Robotic Endoscopic Surgery of the Skull Base

A Novel Surgical Approach

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Objective: To describe a novel robotic surgical approach that allows adequate endoscopic access for resection of tumors involving the anterior and central skull base and allows 2-handed, tremor-free, endoscopic dissection and precise suturing of dural defects.

Design: Transnasal endoscopic approaches are being increasingly used for surgical access and resection of tumors of the anterior and central skull base. One major disadvantage of this approach is the inability to provide watertight dural closure and reconstruction, which limits its safety and widespread adoption in surgery of intracranial skull base tumors. Other disadvantages include limited depth perception and several ergonomic constraints. Four human cadaver specimens were used for this study. The surgical approach starts with bilateral sublabial incisions and wide anterior maxillary antrostomies (Caldwell-Luc). Transantral access to the nasal cavity is gained through bilateral wide middle meatal antrostomies. A posterior nasal septectomy facilitates bilateral access by joining both nasal cavities into 1 surgical field. The da Vinci Surgical System is then “docked” by introducing the camera arm port through the nostril and the right and left surgical arm ports through the respective anterior and middle antrostomies, into the nasal cavity. A 5-mm dual-channel endoscope coupled with a dual charge-coupled device camera is inserted in the camera port and allows for 3-dimensional visualization of the surgical field at the surgeon’s console. Using the robotic surgical arms, the surgeon may perform endoscopic anterior or posterior ethmoidectomy, sphenoidotomy, or resection of the middle or superior turbinates depending on the extent of needed surgical exposure. In addition, resection of the cribriform plate is performed robotically with sharp dissection of the skull base. The dural defect is then repaired with a 6-0 nylon suture.

Results: Adequate access to the anterior and central skull base, including the cribriform plate, fovea ethmoidalis, medial orbits, planum sphenoidale, sella turcica, suprasellar and parasellar regions, nasopharynx, pterygopalatine fossa, and clivus, was obtained in all cadaveric dissections. The 3-dimensional visualization obtained by the dual-channel endoscope at the surgeon’s console provided excellent depth perception. The most significant advantage was the ability of the surgeon to perform 2-handed tremor-free endoscopic closure of dural defects.

Conclusions: Transantral robotic surgery provides adequate endoscopic access to the anterior and central skull base. To our knowledge, this is the first study to report the feasibility and advantages of robotic-assisted endoscopic surgery of the skull base. This novel approach also allows for 3-dimensional, 2-handed, tremor-free endoscopic dissection and precise closure of dural defects. These advantages may expand the indications of minimally invasive endoscopic approaches to the skull base.

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IN THE PAST SEVERAL YEARS, TRANS-nasal endoscopic approaches have been increasingly used for surgical access and treatment of neoplastic and nonneoplastic lesions of the anterior and central skull base. The increasing popularity of these endoscopic skull base approaches may be attributed to a larger trend toward more “minimally invasive” techniques across all surgical disciplines. The main advantage of transnasal endoscopic skull base approaches is providing more direct access to the anterior and central skull base while avoiding craniofacial incisions and extensive bone removal commonly used in open surgical approaches. Also, the wider angle of vision and angled lenses increases the range of the endoscopic visual surgical field compared with the “line of sight” visual field gained by surgical loupes or microscopes. One major disadvantage of transnasal endoscopic approaches is the inability to provide watertight dural closure and reconstruction, which limits its safety and widespread adoption in surgery for intra-
dural skull base tumors. Current techniques of endoscopic skull base reconstruction, such as tissue grafts, mucosal flaps, and tissue sealants, provide adequate reconstruction of limited skull base defects, such as a post-traumatic cerebrospinal fluid leak.\(^1,2\) However, for larger dural defects, these endoscopic techniques have higher cerebrospinal fluid leak rates compared with traditional reconstructive techniques used in open surgery, such as the vascularized pericranial flap.\(^3\) This limitation prompted us to explore the feasibility of robotic-assisted endoscopic surgery and repair of the anterior and central skull base.

**METHODS**

We performed this study on 4 human fresh-frozen cadaver specimens. The surgical approach started with bilateral sublabial incisions in the canine fossae anterior to the maxillary sinuses. Soft tissue flaps were elevated in the subperiosteal plane until the level of the infraorbital nerves superiorly and the nasal piriform aperture medially. Wide anterior maxillary antrostomies (Caldwell-Luc) were then performed using high-speed drills, Kerrison rongeurs, or both (Figure 1). Transantral access to the nasal cavity was gained through bilateral wide middle meatal antrostomies. A posterior nasal septectomy was performed to facilitate bilateral access by joining both nasal cavities into 1 surgical field. The da Vinci Surgical Robot (Intuitive Surgical Inc, Sunnyvale, California) was then “docked” by introducing 3 articulated arm ports: the camera arm port through the nostril and the right and left surgical arms ports through the respective anterior and middle antrostomies, into the nasal cavity, with care taken to avoid traction on the infraorbital nerves (Figure 2). A 5-mm dual-channel endoscope coupled with a dual charge-coupled device camera was inserted into the camera port, and allowed for 3-dimensional (3-D) visualization of the surgical field at the surgeon’s console (Figure 3). Using the robotic surgical arms, the surgeon performed endoscopic anterior and posterior ethmoidectomy, with or without resection of the middle or superior turbinates, depending on the extent of needed surgical exposure (Figure 4). A wide sphenoidotomy was then performed to expose the planum sphenoidale, sella turcica, and parasellar regions (Figure 5). Resection of the cribriform plate was performed robotically with sharp dissection of the skull base, and the dura of the anterior cranial fossa was then incised or resected to provide exposure of the intradural space (Figure 6). The dural defect was then repaired with a meticulous suture technique (Figure 7).

**RESULTS**

Excellent access to the anterior and central skull base, including the cribriform plate, fovea ethmoidalis, medial orbits, planum sphenoidale, nasopharynx, pterygopalatine fossa, and clivus, was obtained in all cadaveric dissections. In addition, excellent surgical access was achieved to the sella turcica and suprasellar and parasellar regions (Figure 5). The 3-D visualization obtained by the dual-channel endoscope at the surgeon’s console provided excellent depth perception. The most significant advantage was the ability of the surgeon to perform 2-handed tremor-free endoscopic closure of dural defects (Figure 7).

**COMMENT**

Transnasal endoscopic approaches are being increasingly used for surgical access and resection of neoplastic and nonneoplastic lesions of the anterior and central skull base. Examples of nonneoplastic conditions include cerebrospinal fluid leaks, mucoceles, encephaloceles, cholesterol
granulomas, and allergic and invasive fungal sinusitis.\textsuperscript{1,2,4-10} Endoscopic surgery is also used with increasing frequency for surgical resection of tumors of the sinonasal tract, such as inverted papilloma, angiofibroma, osteomas, and other benign fibro-osseous lesions, and even in selected patients with malignant sinonasal tumors.\textsuperscript{11-21} Endoscopic approaches are also becoming popular for transsphenoidal access to the sella turcica, and are considered by many centers the preferred surgical approach for treatment of pituitary adenomas.\textsuperscript{22-30} More recently, there has been an emerging trend to expand the use of transnasal endoscopic approaches in the surgical treatment of suprasellar, petroclival, infratemporal, and other intracranial skull base tumors.\textsuperscript{31-34}

The increasing popularity of endoscopic approaches may be attributed to several advantages. In addition to bright illumination and magnification, endoscopic approaches provide a wider angle of vision and, therefore, the ability, using angled lenses, to “see around corners,” a distinct advantage over surgical loupes or the operating microscope.\textsuperscript{24} Another major advantage of transnasal endoscopic approaches is providing more direct access to the anterior and central skull base, while avoiding facial or cranial incisions and extensive bone removal, which are commonly needed for surgical exposure in open approaches.\textsuperscript{35} Despite these advantages, transnasal endoscopic approaches have significant limitations (namely, optical, ergonomic, and reconstructive). The following is a discussion of these limitations and how endoscopic robotic surgery may overcome them.

**OPTICAL LIMITATIONS**

The 2-dimensional visualization provided by single-channel optical systems in current endoscopes lacks the depth perception of 3-D vision provided by the binocular optical systems used in standard microsurgery. During endoscopic surgery, depth perception relies more on tactile than on visual cues. Visual depth perception is particularly important when operating on critical intracranial neurovascular structures, especially when working in a deep and limited space. The 5-mm robotic endoscope used in this study has a dual-channel optical system (Figure 8) coupled with a dual charge-coupled device, which allows for 3-D visualization of the surgical field at the surgeon’s console (Figure 3). This “binocu-
lar endoscope" allows the surgeon to have the combined benefit of a wider angle of vision and the depth perception of 3-D visualization.

ERGONOMIC LIMITATIONS

Current endoscopic techniques have several ergonomic limitations. Bimanual surgery is only feasible if the endoscope is held by an assistant or a mechanical holder. A surgical assistant is preferred because of the constant need to adjust the position (depth and angle) of the endoscope during endoscopic surgery. This not only limits the direct control of the endoscope by the primary surgeon but also requires the assistance of a relatively experienced endoscopic surgeon who can seamlessly follow the primary surgeon in every step of the operation. Also, both surgeons have to work within the confined space provided by the nostrils, which in some cases limits ergonomic freedom. In addition, as the surgical field gets deeper, longer instruments are needed and, with lack of proper arm support, precision may be limited by fine tremor, especially when using fine instrumentation for delicate dissection of critical neurovascular structures.

The robotic system used in this study has 4 arms (Figure 9), all of which are controlled by the primary surgeon sitting at the console (Figure 3). One arm, the camera port, holds the endoscope; 2 arms hold right and left hand instruments; and a fourth “spare” arm may be dedicated for retraction or a third instrument. This allows the primary surgeon simultaneous direct control of the endoscope and the instrumentation, an advantage not feasible with nonrobotic endoscopic techniques. Another advantage of the “endowrist” technology used in the da Vinci robotic instrumentation is its ability to provide movement at the instrument tip with 7° of freedom and 90° of articulation and motion scaling. This allows the surgeon, who sits comfortably at the console with an adjustable arm, support to perform precise tremor-free movement in a deep and confined space, with working angles usually not achievable with nonrobotic instruments.

RECONSTRUCTIVE LIMITATIONS

Finally and perhaps the most significant limitation of current transnasal endoscopic techniques is the inability to suture and provide watertight dural closure or reconstruction of dural defects. Endoscopic repair of dural defects relies on nonvascularized fat, mucosal, or allogeneic grafts, or vascularized septal or nasal rotational mucosal flaps. These reconstructions are then cov-
Figure 9. The da Vinci Surgical System (Intuitive Surgical Inc, Sunnyvale, California) allows the surgeon direct control of 4 surgical arms.

dered with fibrin sealants and supported by either absorbable or nonabsorbable packing. While these methods may provide adequate reconstruction of minor dural tears or defects, their ability to provide safe and reliable reconstruction of larger dural defects remains to be seen. Preliminary results suggest that these methods have a higher cerebrospinal fluid leak rate compared with the more standard dural reconstruction using pedicled (axial) flaps, such as the pericranial flap or microvascular free flaps. Adequate and reliable dural reconstruction is critical in minimizing the morbidity of skull base resections, particularly in patients who received or will undergo high-dose radiation therapy. Therefore, we have elected to limit the use of endoscopic techniques to extradural procedures and those with limited dural involvement until more reliable endoscopic dural reconstruction techniques are developed. This was also the impetus behind our study of robotic applications in endoscopic skull base surgery. In our study, robotic-assisted surgery allowed successful and precise endoscopic suturing of the dura in all 4 cadavers (Figure 7). This may drastically impact the utility and safety of endoscopic surgery of intracranial intradural lesions of the skull base.

In conclusion, to our knowledge, this is the first study to report the feasibility and advantages of robotic-assisted endoscopic surgery of the skull base. Transcranial robotic surgery provides adequate endoscopic access to the anterior and central skull base. This novel approach also allows for 3-D 2-handed tremor-free endoscopic dissection and precise closure of dural defects. These advantages may expand the indications of minimally invasive endoscopic approaches to the skull base. Future development and refinement of endonasal robotic instrumentation is critical before applying these techniques in the clinical setting.

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