional. It involves an opening that essentially replicates the sphenoid-wing drilling of the PTC, but with a much reduced frontal and temporal bony opening and minimal disruption of the temporalis muscle, making some MPTCs as small as 2×1.5 cm. The skin incision is also short, similar to the LSCO. The MPTC provides access to the inferior frontal and superior temporal gyri, the Sylvian fissure dissection to the anterior ascendent ramus, and the aneurysms of the carotid and middle cerebral arteries. Limitations include restricted access to the distal Sylvian fissure, especially in the case of brain swelling or hemorrhage.

**Interhemispheric Craniotomy**

Fukushima et al described an anterior midline keyhole craniotomy for an interhemispheric approach in 1991 for aneurysms involving anterior cerebral artery (ACA), including anterior communicating artery (AComA) aneurysms. Although this is not a variation of the PTC, it may be suitable for high projecting AComA and distal ACA aneurysms.

**Feasibility and Appropriateness of Different MIM Approaches**

The main criticisms of MIM surgery have been concerns that limitations of exposure and freedom to manipulate instruments could compromise patient safety. To address this, Figueiredo et al used cadaveric specimens to quantify the area of surgical exposure and the angular exposure in both the MPTC and PTC. The area of surgical exposure consisted

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**Table 1. Comparison of Pterional and Mini-Craniotomy Approaches**

<table>
<thead>
<tr>
<th></th>
<th>Classic Pterional (PTC)</th>
<th>Supraorbital (SOC)</th>
<th>Lateral Supraorbital (LSOC)</th>
<th>Mini-Pterional (MPTC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin incision</td>
<td>Behind hairline: beginning at root of zygoma (&lt;1 cm from tragus) past midline</td>
<td>Eye-brow; or behind hairline: beginning at 2 cm above zygomatic arch and to midline</td>
<td>Behind hairline: beginning at 2 cm above zygomatic arch to midpupillary line</td>
<td>Behind hairline: beginning at 2 cm above zygomatic arch and midpupillary line</td>
</tr>
<tr>
<td>Temporalsis dissection</td>
<td>Interfacial; temporalis completely disconnected</td>
<td>Interfacial; minimal temporalis dissection anteriorly</td>
<td>Myocutaneous; temporalis incised superoanteriorly</td>
<td>Interfacial or myocutaneous; temporalis incised superoanteriorly</td>
</tr>
<tr>
<td>Craniotomy (location)</td>
<td>Frontal, pterion squamous temporal bones</td>
<td>Between supraorbital notch and frontozygomatic suture</td>
<td>Between lateral orbital rim, greater sphenoid wing, and superior temporal line</td>
<td>Superior temporal line, pterion, and squamous temporal</td>
</tr>
<tr>
<td>Craniotomy (size)</td>
<td>6×6 cm</td>
<td>2.5×1.5 cm</td>
<td>3×2.5 cm</td>
<td>4×3 cm</td>
</tr>
<tr>
<td>Craniotomy (sphenoid drilling)</td>
<td>To superior orbital fissure</td>
<td>Not required</td>
<td>Not required</td>
<td>To superior orbital fissure</td>
</tr>
<tr>
<td>Brain (cortical exposure)</td>
<td>Frontal, temporal lobes, and Sylvian fissure</td>
<td>Frontal pole and orbital gyri</td>
<td>Inferior frontal gyrus, edge of Sylvian fissure</td>
<td>Inferior frontal and superior temporal gyri, Sylvian fissure</td>
</tr>
<tr>
<td>Sylvian fissure opening</td>
<td>Yes</td>
<td>Optional</td>
<td>Optional</td>
<td>Yes</td>
</tr>
<tr>
<td>Surgical corridor</td>
<td>Multiple corridors</td>
<td>Subfrontal</td>
<td>Subfrontal</td>
<td>Trans-sylvian/lateral</td>
</tr>
<tr>
<td>Suitable aneurysms: well visualized</td>
<td>Ophthalmic ICA, PComA, AChoroidalA, terminal ICA, MCA, AComA</td>
<td>AComA, MCA, PComA</td>
<td>AComA, MCA, PComA, AChoroidalA</td>
<td>MCA, terminal ICA, ophthalmic ICA</td>
</tr>
</tbody>
</table>

AComA indicates anterior communicating artery; ICA, internal carotid artery; MCA, middle cerebral artery; and PComA, posterior communicating artery.
of the most distal points exposed along the sphenoidal ridge, middle cerebral artery (MCA) and posterior cerebral artery bilaterally, and represented the working space available under the microscope, whereas the maximum angular exposure was calculated for the ipsilateral internal carotid artery (ICA), MCA, and AcomA. Aneurysms of ACA and AComA may be more amenable to SOC. Additional factors considered in tailoring the approach are orientation and rupture status of the aneurysm, visualization of the proximal, distal, and perforating vessels, presence of brain swelling and hematoma, and surgeon comfort. The choice of incision location is up to both surgeon and patient.

Clinical Outcomes of Mini-Craniotomy Surgeries

Among the MIM variations, most experience over the past 20 years has been gained with the SOC. Aneurysms were located primarily in the MCA (29.2%–36.43%), AComA (23.0%–46.6%), and ICA and PComA (13.4%–27.7%). Early series focused on the feasibility of accessing a given aneurysm location through this approach, whereas subsequent reports compared clinical outcomes of patients with ruptured and unruptured aneurysms treated using the SOC as compared with PTC.

Functional outcomes were consistently comparable between SOC and PTC. Fischer et al reported their 20-year experience of 1297 aneurysm operations, in which SOC constituted 74.7%. Good outcome (mRS ≤ 2) was reported in 96.6% and 72.2% for unruptured and ruptured aneurysms, respectively. Similarly, Radovanovic et al reported a matched case–control series of 30 consecutive unruptured and 24 ruptured aneurysm cases treated with SOC and PTC. Good outcome (mRS ≤ 2) was achieved in all unruptured cases and 91.7% of SOC for ruptured cases, versus 86.9% of PTC. Comparable results were reported in studies of ruptured aneurysms by Chalouhi et al and Paladino et al, in which favorable outcomes (GOS ≥ 4) occurred in 76.6% to 82.6% of SOC and 75% to 79.5% of PTC cases.

Intraoperative rupture (IOR), a factor that may adversely impact functional outcome from aneurysm surgery, was analyzed in a systematic review of 9488 aneurysms treated by SOC and PTC over 15 years. Overall, IOR rate was 5.8% in SOC versus 10.1% in PTC, but among 3039 ruptured aneurysms, there was a statistically higher IOR rate of 19.4% in SOC versus PTC, and MPTC. All 3 craniotomies offered good visualization and potential for surgical manipulation of the specific arterial locations to which the approach was targeted. They noted that the views and maneuverability from all approaches were enhanced by adding an endoscope, particularly views of the contralateral structures. Kang et al compared the size and working angles with AComA, MCA bifurcation, and terminal ICA as targets in SOC and MPTC. Based on CT scans of 13 patients after aneurysm clipping, there was a significantly larger area of exposure and range of operating angles offered by MPTC than SOC, particularly for MCA bifurcation. SOC has a straighter trajectory to AComA, but has a greater distance to ICA terminus and MCA bifurcation than MPTC.

Overall, MPTC is most suited for aneurysms requiring a full Sylvian fissure split, for example, MCA, ICA bifurcation, and ophthalmic artery aneurysms. LSOC provides a narrower access to the Sylvian fissure and may be most suited to aneurysms of terminal ICA (posterior communicating artery [PComA], anterior choroidal artery), simple ACA, and AComA. Aneurysms of ACA and AComA may be more amenable to SOC. Additional factors considered in tailoring the approach are orientation and rupture status of the aneurysm, visualization of the proximal, distal, and perforating vessels, presence of brain swelling and hematoma, and surgeon comfort. The choice of incision location is up to both surgeon and patient.

13.8% in PTC (odds ratio 1.5, 95% confidence interval 1.003–2.119, \( P < 0.05 \)). In contrast, IOR rates for SOC were lower in ruptured aneurysms by Radovanovic et al (12.5%) and Chalouhi et al (10.6%), and no statistical difference was noted when compared with PTC in these more recent series.\(^2\)\(^6\)\(^4\)\(^5\)\(^6\) Caplan et al reported their experience of 82 unruptured aneurysms treated with the MPTC over 4.5 years, which included MCA (44%), PCom\(A\) (27%), and parafloccular artery (27%).\(^2\)\(^0\) Of these, 84.2% of aneurysms were clipped, 13.4% were wrapped with cotton and fibrin glue, and average length of stay was 4.0 days. Welling et al performed a randomized trial evaluating the clinical, functional, and aesthetic results between MPTC and PTC for ruptured and unruptured aneurysms.\(^2\)\(^8\) Between the 2 groups, similar mRS scores, mortality, IOR rates (14% for MPTC versus 17% PTC) were reported, but greater cosmetic satisfaction results (79% versus 52%, \( P = 0.07 \)) and significantly reduced degree of temporalis atrophy (14.9% versus 24.3%, \( P < 0.01 \)) were noted for MPTC.\(^2\)\(^8\)

Additional potential benefits of MIM may include reduced operative time, length of inpatient stay, and costs.\(^8\)\(^,\)\(^2\)\(^9\)\(^,\)\(^3\)\(^0\) Radovanovic et al noted that the duration of surgery using MIM was approximately half that of PTC for both ruptured and unruptured aneurysms, and for unruptured aneurysms, length of stay was reduced from an average of 4.3 to 2.3 days.\(^8\) This translated to significantly lower total treatment costs for unruptured aneurysms because of shorter length of stay. In fact, some patients within the unruptured cohort were treated on an ambulatory outpatient basis.\(^8\)\(^,\)\(^3\)\(^1\) Similar conclusions about reduced operating time and length of hospitalization were derived by Cha et al from a series of 61 patients in which LSOC was compared with PTC in cohorts having similar demographics and aneurysm locations.\(^2\)\(^9\) Thus, overall, MIM aneurysm surgery seems as safe and effective as PTC, but reduces temporalis atrophy, improves cosmesis, and saves on operating time, hospitalization, and costs.

A summary of the major papers reporting clinical outcomes is provided in Table 2.

### Endoscope-Assisted Aneurysm Surgery

Neuroendoscopy has increased in popularity with improved instrumentation. Its utility as an adjunct to microsurgical operations has been promoted by Pernecky and Fries.\(^3\)\(^2\)\(^3\)\(^3\) Modern neuroendoscopes provide excellent illumination in the depth of the surgical field, clear depiction of anatomic details, and extended viewing angles with the ability to see around corners, especially with angled lenses.\(^3\)\(^4\) Therefore, they may complement the standard operating microscope, which is restricted to illumination and magnification along a line of sight.\(^3\)\(^3\)

From a neuroanatomical perspective, the endoscope is ideal for visualizing aneurysms arising medially from the ICA, where

<table>
<thead>
<tr>
<th>Authors and Year</th>
<th>No. of Patients</th>
<th>No. of Unruptured Aneurysm, %</th>
<th>Intra-Operative Rupture Rate %</th>
<th>Length of Stay, Days</th>
<th>Good Outcome, %*</th>
<th>Peri-Operative Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supraorbital craniotomy (SOC)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paladino et al, 1998(^1)(^1)</td>
<td>37</td>
<td>NA</td>
<td>3%</td>
<td>NA</td>
<td>100%</td>
<td>1 infection</td>
</tr>
<tr>
<td>van Lindert et al, 1998(^2)(^3)</td>
<td>139</td>
<td>NA</td>
<td>3%</td>
<td>NA</td>
<td>NA</td>
<td>None</td>
</tr>
<tr>
<td>Czirják et al, 2001(^1)(^3)</td>
<td>102</td>
<td>22 (22%)</td>
<td>2.0%</td>
<td>NA</td>
<td>96%</td>
<td>1 PE</td>
</tr>
<tr>
<td>Mitchell et al, 2005(^4)</td>
<td>47</td>
<td>41 (87%)</td>
<td>4.3%</td>
<td>NA</td>
<td>96%</td>
<td>2 infarcts, 1 seizure, 3 postop hematomas</td>
</tr>
<tr>
<td>Reisch et al, 2005(^2)(^7)</td>
<td>229</td>
<td>117 (51%)</td>
<td>1.7%</td>
<td>NA</td>
<td>NA†</td>
<td>6 infarcts†</td>
</tr>
<tr>
<td>Chen et al, 2009(^2)(^5)</td>
<td>88</td>
<td>0 (0%)</td>
<td>26.1%</td>
<td>NA</td>
<td>89%</td>
<td>10 infections</td>
</tr>
<tr>
<td>Fischer et al, 2011(^1)(^5)</td>
<td>793</td>
<td>319 (40%)</td>
<td>7.7%</td>
<td>NA</td>
<td>97%/72%‡</td>
<td>19 residual aneurysms, 9 infections, 9 cerebrospinal fluid leaks, 14 postop hematomas</td>
</tr>
<tr>
<td>Chalouhi et al, 2013(^3)(^4)</td>
<td>47</td>
<td>0 (0%)</td>
<td>10.6%</td>
<td>NA</td>
<td>77%</td>
<td>1 post-op hematoma, 1 infection, 4 infarcts</td>
</tr>
<tr>
<td>Radovanovic et al, 2014(^4)</td>
<td>54</td>
<td>30 (56%)</td>
<td>0%/12.5%‡</td>
<td>2.1/18.2‡</td>
<td>100%/83%‡</td>
<td>2 CSF leak, 1 seizure, 1 anosmia, 1 infection</td>
</tr>
<tr>
<td><strong>Lateral supraorbital craniotomy (LSOC)</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Cha et al, 2012(^2)(^9)</td>
<td>61</td>
<td>61 (100%)</td>
<td>NA</td>
<td>7.9</td>
<td>NA</td>
<td>4 post-op hematoma</td>
</tr>
<tr>
<td>Mori et al, 2014(^3)</td>
<td>53</td>
<td>53 (100%)</td>
<td>NA</td>
<td>2.4</td>
<td>99%</td>
<td>1 MCA infarct</td>
</tr>
<tr>
<td><strong>Mini-pterional craniotomy (MPTC)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Caplan et al, 2014(^2)(^8)</td>
<td>72</td>
<td>72 (100%)</td>
<td>NA</td>
<td>3.96</td>
<td>NA</td>
<td>1 MCA infarct, 2 post-op hematomas</td>
</tr>
<tr>
<td>Welling et al, 2015(^2)(^8)</td>
<td>28</td>
<td>9 (32%)</td>
<td>NA</td>
<td>14</td>
<td>NA</td>
<td>86%</td>
</tr>
</tbody>
</table>

*Good outcomes defined as mRS ≤2 or GOS ≥4.
†Outcomes and complications specific for aneurysm surgery unavailable. GOS available for entire cohort, including other pathologies.
‡Denotes results separated for unruptured cohort and ruptured cohorts, respectively.
NA indicates not available.
the direct line of sight is obstructed by ICA or optic appara-
tus.\textsuperscript{35} Using 0\degree- and 45\degree-4 mm and 30\degree-2.7 mm endoscopes on
cadaveric specimens, Peris-Celda et al evaluated the additional
endoscopic exposure and available working room at common
aneurysm sites.\textsuperscript{35} Endoscope-assistance was useful for superior
hypophyseal, PComA, and anterior choroidal aneurysms and
may decrease the need for gyrus resect for resection for AComA
aneurysms. Improved visualization was observed in all anterior
circulation aneurysms, except MCA with angled endoscopes,
whereas the basilar apex benefitted from the smaller 2.7 mm
scope to permit larger working space for dissection.

The first report of endoscope-assisted aneurysm surgery was
by Fischer and Mustafa in 1994 using a flexible endoscope.\textsuperscript{36}
Subsequent clinical series have used a rigid neuro-endoscope
with 0\degree, 30\degree, 70\degree, and 110\degree view angles.\textsuperscript{33,34,37-40} In endoscope-
assisted craniotomies, the majority of the dissection and expo-
sure is performed with the operating microscope, regardless of
whether PTC or a mini-craniotomy is used. The endoscope has
3 applications during aneurysm surgery: inspection before clip-
ning, clipping under endoscopic view, and postclipping evalu-
ation.\textsuperscript{34} Use of the neuroendoscope before clipping permits a
greater appreciation of the regional anatomy, particularly of
structures obscured from direct microscopic view. This may
reduce unnecessary maneuvers to retract and dissect around
the aneurysm and may also reduce the duration of temporary clip-
ning. Clipping under endoscopic view requires a holding device
to allow bimanual manipulation during clipping and may only
be necessary if visualization of the aneurysm is limited with the
operating microscope. Post-clipping evaluation ensures that the
aneurysm is completely obliterated, and the perforating vessels
and surrounding neural structures are intact where the clip may
obstruct direct microscopic view.\textsuperscript{33,34}

Several case series have evaluated the usefulness of endos-
copy assistance for aneurysm surgery in association with
PTC.\textsuperscript{33,37,38,40} Greater anatomic clarification was identified with endoscopy in 81.5% to 94.9% of aneurysms, but inter-
estingly, information obtained exclusively through endoscopy
was found in only 16.7% to 19.0% of aneurysms.\textsuperscript{33,37} Clip
repositioning was required in 6.9% to 11.4% of aneurysms
because of incomplete neck obliteration, parent artery or per-
forator occlusion, and compression of surrounding neural
structures.\textsuperscript{33,37,38} Kalavakonda et al reported one IOR when the
endoscope was used without temporary occlusion and recom-
manded that close visualization of a ruptured aneurysm should
be performed only during temporary occlusion.\textsuperscript{37}

Endoscope-assisted aneurysm surgery has been applied to
the SOC.\textsuperscript{34,39} Fischer et al reported 180 aneurysms in which the endoscope was used before clipping (150 cases), during clip-
ing (4 cases), and after aneurysm clipping (130 cases).\textsuperscript{34} No adverse events related to endoscopy were observed. However, 38 aneurysms (21.1%) required clip rearrangement because of
incomplete aneurysm occlusion or neck remnant (15%) and par-
ent or branch vessel occlusion and perforator inclusion (6.1%).
The authors commented that without endoscopy, the incom-
plete clipping and perforator occlusion rates would have been
18.9% and 8.3%, respectively. A larger series of 989 ruptured
and unruptured aneurysms treated with endoscope-assisted
SOC was also presented by Reisch et al.\textsuperscript{39} Favorable outcome
scores (mRS\textless;2) for ruptured and unruptured aneurysm cohorts
were present in 72.2% and 96.6%, respectively. Suboptimal or
incorrect clip position was detected in 19.1% of aneurysms,
which were subsequently corrected.

There are some disadvantages associated with endoscope-assisted microsurgery. Using both the microscope and endo-
scope necessitates switching between the 2 modalities. The
introduction and withdrawal of the endoscope from the sur-
gical field should be monitored under microscopic vision.\textsuperscript{35} Decreased awareness of the endoscope may result in inad-
vertent movements causing contusions on the brain and, at
worst, rupture of the aneurysm if the endoscope is displaced
within close proximity. Maintaining endoscopic and micro-
scopic vision simultaneously requires incorporating the images
through picture-in-picture features on the microscope oculars or
endoscope monitors.\textsuperscript{37} Further limitations of neuroendoscopy
include the lack of stereoscopic 3-dimensional vision, which is
incomparable to the operating microscope, and the inability to
operate bimanually without a fixed endoscope holder.\textsuperscript{38}

Intraoperative angiography using indocyanine green (ICG) has
gained widespread acceptance to evaluate incomplete clip-
ning and occlusion of surrounding vessels. After injection
into a peripheral vein, ICG fluorescence is induced as the
dye circulates through the cerebral vessels under near-infrared
illumination and images are collected through an optical fil-
ter.\textsuperscript{41} Until recently, ICG angiography (ICG-A) was available
only with a microscope integrated with near-infrared camera
to capture ICG fluorescence. Therefore, ICG-A was affected
by the same line-of-sight problems inherent to the operating
microscope. Endoscopic ICG-A has now been developed by
Bruneau et al and Nishiyama et al, which combines the bene-
fits of endoscopy and ICG-A.\textsuperscript{41,42} Preliminary experience com-
paring microscopic with endoscopic ICG-A was published by
Mielke et al on a case series of 26 patients with 30 ruptured
and unruptured aneurysms.\textsuperscript{43} No adverse event relating to the
application of ICG or endoscopy was found, but several obser-
vations were made: (1) endoscopic detection of intra-arterial
fluorescence was 10 times longer than microscopic detection, thus
giving the opportunity to move the endoscope and view the
artery–aneurysm complex from multiple angles; (2) less con-
trast is required for endoscopic ICG-A. In 11 cases (42.3%),
additional information was provided by endoscopic ICG-A,
such as confirmation of neck remnants and flow in vessels
obscured on microscopic ICG-A. As this technology evolves,
endoscopy will become a more useful adjunct to improving
the safety of aneurysm surgery.\textsuperscript{41-43} A listing of the advantages and
disadvantages of endoscope-assisted aneurysm surgery is
provided in Table 3.

**Purely Endoscopic Aneurysm Surgery**

Purely endoscopic craniotomy for aneurysm clipping is still in
its infancy. Currently, few case reports exist using endoscopic
transcranial and endonasal approaches. Perneczky reported 7
aneurysms clipped with exclusive use of the endoscope through
a PTC opening.\textsuperscript{44} More recently, Radovanovic performed a
purely endoscopic aneurysm clipping through a 2\times2 cm crani-
otomy with no complications and good cosmetic result.\textsuperscript{45}

Endoscopic endonasal clipping of medially projecting
paraclinoid aneurysms have been published in sporadic case
Table 3. Advantages and Disadvantages of Endoscope-Assisted and Purely Endoscopic Aneurysm Surgery

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endoscope-assisted aneurysm surgery</td>
<td>Excellent illumination at depth of surgical field</td>
</tr>
<tr>
<td>Clear anatomic details and magnification</td>
<td>No line of sight restrictions</td>
</tr>
<tr>
<td>No line of sight restrictions</td>
<td>Ability to see around corners (with angled lenses)</td>
</tr>
<tr>
<td>Possibly greater maneuverability to adjust angles of vision</td>
<td>Inability to operate bimanually without a fixed endoscope holder</td>
</tr>
<tr>
<td>Useful for</td>
<td>Confirmation of clip placement, complete aneurysm obliteration, and parent/perforator artery patency</td>
</tr>
</tbody>
</table>

(i) Visualization of aneurysms obstructed by ICA or optic apparatus | (ii) Confirmation of clip placement, complete aneurysm obliteration, and parent/perforator artery patency |

Purely endoscopic aneurysm surgery | Advantages as per endoscope-assisted aneurysm surgery, plus | Disadvantages as per endoscope-assisted aneurysm surgery, plus: |
| No need for switching between microscope and endoscope | Purely endoscopic techniques still in infancy; learning curve required |
| May be used with endonasal or even smaller mini-craniotomy approaches | May avoid frontal lobe retraction, gyrus rectus resection for AComA aneurysms with endonasal approach | Narrow operating corridors restrict fine motor function at depth of surgical field |
| May avoid frontal lobe retraction, gyrus rectus resection for AComA aneurysms with endonasal approach | Lack of specifically designed endoscopic instruments for aneurysm clipping |

AComA indicates anterior communicating artery; ICA, internal carotid artery; and ICG, indocyanine green.

Advances in surgery focused on safety and efficacy, the goal of MIM surgery is to achieve those safety and efficacy goals while also maximizing patient comfort, cosmesis, and early resumption of previous activities. In the future, neuroendoscopy may further reduce invasiveness, eliminating long skin incisions and potentially the use of standard operating microscopes.

Acknowledgments
All authors contributed to the writing and illustration of the article. M. Tymianski is a Canada Research Chair (tier 1) in translational stroke research.

Sources of Funding
This article was funded by the aneurysm research fund, neurovascular therapeutics program, University Health Network. J. Wong was supported by the Royal Australasian College of Surgeons for the Stuart-Morson Travel Scholarship.

Disclosures
None.

References


**Key Words:** aneurysms ◼ craniotomy ◼ mini-pterional ◼ minimally invasive surgery ◼ supraorbital
Minimally Invasive Microsurgery for Cerebral Aneurysms
Johnny Ho Yin Wong, Rachel Tymianski, Ivan Radovanovic and Michael Tymianski

Stroke. 2015;46:2699-2706; originally published online July 30, 2015;
doi: 10.1161/STROKEAHA.115.008221
Stroke is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0039-2499. Online ISSN: 1524-4628

The online version of this article, along with updated information and services, is located on the
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