Localization of the Internal Maxillary Artery for Extracranial-to-Intracranial Bypass through the Middle Cranial Fossa: A Cadaveric Study*

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Abstract

The internal maxillary artery (IMAX) is a promising arterial pedicle to function as a donor vessel for extracranial-to-intracranial (EC-IC) bypass procedures. The access to the IMAX through the anterior portion of the middle cranial fossa floor allows a much shorter interposition graft to be used to create a bypass to the ipsilateral middle cerebral artery and prevents a second incision in the neck. One of the challenges of this technique, however, is the difficulty to find the IMAX through an intracranial approach. The purpose of this cadaveric study is to establish a reliable method to localize the IMAX through a middle fossa floor approach based on skull base bone landmarks. In this study 5 latex-injected fixated cadaveric specimens were dissected bilaterally (providing a total of 10 IMAX dissections) to determine the precise location of the IMAX in the pterygopalatine fossa in relationship to bone landmarks of the middle fossa floor as seen through an intracranial approach. Drilling of the middle fossa floor was undertaken through both the originally described “anteromedial” approach, and a new “anterolateral” approach. Measurements were taken correlating the position of the IMAX to ipsilateral foramen rotundum, ipsilateral foramen ovale, posterior wall of the maxillary sinus, and distal V2 branches. Median and standard deviation were calculated for each dataset. The IMAX was found, within the pterygopalatine fossa, by drilling the greater wing of the sphenoid bone on average 10 mm anteriorly and 5 mm laterally to foramen rotundum, at an average depth of 8 mm. The IMAX was also found inferiorly to the maxillary nerve and laterally to the pterygoid head of the lateral pterygoid muscle. A more laterally oriented approach, consisting of drilling the greater wing of the sphenoid bone from a point perpendicular to foramen rotundum posteriorly to the sphenotemporal suture anteriorly, allowed for a longer segment of the IMAX to be easily identified and exposed facilitating its use as a donor vessel in bypass procedures. This cadaveric study provides a reliable and reproducible set of measurements to localize the IMAX within the pterygopalatine fossa through an intracranial middle fossa approach. The ability to find the IMAX consistently is an important step in exploring the possibility of using the IMAX as a routine donor vessel for EC-IC bypass procedures.

Keywords

- internal maxillary artery
- extracranial-to-intracranial bypass
- middle fossa approach
- anatomy

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High flow extracranial-to-intracranial (EC-IC) bypass procedures are often needed when treating large, complex internal carotid artery (ICA) aneurysms that require carotid artery ligation or trapping. Similarly, large skull base tumors may require sacrifice of the carotid artery or its main branches for complete tumor resection and, therefore, a bypass procedure becomes mandatory in these cases. The standard high flow EC-IC bypass involves exposing the common carotid artery (CCA) or external carotid artery (ECA) in the neck to serve as the donor vessel and anastomosing it to the ICA or one of its main branches intracranially using an interposition graft (either radial artery graft [RAG] or saphenous vein graft). This requires a cervical incision and tunneling of a long interposition graft from the neck to the intracranial space with potential for technical complications.

Abdulrauf et al¹ have recently published a case report of a high flow EC-IC bypass using the internal maxillary artery (IMAX) as the donor vessel and connecting it to the proximal middle cerebral artery (MCA) by means of a RAG through a single craniotomy incision. This technique has many potential advantages over standard high flow bypass procedures. It obviates the need for a second incision in the neck, tunneling of an interposition graft, and sacrifice of an external carotid system which may provide critical retrograde flow. The IMAX, RAG, and MCA are closely matched in caliber improving the ease of anastomosis construction. Finally, the EC-IC bypass procedure can be performed through a single intracranial approach, utilizing a significantly shorter graft which decreases the likelihood of graft torsion and may lead to improved long-term patency rates. The main criticisms raised about this technique were regarding the perceived difficulties in finding the IMAX through a middle fossa intracranial approach and in performing the anastomosis between the IMAX and the graft vessel (either radial artery or saphenous vein) considering the small space available and the short loop of the IMAX exposed through this approach.

To address these potential shortcomings, we performed a cadaveric study to identify the relationship of the IMAX to the bone landmarks of the middle cranial fossa floor and structures within the pterygopalatine fossa. The goal of this study was to determine a reliable and reproducible technique to expose the IMAX for EC-IC bypass.

Materials and Methods

In this study, five latex-injected, fixated cadaveric specimens underwent bilateral extradural middle fossa approaches (providing a total of 10 data points) to determine the precise location of the pterygopalatine IMAX in relationship to bone landmarks of the middle fossa floor as seen through an intracranial approach. Two separate drilling techniques were employed to locate the IMAX, the first was the “anteromedial” approach as described by Abdulrauf et al¹ where the anatomic specimens were placed supine, with the head turned 15 degrees to the contralateral side and flexed 30 degrees to allow access to the anteromedial aspect of the middle fossa floor. Initial drilling of the middle fossa floor began anteriorly and laterally to the foramen rotundum. The

second technique was a new “anterolateral” approach where the anatomic specimens were placed in the lateral position with the head turned 60 degrees to the contralateral side and vertex tilted upward ~15 degrees. Drilling of the greater wing of the sphenoid bone proceeded down to the infratemporal crest from a lateral to medial direction until the IMAX was identified. Measurements were taken correlating the position of the IMAX to the ipsilateral foramen rotundum, ipsilateral foramen ovale, posterior wall of the maxillary sinus, and distal V2 branches. All the measurements were performed three times by the same author and the average of three measurements adopted for each data point. Final data are presented as mean $\pm$ standard deviation for each data point.

Results

The “anteromedial” approach reliably found the loop of the IMAX in the pterygopalatine fossa by drilling the greater wing of the sphenoid bone in the anteromedial aspect of the floor of the middle fossa. The starting point for drilling was located on average $9.3 \text{ mm} \pm 2.3 \text{ mm}$ anteriorly and $5 \text{ mm} \pm 0.9 \text{ mm}$ laterally to the lateral edge of the foramen rotundum (**Fig. 1A, 1B**). Upon dissecting the soft tissues of the pterygopalatine fossa, the IMAX was encountered at an average depth of $6.3 \text{ mm} \pm 2.6 \text{ mm}$ from the middle fossa floor (**Table 1**). The loop of the IMAX was invariably found inferiorly to the maxillary nerve and surrounded by fat tissue. However, in the majority of cases only a small length of the artery was visible and it had to be “pulled up” out of the pterygopalatine fossa into the middle cranial fossa before an anastomosis could be entertained (**Fig. 2**).

Using the “anterolateral” approach, a larger expanded area of drilling in the greater wing of the sphenoid bone was taken. Following an extradural exposure of the middle fossa, the floor of the middle fossa (greater wing of the sphenoid bone) was drilled from the sphenoid-zygomatic suture anteriorly to a point intersected by an imaginary line drawn perpendicularly to the foramen rotundum posteriorly (**Fig. 3**). The total drilling measured 15 mm in the anterior to posterior direction, 15 mm in the lateral to medial direction, and extended inferiorly to the infratemporal crest. The fibers of the infratemporal head of the lateral pterygoid muscle and the surrounding adipose tissue were then dissected until the IMAX was visualized within the pterygopalatine fossa. A larger segment of the IMAX was consistently found with ample room to perform an EC-IC bypass (**Fig. 4**).

Discussion

Yasargil et al² performed the first EC-IC bypass procedure, anastomosing the superficial temporal artery to the middle cerebral artery (STA-MCA bypass). Further developments in this field include the first high flow common carotid to intracranial internal carotid bypass using a saphenous vein graft by Loughheed et al,³ the use of RAGs popularized by Sekhar et al,⁴ the use of the occipital artery or the middle meningeal artery as donor vessels by Spetzler et al,^{5,6} and the first petrous internal carotid to supraclinoid internal carotid

Figure 1 Cadaveric dissection showing measurements taken anteriorly (A) and laterally (B) from foramen rotundum to determine place of drilling in the anteromedial middle fossa floor to expose the internal maxillary artery (IMAX).

by Sekhar et al.^{7,8} EC-IC bypass surgery has become an important tool in the modern neurosurgical armamentarium, with a defined role in the treatment of complex, giant aneurysms or large skull base tumors where carotid ligation is needed.

The standard high flow bypass procedure encompasses several steps, including craniotomy and exposure of the intracranial recipient vessel, cervical incision and exposure of the extracranial donor vessel (either CCA or ECA), and the tunneling of a suitable graft (most likely either radial artery or saphenous vein) between these two sites. Such steps add to the complexity of the operation and potential for technical complications, such as graft torsion or occlusion related to tunneling from the neck to the intracranial site.

The idea of using the IMAX as the donor artery for a high flow EC-IC bypass has been previously proposed by other

authors, including Vrionis et al.⁹ and Ustün et al.¹⁰ It has many potential advantages over the standard high flow bypass technique, such as the closer proximity between donor and recipient vessels (which allows a much shorter graft with likely longer graft patency), the ability to perform an EC-IC bypass through a single craniotomy incision, with avoidance of cervical incisions and need for tunneling the graft, improved ease of anastomosis construction using vessels of similar caliber (IMAX-RAG-MCA), and the possibility of making this procedure technically simpler to perform.

More recently, Abdulrauf et al have published the first case report describing an actual IMAX to MCA bypass with a RAG followed by carotid artery ligation for treatment of a giant cavernous and supraclinoid carotid aneurysm.¹ One of the main criticisms of the technique, however, was the apparent difficulty in isolating a suitable segment of the IMAX within the pterygopalatine fossa through an intracranial approach to

Table 1 Cadaveric Dissection Measurements

Cadaver Specimens	Anterior to Edge of Rotundum (mm)	Lateral to Edge of Rotundum (mm)	Depth of Drilling (mm)
1	8	5	3
2	10	3	4
3	8	5	5
4	15	5	11
5	10	5	8
6	10	5	10
7	7	5	5
8	8	7	5
9	10	5	7
10	7	5	5
Mean	9.3	5	6.3
Standard deviation	2.35	0.94	2.63

Figure 2 Cadaveric dissection showing the window drilled in the anteromedial middle fossa floor with the head turned about 15 degrees to the contralateral side and slightly flexed. Note the small extent of the internal maxillary artery (IMAX) exposed through this anterior-middle fossa approach and the need to “pull it out” of the pterygopalatine fossa into the middle cranial fossa to perform an anastomosis.

perform the anastomosis. We, therefore, decided to pursue the present cadaveric study in an effort to better elucidate the technique of exposing the IMAX through the middle fossa, hoping to address this problem and make the technique more accessible.

The IMAX is the larger of the two terminal branches of the ECA. It arises posterior to the neck of the mandible and travels anteriorly, either medial or lateral to the lateral pterygoid muscle, which divides the IMAX in three main segments.¹¹ The first, or mandibular segment, is located posterior to the neck of the mandible and gives off several branches, among them the middle meningeal artery to the dura mater and calvarium and the inferior alveolar artery to the mandible, gingivae, and teeth. The second, or pterygoid segment of the IMAX, travels in the infratemporal fossa up to the pterygo-maxillary fissure and supplies the masticatory muscles, including the temporalis muscle by means of its anterior and posterior deep temporal branches. Once the IMAX crosses the pterygomaxillary fissure, it enters the pterygopalatine fossa where its third, or pterygopalatine, segment divides in its terminal branches, including the sphenopalatine artery, which supplies the lateral nasal wall and the nasal septum, the descending palatine artery, which supplies the maxillary gingivae and the roof of the mouth, and the infraorbital artery, which supplies the inferior eyelid, the lacrimal sac, the side of the nose, and the superior lip.¹²

In its third, or pterygopalatine segment, the IMAX is located slightly inferior to the maxillary nerve and anterior to the pterygopalatine ganglion. It lies over the posterior wall of the maxillary sinus and it forms a loop within the pterygopalatine fossa, which can be well visualized in lateral views of external carotid angiograms.¹³ It is the third segment of the IMAX, within the pterygopalatine fossa, that we aim to

Figure 3 Cadaveric dissection showing the anterolateral middle fossa approach to the internal maxillary artery (IMAX). A wider drilling of the greater wing of the sphenoid bone was carried out all way down to the infratemporal crest and extending from the sphenoid-zygomatic suture anteriorly to a point crossed by an imaginary line drawn perpendicularly to foramen rotundum posteriorly.

Figure 4 Artistic graphic representation of the anteromedial and anterolateral approaches to the internal maxillary artery (IMAX) depicting the extent of middle fossa drilling and IMAX exposure.

identify and isolate through an intracranial approach to use as a donor site for EC-IC bypasses.

Our cadaveric dissections have shown that access to the pterygopalatine fossa can be easily achieved from an intracranial approach by drilling the anterolateral wall of the middle fossa, specifically the greater wing of the sphenoid bone, all the way down to the infratemporal crest. Our initial technique, the “anteromedial approach” resulted in a relatively small opening into the pterygopalatine fossa. The IMAX had to be dissected free from surrounding tissues and “pulled” into the middle fossa, before having a segment isolated with temporary aneurysm clips for the actual end-to-side anastomosis to be performed (►Fig. 2).

This technique, albeit already used successfully in a clinical setting,¹ has some clear disadvantages. First, the opening into the pterygopalatine fossa is very small, making it fairly difficult to dissect and isolate a suitable piece of the IMAX for the anastomosis. Second, the multiple branches and depth of the IMAX in the pterygopalatine fossa may lead to kinking of the vessel during its retrieval into the middle fossa and potentially prevent adequate blood flow through the IMAX, therefore rendering the pedicle useless. Therefore, we devised a simple modification of the original technique, called the “anterolateral” approach to the pterygopalatine fossa. The initial positioning is similar to the standard middle fossa approach with the head turned almost to the horizontal. A

slight upward tilt of the vertex provides a more direct view of the greater wing of the sphenoid bone. This new positioning creates a shallower angle than that provided by the “anteromedial” approach (►Fig. 5). Extended drilling of the greater

Figure 5 Cadaveric dissection showing a much longer segment of the internal maxillary artery (IMAX) exposed within the pterygopalatine fossa through an anterolateral middle fossa approach. A much shallower angle also allows for easier end-to-side anastomosis between an interposition graft and the IMAX.

Figure 6 Intraoperative color picture demonstrating adequate segment of the IMAX exposed within the pterygopalatine fossa through an anterolateral middle fossa approach in preparation for a bypass procedure.

wing of the sphenoid bone provides a larger area of exposure into the pterygopalatine fossa and easier dissection of the IMAX. This exposes a longer segment of the vessel available for an end-to-side anastomosis, (► **Figs. 4 and 6**), assures preservation of distal V2 branches, and avoids the need to pull the IMAX into the middle fossa, preventing potential kinking of the vessel. The major drawback of this more lateral positioning is an increased difficulty in opening the Sylvian fissure and exposing the proximal ICA. However, this can be easily overcome through rotation of the operating table during this portion of the procedure.

Conclusion

The technique of using the IMAX as a donor vessel for high flow EC-IC bypass procedures is an appealing alternative to standard high flow bypasses. We believe that the lateral middle fossa approach to the IMAX, as described in this article, provides a reliable and reproducible method to consistently find and isolate a suitable segment of the IMAX for the purpose of performing an EC-IC bypass. This technique is an example of how specific skull base approaches may

facilitate the execution of complex vascular procedures, such as EC-IC bypasses. Further studies are needed to determine whether the IMAX bypass will have a higher long-term patency rate than standard bypasses from the cervical ECA or CCA.

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