

Transoral robotic surgery of the central skull base: preclinical investigations

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Abstract In this study we explored possible applications of the da Vinci system in approaching the skull base at optic chiasm level on two cryopreserved cadavers, using an entirely transoral robotic technique (TORS). We used a standard 12 mm endoscopy and 8 mm terminals. Bone drilling was performed manually. The da Vinci system is equipped with very good illumination and 3D viewing, thus providing excellent vision and great maneuverability even in the less accessible areas of the skull. Our experience demonstrates that an entirely transoral skull base robotic approach to this complex anatomical region has many advantages as compared to traditional techniques.

Keywords Transoral robotic surgery · Skull base

All authors are research group for the implementation of robotic surgery on skull base and head and neck surgery.

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Introduction

The application of robotics to surgery has rapidly expanded over the last 5 years. At present, the most widely used robot is the da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA). The advantage of robot-assisted surgery is that it allows the performance of bimanual surgery in confined cavities with instrumentation that exceeds the capabilities of the human hand, while it provides the surgeon with a 3D view of the surgical field. Robotic and robot-assisted surgery are gaining increasing popularity among surgeons who perform endoscopic or laparoscopic surgery of the abdominal and pelvic cavities, such as general surgeons, urologists and gynecologists. Additionally, the application of robotic and robot-assisted surgery have extended to other fields such as cardiac and thoracic surgery. Da Vinci robot-based TORS was introduced after a series of experimental studies on the upper aerodigestive tract that were initially performed on dummies and then continued on cadavers. Modern mouth gags—which keep soft tissue sufficiently retracted—allow the surgeon to directly approach the oropharynx and the supraglottis without the need of an endoscope [1, 2]. It is much more difficult to apply robot-assisted surgery to less accessible areas such as the base of the skull, where the anatomy is extremely complex. Although significant advances have been made in surgical robotics, the application of robotics to skull-base surgery has not yet been clearly defined. To explore the potential applications of robotics to skull-base surgery, we developed an experimental and entirely transoral approach to the medial skull base through the nasopharynx and tested it on two cryopreserved cadavers. The aim of this study is to investigate a new robotic surgery technique that allows surgeons to overcome the current limitations. In this work, we present the current state of the

art regarding the potential application of the robotic approach to the skull base, trying to answer questions about the future role of such technology in this exciting area.

Material used

We used the da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA), which is composed of a surgical console, a patient-side cart with four robotic arms, two light sources, a dual camera, a 30° and 12 mm endoscope, 8 mm Maryland forceps mounted on the robot's left arm, and 8 mm scissors mounted on the right arm. We did not use modern 5 mm instruments because they are not currently available for experimental use at our center. Additionally, we used a surgical head support, two medium-sized autostat retractors, surgical instruments for general endoscopic abdominal surgery, standard engine cutting drills, an aspirator, suction tips, saline solution for irrigation, and a 2D monitor. Surgery was performed on the heads of two cryopreserved human cadavers.

Surgical technique

The cadaver head was placed on a platform on the operating table and fixed with tape. The mouth was held open with two large autostat retractors separating the maxilla, and the jaw and the cheeks, respectively. This allowed us to achieve a mouth opening greater than that produced with standard mouth gags. The da Vinci system was placed cranially with the skull facing the patient-side cart, so that the robotic arms had greater maneuverability and could easily form an acute angle with the terminals and the endoscope (Figs. 1, 2).



Fig. 1 The cadaver head placed on the platform, on the operating table, fixed with tape. The da Vinci system was placed cranially in order to give the robotic arms greater maneuverability while the terminals and endoscope were directed at the soft palate and rhinopharynx

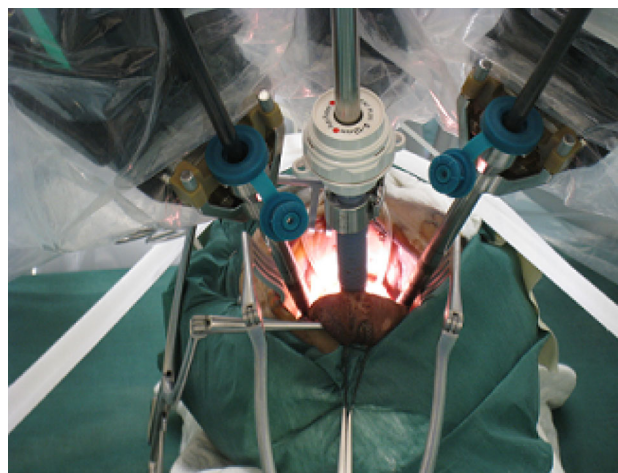


Fig. 2 Arrangement of retractors used as mouth gag. 30° endoscope and robotic terminals inserted through the mouth

Robotic part of the procedure

A 30° endoscope was inserted through the middle of the mouth at a depth of 3–4 cm looking towards the soft palate. We made an incision in the soft palate from left to right along the edge of the hard palate. We inserted the endoscope 1 or 2 cm deeper into the nasopharynx until the upper part of the choana and the posterior edge of the vomer were at the upper part of the surgical field. The posterior wall of the nasopharynx, the opening of the Eustachian tube and Rosenmüller's fossa were perfectly visible on a single surgical image. Next, we dissected the mucosa of the posterior wall of the nasopharynx starting with an incision in the upper left edge of the left choana using the scissors (Fig. 3). The dissection continued to the upper right part of both choana along the right posterolateral portion of the nasopharynx behind the posterior limit of the Eustachian

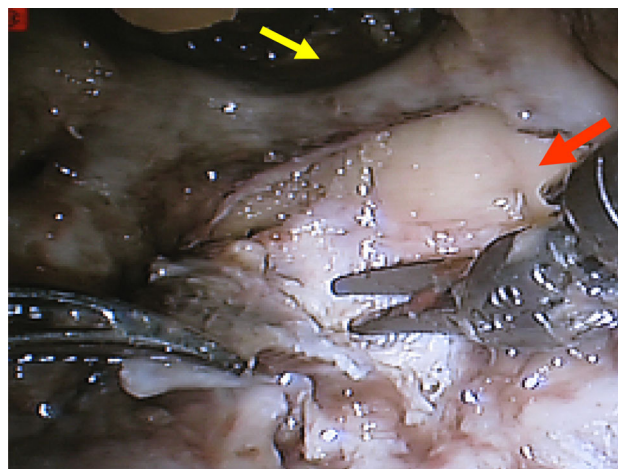


Fig. 3 Detachment of the posterior wall of the nasopharynx. Insertion of vomer (red arrow). Right choana (yellow arrow)

tube including Rosenmüller's fossa, until we reached the boundary between the oro- and nasopharynx. The same procedure was performed in the left posterolateral region. The mucous membrane of the posterior wall was detached from top to bottom by dissecting and cutting it with the scissors. We pulled down the mucous membrane and soft tissues with Maryland forceps until we could see the insertion of the vomer in the floor of the sphenoid sinus, which presented its characteristic bifurcation on the upper portion of the clivus.

Non-robotic part of the procedure

At this point, we passed to the non-robotic part of the surgical procedure. The drill was inserted through the mouth towards the upper portion of the nasopharynx. We drilled the outer wall of the sphenoidal floor bone just behind the insertion of the vomer (Fig. 4), the floor of the sella, the bony covering of the internal carotid parasellar arteries, the bony covering of the optic nerves and the optic chiasm, the *planum sphenoidale*, and the upper clivus (Figs. 5, 6). Before the drilling, we removed the robotic arms with the forceps and the scissors mounted on them. The 30° endoscope was left inside to provide a clear view on the 2D monitor. During the drilling, profuse saline solution irrigation was used by inserting the suction tip alternatively into the nose and mouth, as necessary. The robotic arms were put back into the nasopharynx after the drilling was completed. We used the robotic terminals to manipulate the confined anatomical structures described above and verified that the region was easily accessible with these instruments. Finally, we proceeded to dissect the middle portion of the chiasm to practice robot terminal handling at that level (Fig. 7).



Fig. 4 Drilling posterior to the vomer insertion (red arrow)

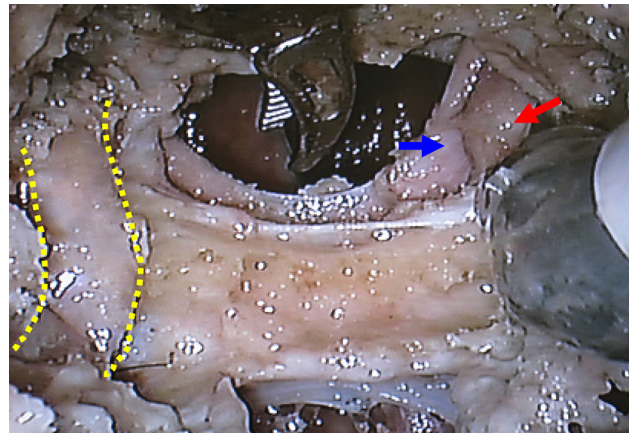


Fig. 5 Right parasellar carotid (dotted yellow lines). Left optic nerve (blue arrow). Left ophthalmic artery (red arrow). The terminal of the robotic left arm is over the chiasm. The right arm is near the left optic nerve and the left ophthalmic artery

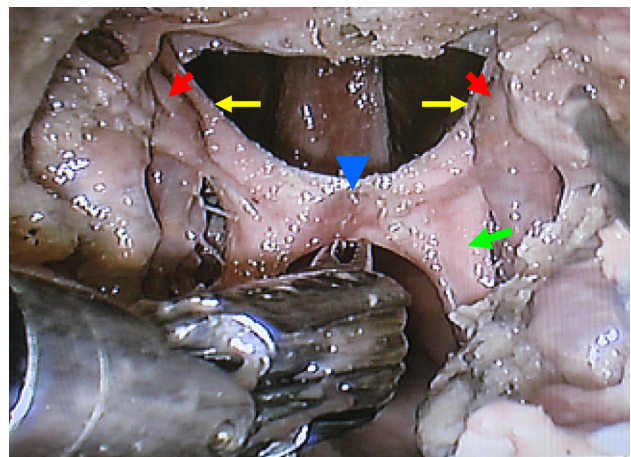


Fig. 6 Ophthalmic arteries at both sides (red arrows). Optic nerves (yellow arrows). Chiasm (blue arrow head) and left optic tract (green arrow). The left terminal is in the lower portion of the chiasm

Results

The correct positioning of the specimens was crucial. The positioning of the cadaver heads required a specific angle keeping the upper portion of the head slightly higher than the lower cervicomandibular part, which was enabled by the shape and design of the head support, and imitated the position of a patient's head on the surgical table (Figs. 1, 2). Autostat retractors were placed perpendicular to each other, which enabled a better mouth opening as compared to that achieved with conventional surgical mouth gags. The insertion and orientation of the 30° endoscope and the left and right robotic arm terminals through the mouth were uneventful (Fig. 2). The dissection of the soft palate was quick, and redirecting the optical terminals to the nasopharynx was easy. The 3D view of the nasopharynx was

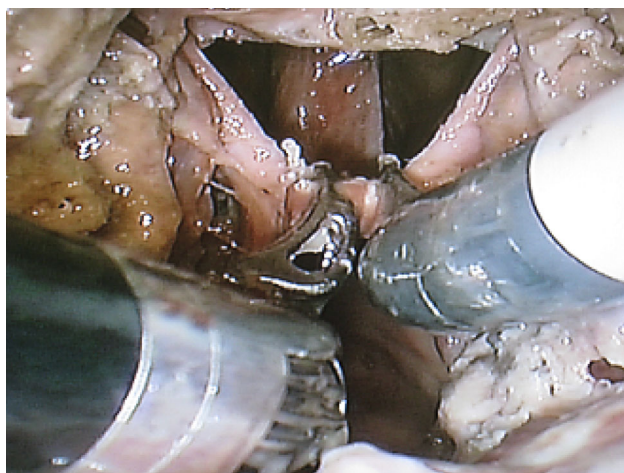


Fig. 7 Chiasm section showing the ability of terminals to work at that depth

excellent, showing the whole surgical field from the upper portion of the choana to the limit between the oro- and nasopharynx from top to bottom and from one Eustachian tube to the other. The mobility of the robot terminals and optical arms was very good, with little conflict of space between the arms and the terminals and, in general, with a great sense of freedom despite the restricted space. The view of the surgical field and free movement of the robotic terminals were much better as compared to those achieved with the traditional transnasal endoscopic technique. The dissections described above were comfortably performed, and it was not necessary to exchange side terminals. No help was required except for irrigation during drilling. The lack of tremor and the possibility of automatically locking the terminals to any position were some of the advantages of this robot-assisted procedure. The dissections described above were carried out with ease, despite the fact that the mucous membrane of the nasopharynx was firmly attached to the deepest rhinopharyngeal structures by a hard and fibrous tissue (Fig. 3). Drilling was carried out with ease and excellent control was maintained through the 2D monitor. The internal carotid arteries, their relationship with the optic nerve, the inferolateral position of the ophthalmic artery in relation to the nerves, the chiasm and the optic tracts were clearly visible (Figs. 5, 6). Therefore, we confirmed that the robotic terminals can be perfectly handled in the vicinity of these structures for the dissection of the middle portion of the optic chiasm (Fig. 7).

Discussion

The traditional external approach to the skull base is complex and is associated with non-negligible morbidity.

In recent years, endoscopic transnasal techniques have emerged as a valid alternative. 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 avoiding craniofacial incisions and extensive bone removal. However, they are performed through the nose with a 2D view and a limited manipulation capacity of the end-effector of instruments [3]. These limits can be overcome through new robotic technology [4].

Background

In 2007, Hanna et al. published the first experimental study on robot-assisted transnasal–transantral surgery of the middle and upper regions of the cranial base. After wide anterior bilateral antrostomies (Caldwell–Luc) the da Vinci was “docked” by introducing the endoscope through the nostril and the right and left surgical arms through antrostomies. 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 one surgical field. The authors of this study reported that this new robotic technique gave them adequate access to the cribriform plate, the *fovea ethmoidalis*, the medial orbits, the *planum sphenoidale*, the *sella* and *parasellar* regions, the nasopharynx, the pterygopalatine fossa and the *clivus* [5]. In the same year, the developers of the TORS concept conducted a pilot study on a cadaver and an animal model that showed the feasibility of the transoral–transpalatal approach to the nasopharynx, and proved the possibility of reaching the nasopharynx and sellar region using a cervicotransoral (C-TORS) approach. In this approach, the endoscope is inserted through the mouth, while the robotic terminals are inserted through the neck, small neck incisions are made for the trocars inserted into the back of the submandibular glands. The authors found no significant lesions on neck arteries, veins or nerves. They used C-TORS because their standard TORS approach provides only limited access to the midline skull base with maximal access to the level of the lower nasopharynx [6]. With this new approach they could reach the cavity of the sphenoid sinus and the outer face of the sella, however, deeper structures could not be reached. In 2008, Ozer et al. published the first study on the application of the da Vinci robotic approach to nasopharynx surgery. In this study the transoral–transpalatal technique was applied on cadavers [7]. In 2009 Kupferman et al. published the first report on the robotic transnasal–transantral pituitary approach applied on human cadavers [8]. In 2011 Dallan et al.

describe the results of the dissection of the nasopharynx on two cadavers' heads. The dissection was performed through a pure TORS technique on one cadaver, and a combined transnasal–transoral procedure (CTTP) with a conventional endoscope placed transnasally, a posterior septectomy, and with the 5 mm terminals of the robot placed transorally, on the other one. According to Dallan et al., the TORS technique does not provide the surgeon with an adequate view of the surgical field when employed for surgery of the upper portion of the rhinopharynx, as the surgeon can only see the borders of the surgical field; conversely, CTTP provides a better view of the rhinopharynx [9].

Our results

According to our experience based on an entirely transoral procedure, we achieved a panoramic view of the rhinopharynx with a view of the upper margin of the surgical field better than that offered by transnasal endoscopy without posterior nasal septectomy. This is relevant considering that the robotic transoral approach to the base of the skull is intended to be minimally invasive. For this reason, future areas of investigation would be to perform the same surgical procedure with the same approach while preserving the integrity of the soft palate. In this context, the results of this and previous studies demonstrate the advantages and possibilities of a robotic transoral approach as compared to the standard endoscopic transnasal approach. The robotic 3D view is better than the 2D view offered by conventional endoscopy; the lighting provided by a dual source is better, robot terminals can be inserted near the surgical field; the robot has anti-tremor filtering; the surgeon can automatically maintain the position of the instruments, as the robot has position memory for instrument changes; its freedom of movement is far greater than that of the outer instruments used in conventional endoscopy; it allows for greater maneuverability in the paramedian regions and, most importantly, the transoral approach allows greater freedom of action than the transnasal approach.

Conclusions

This study demonstrates that the robotic transoral approach to the skull-base surgery presents some advantages over the transnasal, trans-septal and transrostral approaches applied in conventional endoscopy. In the treatment decision-making process, the surgeon can compare the advantages and disadvantages of robot-assisted surgery and traditional

endoscopy. In this respect we perfectly agree with Kupferman et al. who state that the ideal surgical technique should offer the distinct advantage of 3D vision and bimanual surgical dissection, possibly guided by a navigation system [8]. Based on this, we maintain that robotic skull base surgery should offer all this opportunities to the surgeon. Based on our preclinical experience we believe that robotic surgery truly represents a great opportunity for surgeons and patients. We are strongly convinced that robotic systems can be considered the natural evolution of traditional endoscopic approaches in skull base surgery [10], for this reason, it is absolutely necessary to progressively incorporate robotic techniques in ENT and skull base surgery in a near future [11–13].

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