The pterional approach described by Yaşargil is perhaps the most often used neurosurgical approach, especially for lesions located in the anterior, middle, and posterior fossae. However, the pterional approach sometimes provides suboptimal exposure, particularly when dealing with pathologies that are deeply located, such as aneurysms of the ACoA complex. Consequently, sylvian fissure dissection and/or brain retraction are usually needed to improve exposure, thereby increasing the risk of surgical morbidity. Cranial base approaches were developed to overcome these difficulties and to improve the exposure of deeply located structures without causing significant brain retraction based on the premise of increased bone removal. However, these techniques are time-consuming and result in extensive, usually more-than-needed brain exposure. In contrast, minimally invasive or keyhole approaches (that is, supraorbital or transorbital craniotomies) proposed as an alternative to the pterional approach, especially for some anterior circulation aneurysms, were based on the provision of a tailored exposure through a minimal opening, obviating the need for retraction and unnecessary brain dissection. However, few morphometric data exist to support such benefits.

Therefore, in this cadaveric morphometric study, we systematically quantified and compared the operative exposures afforded by the pterional, supraorbital, and transorbital keyhole approaches to the perisellar region.

Abbreviations used in this paper: ACA = anterior cerebral artery; ACoA = anterior communicating artery.

Image-guided anatomical and morphometric study of supraorbital and transorbital minicraniotomies to the sellar and perisellar regions: comparison with standard techniques

Laboratory investigation

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Object. Minimally invasive approaches have been proposed for the treatment of anterior cranial base pathology. Whereas earlier studies have quantified surgical exposure by referring to the opening on the surface, this cadaveric morphometric study redefines the concept of working area by examining the deep exposures afforded by several different approaches. Specifically, the authors systematically quantify and compare the operative exposure afforded by the pterional, supraorbital, and transorbital keyhole approaches to the sellar, suprasellar, and perisellar regions, including the anterior communicating artery complex.

Methods. Pterional, supraorbital, and transorbital approaches were sequentially performed in 5 embalmed cadaveric heads on both sides. Preoperative and postoperative CT scans were obtained for frameless stereotactic navigation and measurements. Using reproducible anatomical landmarks, 6 triangles were defined to systematically measure the working area, depth of the surgical window, and angle of observation for each approach. Areas of the triangles were calculated using the Heron mathematical formula based on stereotactic navigation measurements. Ten sets of data were analyzed.

Results. The pterional, supraorbital, and transorbital keyhole approaches provided progressively increasing working areas. The transorbital approach was associated with significantly increased exposure when compared with the pterional approach (p < 0.01). The transorbital approach was associated with a shallower depth of the surgical window when compared with either the supraorbital (p < 0.05) or pterional (p < 0.01) approach. The angle of basal view increased 56.6% with the transorbital approach (p < 0.001) when compared with the supraorbital approach. The transorbital route provided greater exposure on deeply located midline and contralateral structures.

Conclusions. In refining the concept of working area as deep rather than superficial in the surgical field, the authors quantified the 6 triangles whose boundaries were relative to the target structures to be exposed in the approach. The authors’ morphometric findings support the use of the supraorbital and transorbital approaches as a valid alternative to the pterional approach for the treatment of sellar and perisellar pathology. The transorbital approach combines the advantages of minimal invasiveness with those of cranial base techniques. (DOI: 10.3171/2009.10.JNS09435)
Methods

The heads of 5 embalmed adult cadavers with no known brain pathology were prepared for bilateral dissections, yielding a total of 10 data sets. The arterial and venous systems of all specimens were injected under pressure with colored silicone rubber (Dow Corning) via the internal carotid and vertebral arteries, and the internal jugular veins, respectively. Dissections were performed macroscopically and then with magnification (× 3–40) using a Contraves microscope (Carl Zeiss Co.). A high-speed craniotome and drill (Midas Rex, L.P.) were used to cut and drill the bone.

Cranial fiducial markers were inserted in the cadavers using a standard protocol for frameless stereotactic study. The heads were then fixed in the Mayfield headholder (Integra Neurosciences); they were consistently, reproducibly rotated 45° to the contralateral side of the approach and tilted backward with the zygoma at the uppermost point. Navigation to predetermined landmarks was sequentially undertaken (described later in more detail) after performing the pterional, supraorbital, and transorbital approaches. Figure 1 depicts the anatomical landmarks selected for this study.

Surgical Technique

Initially, a pterional approach was performed on both sides of each specimen. The heads were removed from the Mayfield headrest, they underwent CT scanning using a frameless stereotaxy protocol, and then were replaced in the headrest. The dura was opened in a semicircular manner and reflected inferiorly with tack-up sutures. Stereotactic navigation to predefined points described in Table 1 and Fig. 1 was performed, and data were collected. Next, a supraorbital keyhole approach, as described by van Lindert et al.,37 was made; the size of the supraorbital craniotomy flap averaged 3.5 × 2 cm. The frontal dura mater was dissected off the anterior fossa, and the inner cortical layer of the orbital rim was drilled off to obtain better alignment with the orbital roof and facilitate the introduction of microinstruments. After extending the durotomy, a single brain retractor was placed subfrontally. Again, landmarks were identified and marked with titanium miniscrews, and measurements were made for later analysis. Finally, an orbital osteotomy was made by extending the medial edge of the supraorbital craniotomy into the orbit, staying immediately lateral to the supraorbital notch. A second cut was made (while retracting the globe) from within the orbit through the inferior orbital fissure, directing the drill parallel to the superior edge of the zygoma through the lateral wall of the orbit. The bony bridge in between these cuts was cut with a chisel at a distance no more than 3 cm posterior to the orbital rim, a distance proven to be safe for the neurovascular structures at the orbital apex.29 The incision of the dura mater was extended in a semicircular fashion with an inferior base. Tack-up sutures at the base of the dural flap were made to retract the globe and to achieve maximal exposure under the orbitofrontal cortex. A single brain retractor was placed subfrontally to visualize, under magnification, the sellar and perisellar regions. The ipsilateral internal carotid artery, ACoA complex, and optic nerves and chiasm were dissected and marked with titanium miniclips for later analysis.

To quantify the amount of cerebral retraction necessary to achieve adequate exposure of the sellar and perisellar regions, and to overcome the issue of a fixed brain, the same approaches were first performed using a fresh cadaver. The same amount of retraction necessary to safely expose the neurovascular structures and avoid brain damage in the fresh cadavers was used in the fixed brain of our specimens. The retractor was firmly secured during each procedure and when measurements were taken; this predefined retraction was confirmed by surgical experience and observations.

After all 3 approaches were performed, postoperative CT scans were obtained with a standard stereotactic protocol (3-mm slices, 0° angulation). Images were loaded into the BrainLAB VectorVision Navigation System for stereotactic navigation and measurement of the distances between pairs of specific target points.
Minicraniotomies in the sellar and perisellar region

The working area was defined relative to the target deep in the surgical field rather than the surgical window at the surface, which is solely relevant to the freedom of movement of the instruments. For each approach, the working area was defined as a sum of 6 triangles whose sides were the distances between pairs of anatomical landmarks (Fig. 1). The main target point at the center of the working area was the midpoint of the ACoA; 6 additional anatomical landmarks around the ACoA defined the triangles and represented the structures that are visualized via the 3 approaches. Of 6 points, 3 were fixed and did not vary with the approach; these included the lateral aspect of the optic foramen ipsilateral to the craniotomy, the medial aspect of the optic foramen contralateral to the craniotomy, and the ipsilateral carotid bifurcation (that is, the entire length of the ipsilateral A1 segment of the ACA). Therefore, 2 areas of the 6 triangles (Triangles GAF and HBA; refer to the legend to Fig. 1 for explanation of the lines) did not vary within the same specimen and on the same side. For this reason, their areas were not compared in the different approaches. The remaining 3 points varied according to the specific approach, including the exposure of the contralateral A1 segment of the ACA, and the exposure of the ipsi- and contralateral A2 segments of the ACA. These variable landmarks were marked with aneurysm clips.

The distances between pairs of these anatomical landmarks, which represented the sides of the triangles, were measured (VectorVision Navigation System, BrainLAB). Each of the 7 landmarks was selected as a primary target. The landmarks related to it, in defining a side of the triangle, were registered and selected as secondary targets to measure the relative distances. The areas of the triangles were calculated using the Heron mathematical formula (Fig. 2).

### Depth of Surgical Window

The depth of the surgical window was defined as the distance from the center of the working area, that is, the ACoA, to the operative surface as represented by the point of dural covering that ideally corresponded to the center of the craniotomy. Distances between points in all approaches were also measured using the VectorVision Navigation System. Because the center of the craniotomy can be a subjective landmark or not reproducible, we used an alternative method to calculate the depth of the surgical window. Specifically, we used the Heron formula to calculate the area of a triangle in an axial projection whose boundaries were the ACoA and the medial and lateral edges of the craniotomy; the height of this triangle, which represented the depth of the surgical window, was calculated from the area of the triangle using the Pythagoras formula (height = 2 x area/base of the triangle). When we compared the values representing the depth of the ACoA relative to the operative surface from these 2 methods of measurement, we found that the relative mean values were comparable and did not significantly differ (p < 0.05).

### Working Area

The working area was defined relative to the target deep in the surgical field rather than the surgical window at the surface, which is solely relevant to the freedom of movement of the instruments. For each approach, the working area was defined as a sum of 6 triangles whose sides were the distances between pairs of anatomical landmarks (Fig. 1). The main target point at the center of the working area was the midpoint of the ACoA; 6 additional anatomical landmarks around the ACoA defined the triangles and represented the structures that are visualized via the 3 approaches. Of 6 points, 3 were fixed and did not vary with the approach; these included the lateral aspect of the optic foramen ipsilateral to the craniotomy, the medial aspect of the optic foramen contralateral to the craniotomy, and the ipsilateral carotid bifurcation (that is, the entire length of the ipsilateral A1 segment of the ACA). Therefore, 2 areas of the 6 triangles (Triangles GAF and HBA; refer to the legend to Fig. 1 for explanation of the lines) did not vary within the same specimen and on the same side. For this reason, their areas were not compared in the different approaches. The remaining 3 points varied according to the specific approach, including the exposure of the contralateral A1 segment of the ACA, and the exposure of the ipsi- and contralateral A2 segments of the ACA. These variable landmarks were marked with aneurysm clips.

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### Comparison of Working Areas

<table>
<thead>
<tr>
<th>Comparison of Areas</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>between pterional &amp; supraorbital area (mm²)</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>425.73 ± 85.85</td>
</tr>
<tr>
<td>Triangle ICB</td>
<td>66.48 ± 24.59</td>
</tr>
<tr>
<td>Triangle JDC</td>
<td>24.86 ± 13.26</td>
</tr>
<tr>
<td>Triangle KED</td>
<td>33.71 ± 18.41</td>
</tr>
<tr>
<td>Triangle LFE</td>
<td>61.23 ± 21.02</td>
</tr>
<tr>
<td>between supra- &amp; transorbital area (mm²)</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>460.24 ± 160.19</td>
</tr>
<tr>
<td>Triangle ICB</td>
<td>64.73 ± 24.93</td>
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<tr>
<td>Triangle JDC</td>
<td>18.45 ± 7.58</td>
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<tr>
<td>Triangle KED</td>
<td>40.22 ± 22.74</td>
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<tr>
<td>Triangle LFE</td>
<td>97.39 ± 30.11</td>
</tr>
<tr>
<td>between pterional &amp; transorbital area (mm²)</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>425.73 ± 85.85</td>
</tr>
<tr>
<td>Triangle ICB</td>
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</tr>
</tbody>
</table>

* Values are reported as the mean ± SD. See the legend to Fig. 1 for the definitions of the triangles. Abbreviation: NA = not applicable.
† Significant difference.
Angle of Observation

For each approach, the angle of observation was translated into 2 parameters: the angle of basal view and operative view.

Basal View: The basal view was defined as the angle of observation relative to the ACoA in the coronal and sagittal planes. In the cadaveric dissections, we compared the basal view provided by the supraorbital and pterional approaches, which share the same inferior bony boundary, with the view provided by the transorbital approach. The basal view was translated into the angle at the vertex of a triangle in a sagittal projection whose sides were the following: the distance from the ACoA to the superior edge of the craniotomy, the distance from the ACoA to the inferior edge of the osteotomy, and the distance from the superior to inferior edges of the osteotomy. The inferior edge of the approach in the transorbital route was represented by the superior aspect of the globe. Given the sides of the triangle, the angles could be calculated using the Carnot theorem. This states that the signed sum of the perpendicular distances from the circumcenter of a triangle to the 3 sides is equal to the sum of the circumradius and the inradius of the triangle; therefore, \( OMa + OMb + OMc = R + r \), where \( O \) represents the circumcenter; \( M \), the midpoint of the segment; \( R \), the circumradius; and \( r \), the inradius. We directly compared the angle at the vertex in the supra- and transorbital approaches where the superior edge of the craniotomy was shared, and the inferior edge varied after removal of the orbital rim.

Operative View: The operative view is a 3D space represented by the measurements and structures visualized, and by the visual perspective of the surgical field. As this 3D representation of the surgical view could not be measured, it was interpreted by surgical pictures, sketches, and artistic renderings.

Statistical Analysis

Data were loaded into a computer program (Microsoft Excel, Microsoft Corp.). Statistical comparisons were performed using the Student t-test to extract significance in individual comparisons (p < 0.05).

Results

Working Area

Considering the working area as the sum of 6 triangles, the area provided by the supraorbital approach (460.24 ± 160.19 mm²) was greater than that of the pterional approach (425.73 ± 85.85 mm²; p = 0.55), but less than that of the transorbital approach (568.78 ± 70.09 mm²; p = 0.0766). The working area of the transorbital approach was significantly greater than that of the area of the pterional approach (568.78 ± 70.09 mm² vs 425.73 ± 85.85 mm²; p = 0.0006). Comparisons between the individual triangles of the pterional, supraorbital, and transorbital keyhole approaches, along with their statistical significances, are summarized in Table 1.

Depth of Surgical Window

The depth of the ACoA relative to the operative sur-

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view. Using the midpoint of the ACoA as the main target, we noted that the working area (that is, the area deep in the field where the target lesion lies) was largest for the transorbital keyhole compared with either the supraorbital (p < 0.07) or pterional (p < 0.0006) craniotomy.

In this analysis, we have redefined the concept of working area as deep within the surgical field where the surgical target lies. Previous studies have referred to the “working area,” which we prefer to call the “surgical window,” that is, the opening on the surface.4,30 Quantification of the working area deep in the surgical field where the target structures are located was defined by 6 triangles whose boundaries were the deep structures to be exposed in the approach. In using this sum to represent the working area, we found that the pterional, supraorbital, and transorbital keyhole approaches provided a progressively increasing working area. The working area of the transorbital approach was larger than that of the supraorbital approach (p < 0.07) and statistically significantly larger than that of the pterional approach (p < 0.001). Our findings contrast with those of Figueiredo et al.,10 who showed no significant difference in the total areas of surgical exposure between the pterional, orbitozygomatic, and minisupraorbital approaches. However, their methodology differed from ours; the 6 points they selected to measure the area of surgical exposure did not represent the anatomical structures usually exposed for ACoA complex lesions. Additionally, as no comparisons were made to assess the individual triangles of each approach, this likely contributed to their interpretation of the role of each technique for exposure of the different structures. When considering the individual triangles in our study and comparing the pterional and supraorbital approaches, we found that

Fig. 3. Neuroimages demonstrating measurement points for triangular areas selected for comparison of approaches. ACoA = ACoA. Reprinted from Neurosurgical Approaches: A Dissection Guide for Residents, Mayfield Clinic, Cincinnati, OH, 2007, with permission from the Mayfield Clinic.

Fig. 4. Comparison of the minicraniotomy opening (upper), angle of view to surgical target (center), and cadaveric dissection (lower) for the pterional (A), supraorbital (B), and transorbital (C) craniotomies depicting operative views afforded by each. Reprinted from Neurosurgical Approaches: A Dissection Guide for Residents, Mayfield Clinic, Cincinnati, OH, 2007, with permission from the Mayfield Clinic.
Triangle LFE (formed by the ACoA, the medial aspect of the contralateral optic foramen, and the contralateral A1 segment) was significantly larger in the supraorbital approach. Because the contralateral A1 segment is the only variable landmark in this triangle, we can conclude that the supraorbital approach increases exposure of the contralateral A1, which is of utmost importance when dealing with ACoA aneurysms. In comparing the relative areas for the remaining variable triangles between the 2 approaches, we found no significant differences. When comparing the individual triangles in the supraorbital and transorbital surgical exposures, 3 triangles were significantly greater in the transorbital keyhole: 1) Triangle ICB (defined by the ACoA, ipsilateral carotid bifurcation, and ipsilateral A2 segment); 2) Triangle JDC (defined by the ACoA and ipsi- and contralateral A2 segments); and 3) Triangle KED (defined by the ACoA and contralateral A1 and A2 segments). We concluded that the transorbital route provides better exposure of both A1 segments, which thus improves the exposure of structures located in the interhemispheric fissure for greater anterior observation of the ACoA complex. Finally, when considering the individual triangles and comparing the pterional versus transorbital keyhole approaches, the areas of all variable triangles (Triangles ICB, JDC, KED, and LFE) were significantly greater in the transorbital exposure.

The angle of basal view refers to the increase in inferior projection of the inferior boundary of the craniotomy in the sagittal and coronal planes. Since the supraorbital and pterional approaches share the same inferior boundary, this measurement is only relative to the addition of an orbitotomy. As expected, the angle of basal view increased by 11 ± 3°, or 56.6%, with removal of the orbital rim, a finding similar to that previously reported by us and others.\(^{1,2,4,10,11,14}\)

The aggregate of these arbitrarily selected parameters was summarized in a more "gestaltic" concept, that is, the operative view, which is the final view and vector of attack afforded by each approach. In a sequence starting with the pterional approach, followed by the supraorbital craniotomy, and ending in the transorbital craniotomy, we found that the operative view results in anterior translation of the field, with an increasing widening of a rhomboidal field, as seen with the pterional approach, into a rather pentagonal field as seen with the transorbital approach, which has the widest field. Figure 4 depicts this anterior-mesial translation, which results in a more superficial, wider working space, with better visualization of the vessels contralateral to the side of the approach.

Limitations of the Study

Our study was performed using chemically fixed cadaveric heads, whose material properties differ from those of brain in vivo, a fact that may affect the applicability of the results to surgical situations. In attempting to standardize brain retraction for minimal tissue injury yet adequate exposure, we first performed the 3 approaches on a fresh cadaver and measured the amount of brain elevation necessary for the exposure, based on surgical experience. To safely dissect the neurovascular structures and avoid brain damage in all 3 approaches, elevation of the frontal lobe ranging from 1.5 to 2 cm was sufficient, whereas 1 cm of retraction of the temporal lobe was necessary in the pterional approach. Our findings are within the range of those of Cardali et al.\(^4\) who, in a study of olfaction preservation, found that elevation of the frontal lobe limited to 1.5 cm resulted in low rate of postoperative deficits in patients who underwent the pterional approach.

Our study provides systematic measurements of the working areas, surgical window depth, and observation angle of the pterional, supraorbital, and transorbital keyhole exposures. When using the mid-ACoA as the main target, we noted the transorbital keyhole craniotomy afforded the best visualization of the entire ACoA complex when compared with the supraorbital and pterional approaches. Our laboratory findings corroborate our recent report of 8 patients who underwent a transorbital keyhole craniotomy through an eyelid incision.\(^5\) The readers are warned, however, that patient selection for the supra- and transorbit approaches should be based on clinical judgment and experience, which will come only with thorough knowledge of the classic standard, that is, the pterional approach. Our work may provide tangible measures to support a rationale when an alternative approach may overcome the shortcomings of the pterional approach.

Conclusions

Our morphometric data support the supraorbital and transorbital approaches as valuable alternatives to the pterional approach for the treatment of ACoA aneurysms. Superior exposure can be achieved by minimally invasive techniques. The transorbital keyhole approach seems to reconcile the tenets of minimally invasive and cranial base surgery, that is, maximal exposure, minimal brain retraction, and minimal access.

Disclaimer

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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