# Minimally Invasive Bilateral Anterior Cingulotomy via Open Minicraniotomy Using a Novel Multiport Cisternoscope: A Cadaveric Demonstration

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**BACKGROUND:** Bilateral anterior cingulotomy has been used to treat chronic pain, obsessive compulsive disorder, and addictions. Lesioning of the target area is typically performed using bilateral stereotactic electrode placement and target ablation, which involves transparenchymal access through both hemispheres.

**OBJECTIVE:** To evaluate an endoscopic direct-vision lesioning using a unilateral parasagittal minicraniotomy for minimally invasive bilateral anterior cingulotomy using a novel multiport endoscope through the anterior interhemispheric fissure.

**METHODS:** A novel multiport magnetic resonance imaging (MRI)-compatible neuroendoscope prototype is used to demonstrate cadaveric cingulate lesioning through a lateral imaging port while simultaneously viewing the pericallosal arteries as landmarks through a tip imaging port. The lateral port enables extended lesioning of the gyrus while rotation of the endoscope about its axis provides access to homologous areas of both hemispheres.

**RESULTS:** Cadaver testing confirmed the capability to navigate the multiport neuroendoscope between the hemispheres using concurrent imaging from the tip and lateral ports. The lateral port enabled exploration of the gyrus, visualization of lesioning, and subsequent inspection of lesions. Tip-port imaging provided navigational cues and allowed the operator to ensure that the endoscope tip did not contact tissue. The multiport design required instrument rotation in the coronal plane of only 20° to lesion both gyri, while a standard endoscope necessitated a rotation of 54°.

**CONCLUSION:** Multiport MRI-compatible endoscopy can be effectively used in cisternal endoscopy, whereby a unilateral parasagittal minicraniotomy can be used for endoscopic interhemispheric bilateral anterior cingulotomy.

**KEY WORDS:** Anterior interhemispheric approach, Bilateral cingulotomy, Cisternoscopy, Minimally invasive neurosurgery, MRI-compatible, Multiport neuroendoscope, Neuropsychiatry

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Manjila et al[1] demonstrated the successful use of an MRI-compatible potentially disposable neuroendoscope for ventricular procedures; however, a cisternal application for this dual port endoscope has not been described. Given the recent resurgence of clinical interest in anterior cingulotomies, cingulate stimulations, and direct subdural electrode monitoring, we have chosen bilateral endoscopic mini-open anterior cingulotomy as a prototype for cisternal application. The anterior cingulate cortex (ACC) has been a focus of interest in many psychiatric conditions and even magnetic resonance imaging (MRI)-guided cingulotomies were used in selected indications. Cingulotomy has been traditionally performed through transparenchymal stereotaxy. While the ongoing development of modern psychiatric medications has reduced the need for surgical interventions, surgery continues to provide relief to patients who are unresponsive to medical

**ABBREVIATIONS: ACC,** anterior cingulate cortex; **EM,** electromagnetic; **MR,** magnetic resonance; **MRI,** magnetic resonance imaging; **SSS,** superior sagittal sinus

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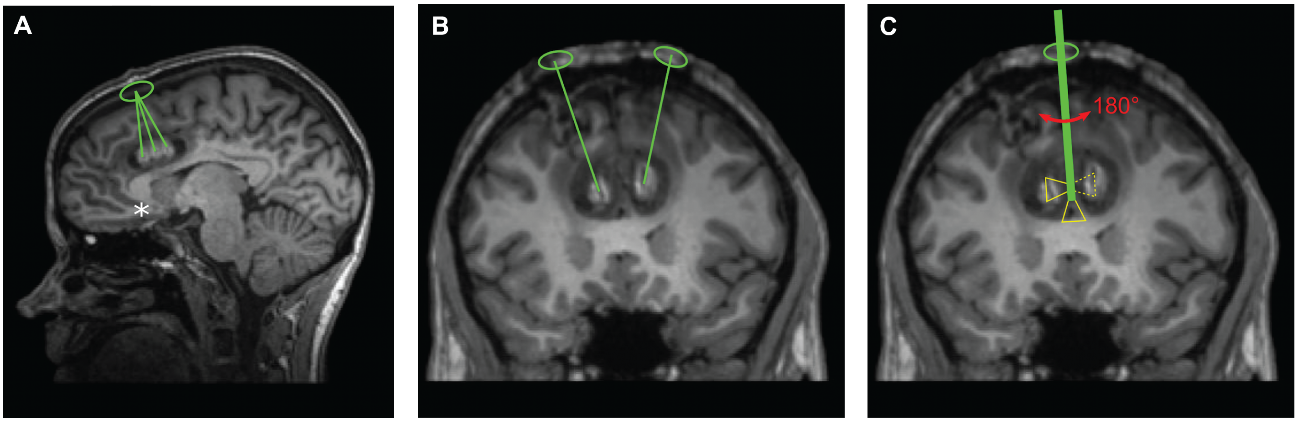


**FIGURE 1.** *MRI scan images after cingulotomy showing 3 classic ablation sites in the sagittal plane adjacent to each other,* **A**, *also revealing the subcallosal gyrus (white asterisk) as a preferred additional lesioning target, which also can be accessed interhemipsherically.* **A** *and* **B** *depict the lines of insertion of ablation electrodes through cranial burr holes, while* **C** *depicts the proposed interhemispheric approach via open minicraniotomy using a multiport endoscope between the bridging veins. Note the retraction-free axial rotation of the cisternal endoscope in such a way that the side port faces the treated ACCs by 180° turns. © 2014 JNSPG. Reprinted with permission from Yang et al, J Neurosurg.*[18]

treatment. The major psychiatric diagnostic groups that may benefit from cingulotomy are chronic severe and disabling anxiety states, including obsessive compulsive disorder,[2-6] and major affective disorder (ie, major depression or bipolar disorder),[7-11] along with heroin addictions, and various refractory pain syndromes.[12-16]

Cingulotomy is typically performed via transcortical electrode implantation into the ACC, which requires preoperative planning, frame placement in most cases, and 1 burr hole on each side. The extent of lesioning has a significant impact on the clinical outcome.[11] Initially, in thermocoagulation studies, a lesion of 1 to 2 cm height and 8 to 10 mm diameter has been made out of 2 targets 5 to 10 mm apart.[4,17] However, lately, 3 consecutive lesions (Figure 1) are made starting from posterior, and advancing to 7 and 14 mm in front, to adjust for the curvature of the cingulate gyrus, thus achieving a lesion that measures 2.5 cm anteroposteriorly.[18] Of note, the anatomy of the corpus callosum and cingulate gyrus is highly variable, and the current systems for stereotactic cingulate lesioning cannot accommodate these wide variations. A high arching or low flat callosum would lead to errors in representation of the cingulate cortex, whether callosal reference system (ACP-PCP; anterior callosal point-posterior callosal point) or the traditional AC-PC (anterior commissure–posterior commisure) line based reference system is used for localization.[17] The advantages of using intraoperative MRI include direct target visualization of the cingulate cortex and cingulum bundle, compared to other callosal coordinate systems.

We propose a novel MRI-guided technique that avoids transparenchymal insertion while achieving the same volume of cingulated tissue treated, using an MRI-compatible cisternal endoscope. The ACC can be safely accessed while getting electrophysiological recordings from the callosum and cingulate as needed.[17] The blood supply of the cingulate gyrus through the pial plexus comprises of the recurrent callosal and medial callosal branches arising from the pericallosal and callosomarginal arteries; they can be better visualized and controlled in an interhemispheric approach.[19-21] Both of the latter arteries comprise the pathognomonic anatomic landmarks for this novel technique. Here, we demonstrate the use of a multiport endoscope in a human cadaveric fixed brain to perform transcisternal bilateral minimally invasive anterior cingulotomies for the first time. In the proposed technique, a side-firing port is rotated 180° to ablate the mutually facing homologous cingulate gyri on ipsilateral and contralateral hemispheres, by passing the endoscope through a narrow anterior interhemispheric corridor (Figure 1C). Barring the superficial drainage veins into the superior sagittal sinus (SSS), the rest of the medial hemispheres are easily separable from the falx cerebri, offering a wide entrance for accessing the surgical targets on either side (Figure 2).

The endoscope prototype comprises a 7-mm diameter cylindrical body housing 2 imaging ports—1 on the distal tip and 1 on the lateral surface (Figure 3).[1] Imaging at both ports is provided by complementary metal-oxide semiconductor cameras (NanEye, Awaiba Inc, Nürnberg, Germany) and LEDs encased in optically clear silicone. The lateral port contains a 1-mm diameter working channel with a 7-mm radius of curvature. This enables a flexible device, such as an electrode, to be inserted through the proximal end of the endoscope and exit the lateral port (Figure 3). Tip-port imaging is used to guide instrument insertion into the interhemispheric corridor and for safe navigation during lateral-port ablation. The tip port also contains 3 1-mm diameter working

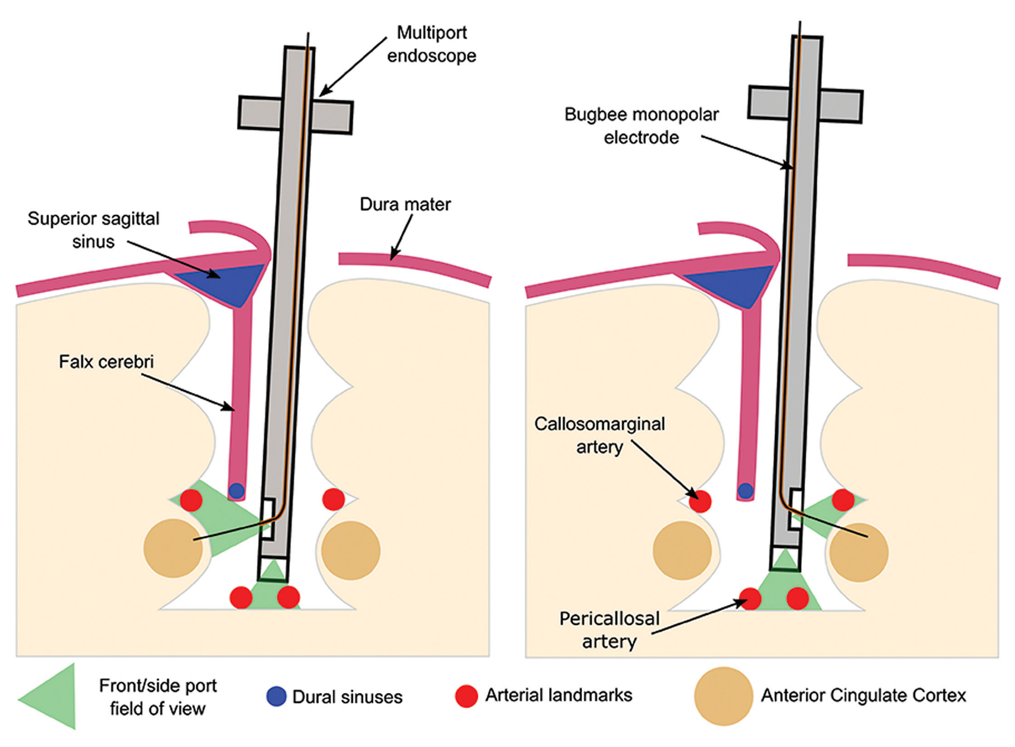


**FIGURE 2.** *Schematic of unilateral minicraniotomy and interhemispheric approach to bilateral cingulate gyri using neuronendoscope incorporating 2 imaging and instrument ports. The tip port is used to guide endoscopic instrument insertion and navigation while the lateral port is used for lesion creation and inspection. Both gyri can be accessed via rotation of the endoscope about its axis.*

channels employed for hemostasis using irrigation, suction and cautery.

## METHODS

A small frontoparietal craniotomy on the nondominant hemisphere was stereotactically fashioned in a silicone-injected human cadaver head to simulate an anterior interhemispheric approach to access the ACC bilaterally. The head was obtained under Institutional Review Board approval and with patient consent. This particular approach allows direct extraparenchymal access, enables dissection of adherent cingula, and permits the use of cisternal landmarks to identify the target area for cingulate lesioning.

To make this procedure retractor-free, we have devised an inflatable flat-balloon catheter to create a temporary working corridor (Figure 4A). While not shown here, a three-dimensional computed tomography angiography/venogram can be used to locate and avoid bridging veins during corridor creation. The balloon was inserted in the interhemispheric cistern after reflecting the dura mater, inflated with a syringe, and kept in place for 5 min as a means of soft brain retraction (Figure 4B). After removing the balloon, the multiport neuroendoscope was inserted interhemispherically (Figure 4C) and advanced until the pericallosal arteries were visualized through the front port and a callosomarginal artery through the side port. We then rotated the endoscope by 180° about its axis to verify the ability to visualize the ACC between the pericallosal and callosomarginal arteries of the opposite hemisphere, through the side port.

Next, we used an electromagnetic (EM) tracking system to measure the pivoting angle in the coronal plane necessary to perform ablation in both hemispheres (Figure 5; Note that EM tracking was used purely for experimental evaluation and would not be used during actual surgery). This involved positioning the side port with respect to 1 ACC and extending an electrode into the brain surface at the desired lesion location. The electrode was then retracted and the endoscope was rotated for targeting the opposing ACC. The pivoting angle, $\alpha$, was recorded as the rotation in the coronal plane between these 2 orientations (Figure 5A). To evaluate the effectiveness of the lateral port, the multiport endoscope was then removed and this procedure was repeated using the tip port of a standard straight clinical endoscope (Figure 5B, pivoting angle $\beta$).

To evaluate the capability to access the full length of the ACC, the multiport endoscope was reinserted and, using the arterial landmarks for guidance, the endoscope was navigated to provide inspection of both ACCs. To demonstrate lesioning, a sequence of ablations was performed at the 3 standard lesion locations using a Bugbee wire. Our goal was to demonstrate procedural feasibility by creating lesions under endoscopic guidance, constantly verifying the location and extent of lesioning. No attempt was made to generate lesions as large as those that would be used clinically. In an actual procedure, any type of flexible lesioning system

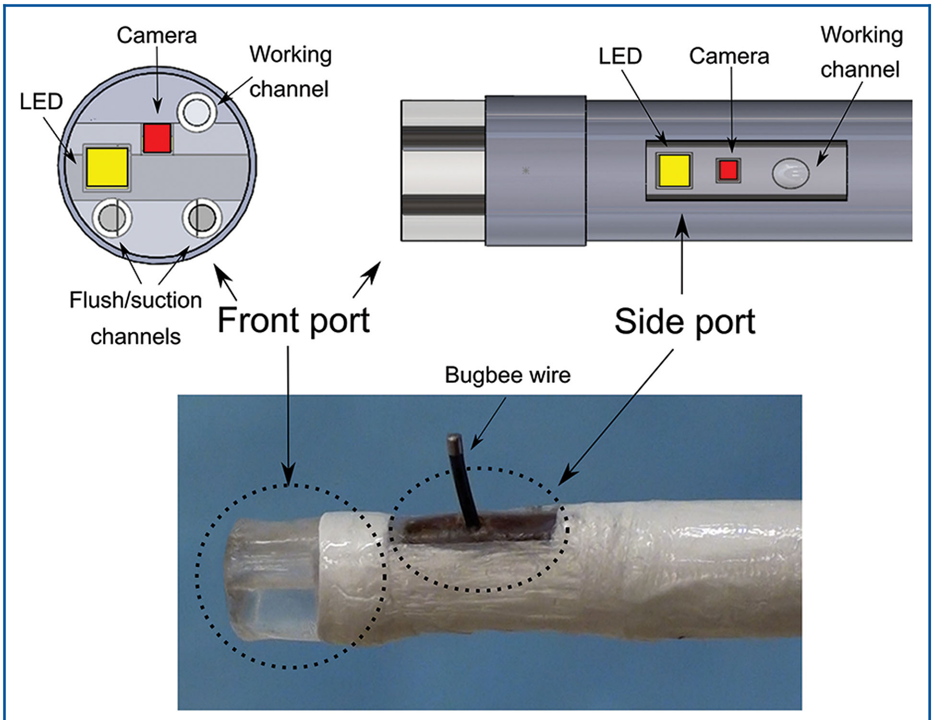


**FIGURE 3.** *Computer aided design and photograph of multiport neuroendoscope prototype. The front port enables visualization of the pericallosal arteries while the side port is used for lesioning of both cingulate gyri.*

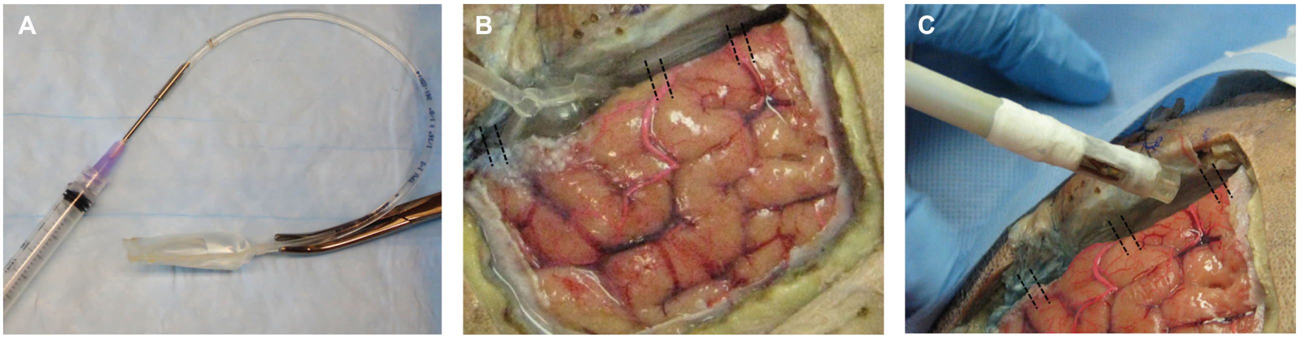


**FIGURE 4.** *Technique for retractor-free access into the interhemispheric cistern.* **A**, *Inflatable flat-balloon catheter designed for interhemispheric soft brain retraction.* **B**, *Gradual inflation of the catheter in the interhemispheric cistern to avoid use of metal retractors and resultant direct impact brain injury.* **C**, *Multiport neuroendoscope entering the cistern between draining veins. In* **B** *and* **C**, *locations of parasagittal draining veins are marked with dashed black lines across the interhemispheric fissure. Note that depicted craniotomy has been made large for visualization purposes.*

could be substituted for the Bugbee wire. Finally, all 3 lesion locations were endoscopically inspected before removing the endoscope from the interhemispheric cistern.

## RESULTS

Cadaver testing confirmed the capability to perform direct anterior cingulotomy via a small microsurgical retractor-free corridor maintained by a soft flat-balloon catheter. Inserting the balloon in the interhemispheric cistern was easily accomplished. Moreover, the soft edges of the balloon did not damage the adjacent brain surfaces. After removing the balloon, the interhemispheric cistern remained open for approximately 20 min, sufficient to perform the cadaveric experiments.

Navigation into the cisternal space was aided by simultaneous real-time visualization through the 2 imaging ports. The tip port

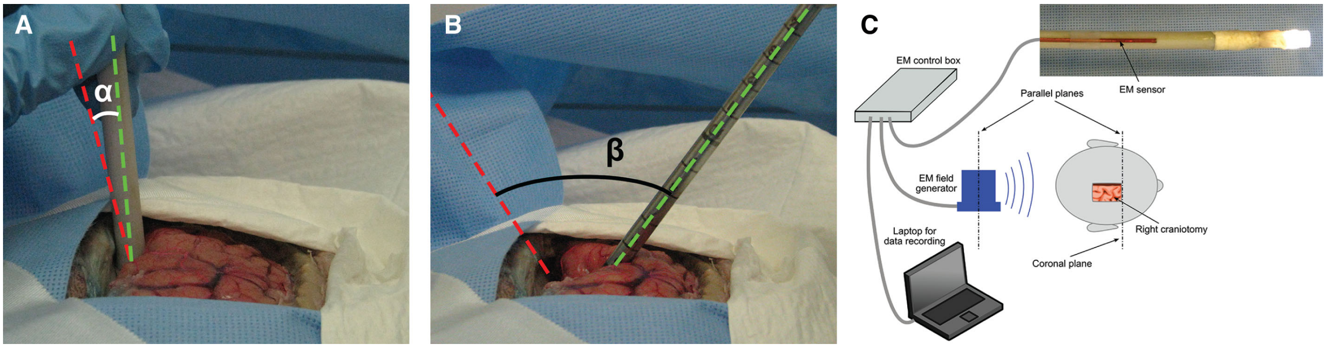


**FIGURE 5.** *Comparison of coronal-plane pivoting angles (α and β) necessary to create lesions in both hemispheres using* **A**, *multiport prototype and* **B**, *standard neuroendoscope. Red line indicates instrument position for ipsilateral cingulotomy and green line represents contralateral instrument position.* **C**, *Electromagnetic measurement system (Trakstar, Ascension Technology, Shelburne, Vermont).*

enabled safe passage between the hemispheres until the pericallosal arteries could be seen. Then, the lateral port was used to locate the left callosomarginal artery. Corresponding views from the two ports are shown in Figure 6, Figure 7 and in **Video, Supplemental Digital Content 1**. The endoscope was then rotated by 180° to confirm visibility of the right callosomarginal artery.

Following Figure 5, we measured the coronal-plane pivoting angles necessary to perform ablation in both hemispheres. Visualization of opposing ACCs required only rotating the endoscope about its axis. To position the Bugbee wire on the brain surface at opposing desired lesion locations, however, the endoscope had to be rotated in the coronal plane. In particular, rotation was needed to reach beyond the dural sinuses (Figure 5) to create contact (Figure 7). Using the multiport endoscope, the pivoting angle was measured to be $\alpha = 20^\circ$. Repeating the experiment with a conventional straight neuroendoscope, coronal-plane pivoting was $\beta = 54^\circ$. It was observed that during the 20° rotation of the multiport endoscope, the endoscope body remained within the surgical corridor and did not compress the surrounding tissue. In contrast, the 54° rotation of the standard single-port endoscope extended outside the surgical corridor and required compression of both hemispheres.

Our multiport endoscope provides a head-on view of the cingulate gyrus through the side port (Figures 7B and 7C). Reaching definitive target sites within the ACC with the Bugbee wire using the side port was easier, more precise and involved less brain retraction, compared to a conventional endoscope.

We then investigated the potential to explore the ACC from its anterior to posterior limits. Following the arterial landmarks, the multiport endoscope was guided along the ACC. The endoscope was then rotated 180° and this procedure was repeated for the contralateral ACC. It was found that the interhemispheric approach provided access to the entire surface of both left and right ACC. This is illustrated in the image mosaic of Figure 8A and in **Video, Supplemental Digital Content 2**. The soft silicone tip port could be brought in contact with the pericallosal arteries without causing any visible damage.

After inspection of the right ACC, the endoscope was navigated to 3 lesion locations evenly distributed along the posterior–anterior limits of the ACC. Note that, while the cadaver brain vasculature was injected with dyed silicone, the dye did not fully penetrate the right hemisphere. This created a white tissue surface on which ablations could be easily visualized (Figure 8B). The creation of one lesion and inspection of all 3 ablations are shown in **Video, Supplemental Digital Content 3**.

## DISCUSSION

Cadaver testing confirmed the capability to perform endoscopic transcisternal ablation of bilateral cingulate gyri through a microsurgical corridor. This minimally invasive approach avoids hemorrhagic risk of transparenchymal electrode insertions, and minimizes the brain retraction injury with interhemispheric use of endoports.

It also allows for electrophysiological recording, stimulation, and resection. Moreover, since there is a reduction in preplanning and intraoperative set-up time, anesthesia time is shorter.

The presented multiport endoscope enables direct vision of the ACC for extended lesioning and simultaneous imaging from the tip port, yielding greater awareness of device location inside the cistern, and facilitating safe navigation and immobilization of the device during ablation. The dual port visualization also provides the capability to closely monitor for inadvertent hemorrhage away from ablation site. The silicone tip of the front port can offer tamponade for bleeding and provide visualization under a column of blood.

With the novel endoscope, multiple ablative passes can be made using the side-firing lateral port without any parenchymal disruption, reducing risk of intracerebral hematoma. This novel endoscope is also magnetic resonance (MR)-compatible, which can enhance precision of cingulate lesioning.

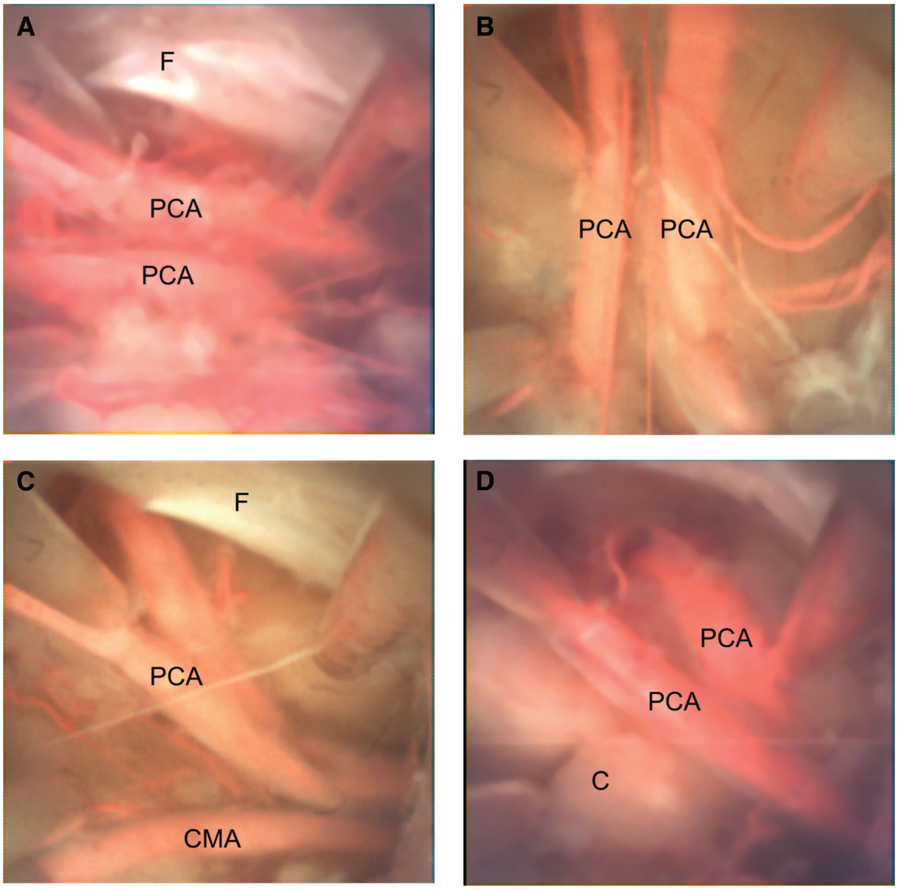


**FIGURE 6.** *Landmark-based endoscope navigation of the interhemispheric fissure using the front viewing port with 3 transparent working channels.* **A**, *Initial visualization of supracallosal vessels after parafalcine insertion of multiport endoscope.* **B**, *View showing the parallel-running pericallosal arteries.* **C**, *View showing localization of the CMA in relation to PCA.* **D**, *Close-up view identifying the cingulate gyrus, marked C in between PCA and CMA. F: falx cerebri; PCA: pericallosal artery, CMA: callosomarginal artery.*

We propose a minicraniotomy-assistance to perform this endoscopic procedure for several reasons. (a) The falx cerebri could be low-lying and would require fenestration of falx with ligation-cutting of the inferior sagittal sinus to expose the contralateral cingulate gyrus. Modern neurosurgical literature has reported the use of transfalcine approach showing the promise and familiarity with this access.[20] (b) The cingulate gyrus, ipsilateral or contralateral, could be tucked tightly under the falx, and it would be safer and more efficient to use microsurgical instruments to lever out the gyrus. A recent publication has demonstrated ways to dissect out intercingulate adhesions in the fissure using multiple incisions, and introduction of electrodes facing the falx to facilitate cisternal electrode manipulation and avoid brain injury.[22] (c) Compared to single bur-hole endoscopic access, an additional minicraniotomy provides the ability to use multiple parasagittal/interhemispheric corridors between the superficial cortical veins draining to the SSS. Our approach is safer compared to large tubular retractors or endoports used for callosotomies and colloid cyst removals.[23-27] (d) Minicraniotomy allows bimanual and concurrent use of stereotactic probes directly within the cistern to point to various interhemispheric landmarks, along with our neuroendoscope. While using tubular retractors or endoports via a single burr hole, the stereotactic pointer has to be navigated deep through the port struggling alongside the surgical instruments, and there is no opportunity to concurrently select a deeper structure lying outside the port.[24,27,28]

This procedure does not affect the feasibility of any adjunct invasive (eg, anterior capsulotomy) or noninvasive neuropsychiatric procedure (like electro convulsive therapy or Transcranial Stimulation) that may follow. If necessary, it can be repeated easily using either a same-side or opposite-side craniotomy while also allowing for alternate follow-up psychosurgical procedures.

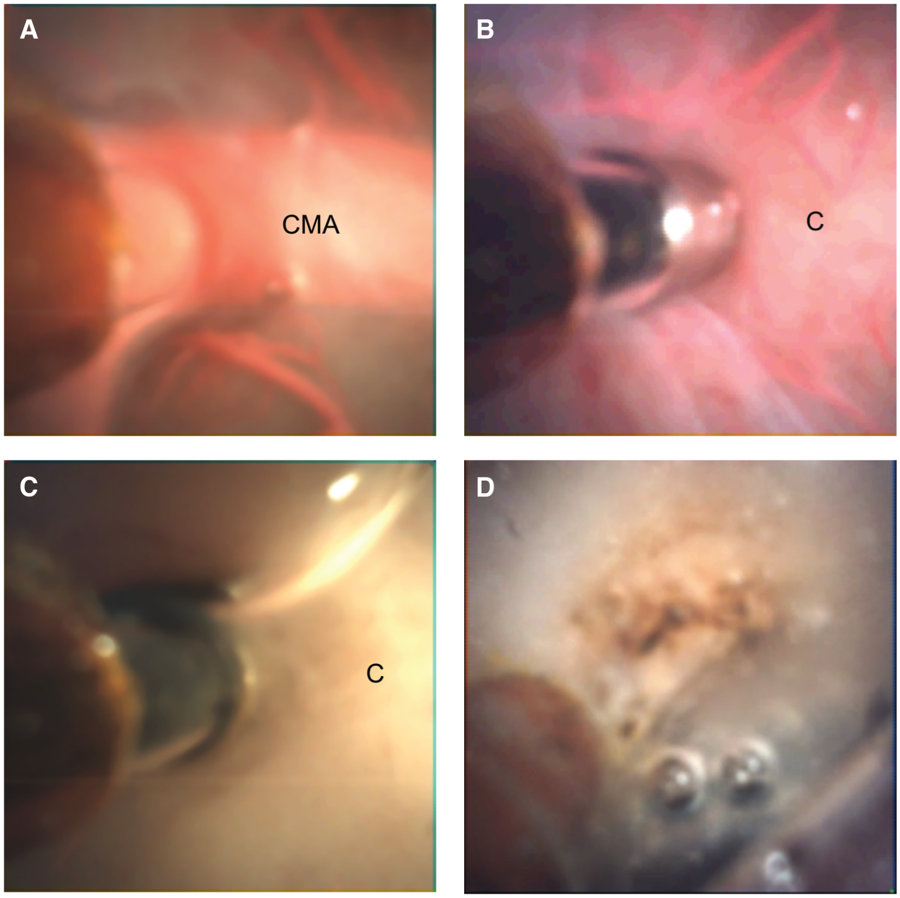


**FIGURE 7.** *Side port views showing sequential positioning of Bugbee wire on opposing ACCs used to measure coronal-plane pivoting.* **A**, *Verification of the boundaries of cingulate gyrus by visualizing long axis of CMA.* **B**, *Contact with left ACC.* **C**, *Contact with right ACC after an axial turn of 180°.* **D**, *View of ablation site on the right ACC.*

Furthermore, the interhemispheric access produces less scarring due to limited tissue dissection, hence the procedure is readily repeatable if the first cingulotomy did not give the desired clinical outcome. While the procedure itself is an endoscopic ablation, with or without MRI guidance, this minimally invasive method could be a useful addition to the armamentarium of surgeons practicing in underprivileged communities that cannot afford an MRI or even a stereotactic head-frame system in the operating room.

## Limitations of Prototype and Study

The multiport endoscope used in this study was fabricated in our laboratory and, consequently, is not of comparable optical quality to a commercially produced endoscope.[1] In addition, heat production would need to be studied for the desired type of lesioning device. Furthermore, significant further technical and procedural development would be needed to adapt the proposed method for cisternal stabilization of stimulation electrodes at the ACC and to avoid contamination of recordings from the contralateral cingulate gyrus.[29] In particular, a method for firmly securing the stimulation electrode to the cingulate cortical surface would be needed together with a technique for safe electrode traversal between the bridging veins entering the SSS. Finally, if a concurrent procedure like cingulotomy-anterior capsulotomy is intended, additional setup, planning, and stereotactic infrastructure would be needed, as these structures are not easily accessible endoscopically from cisterns or ventricles. If a transparenchymal adjunct procedure is planned along with cingulotomy, we recommend combining with a nonendoscopic cingulotomy, to enable fast and combined stereotactic planning, shorter anesthesia time, and a less cumbersome procedure.


**FIGURE 8.** **A**, *Image mosaic demonstrating interhemispheric exploration of the left ACC using side port, anterior to posterior direction. Left callosomarginal artery can be seen curving upward at right side of image.* **B**, *Image mosaic of right ACC illustrating inspection of 3 lesions (arrows). Note that both arterial and venous contrast silicone dye did not adequately penetrate this hemisphere unlike the left hemisphere.*

## CONCLUSION

Multiport endoscopes combined with flexible instruments can significantly increase the functionality of rigid neuroendoscopes. As demonstrated in this cadaveric study, these novel MRI-compatible endoscopes can be used in cisternal procedures, whereby a unilateral nondominant parasagittal frontoparietal minicraniotomy is demonstrated for the feasibility of an endoscopic bilateral anterior cingulotomy. This minimally invasive approach may substantially reduce operating time while avoiding multiple bihemispheric parenchymal electrode insertions.

### Disclosures

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***Supplemental digital content** is available for this article at www.operativeneurosurgery-online.com.*

**Supplemental Digital Content 1. Video.** Landmark-based anterior interhemispheric navigation showing left ACC—Simultaneous views of front and side ports. ACC = anterior cingulate cortex; PC = pericallosal

**Supplemental Digital Content 2. Video.** Interhemispheric navigation along left ACC through the side port. ACC = anterior cingulate cortex; PC = pericallosal

**Supplemental Digital Content 3. Video.** Lesioning and inspection on right ACC—Side port view. ACC = anterior cingulate cortex; PC = pericallosal