Case Report

ORL

ORL 2010;72:91–95
DOI: 10.1159/000278256

Received: December 22, 2009
Accepted: January 18, 2010

Da Vinci Robot-Assisted Transoral Odontoidectomy for Basilar Invagination

John Y.K. Lee[a] Bradley Lega[a] Deb Bhowmick[a] Jason G. Newman[b]
Bert W. O'Malley, Jr.[b] Greg S. Weinstein[a, b] M. Sean Grady[a] William C. Welch[a]

Departments of [a]Neurosurgery and [b]Otolaryngology, University of Pennsylvania, Philadelphia, Pa., USA

Key Words
Transoral robotic surgery · Craniocervical junction · Basilar invagination

Abstract

The transoral approach is an effective way to decompress the craniocervical junction due to basilar invagination. This approach has been described and refined, but significant limitations and technical challenges remain. Specifically, should the transoral route be used for intradural pathology, such as a meningioma, or should an inadvertent durotomy occur during extradural dissection, achieving a watertight closure of the dura in such a deep and narrow working channel is limited with the current microscopic and endoscopic techniques. Even closure of the posterior pharyngeal mucosa can be challenging, and problems with wound dehiscence encountered in some case series may be attributable to this difficulty. These problems, and the corollary aversion to the procedure felt by many neurosurgeons, led our group to investigate an alternative approach.

Robot-assisted surgery has gained importance in multiple surgical specialties [1–4], including cardiac surgery, urology, obstetrics and gynecology, and, most recently, minimally invasive head and neck surgery. Proponents of robot-assisted surgery refer to the excellent 3-dimensional visualization as well as the 'intuitive' dexterity offered by the robotic instruments. Our otolaryngology group has pioneered the world's first transoral robotic surgery program using the da Vinci Surgical System Robot (Intuitive Surgical, Sunnyvale, Calif., USA). We have previously reported on the development of transoral robotic surgery in preclinical models [5–9] and its application to the treatment of glottic, tonsillar and infratemporal fossa lesions [10–12]. We also sought to apply the da Vinci system to skull base approaches to the clivus, sella and foramen magnum, exploring its features in cadaver studies [13]. The cumulative success of these studies led us to attempt a robot-assisted transoral procedure to treat a patient with severe myelopathy and basilar invagination under an institutional-review-board (IRB)-approved protocol.

Case Report

History

The patient is a 39-year-old woman suffering for several months of worsening neck and suboccipital pain. She reported tingling in both arms extending into her hands, frequently leading to her dropping items. She fell occasionally but reported no incontinence of the bowel or bladder. Physical examination revealed diffuse hyperreflexia in both arms and legs with typical myelopathic signs, including sustained clonus in both ankles, bilateral Babinski signs and the presence of Hoffman's sign in the

KARGER

Fax +41 61 306 12 34
E-Mail karger@karger.ch
www.karger.com

0301–1569/10/0722–0091$26.00/0

Accessible online at:
www.karger.com/orl

John Y.K. Lee, MD
Department of Neurosurgery, 3 Silverstein
3400 Spruce Street
Philadelphia, PA 19104 (USA)
E-Mail leejohn@uphs.upenn.edu

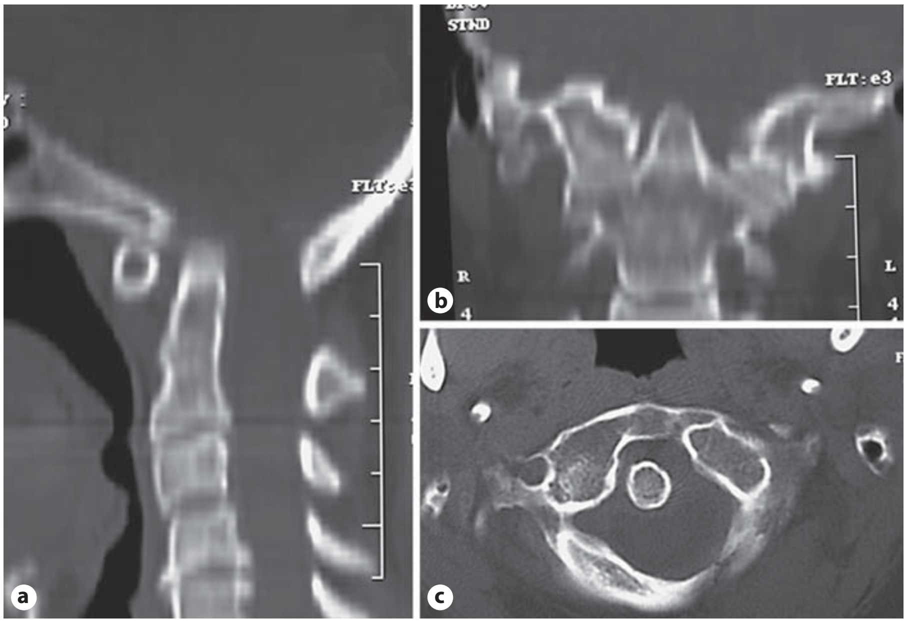

Fig. 1. a Preoperative sagittal CT scan demonstrating assimilation of the C_1 arch into the occiput and basilar invagination. **b** Preoperative coronal CT scan demonstrating eccentric location of the odontoid. **c** Preoperative axial CT scan demonstrating eccentric location of the odontoid.

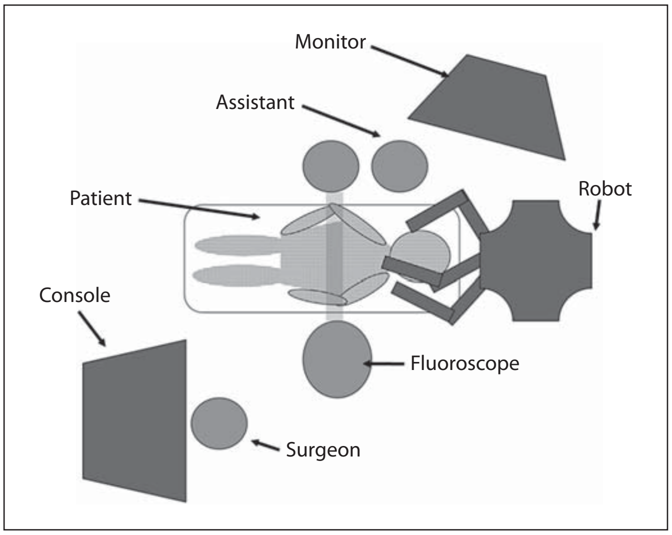

Fig. 2. Schematic drawing of the operating room setup. The da Vinci robot is positioned at the head of the patient. The C-arm fluoroscope is brought in and out of the field to confirm location. Two surgeons work together: one sits at the robot console, and the other works at the bedside through the mouth.

right upper extremity. CT scan demonstrated a congenital anomaly at C_{1-2} with basilar invagination and impaction of the brainstem by the dens. The odontoid sat eccentrically to the right (fig. 1). The clinical and radiographic picture confirmed a diagnosis of basilar invagination with worsening myelopathy. IRB approval was obtained to employ the da Vinci robot in performing a transoral odontoidectomy, and after careful explanation of the risks and benefits, the patient wished to proceed with the surgical procedure.

Procedure

The patient was positioned supine and intubated with a fiberoptic endoscope. An armored tube was placed and kept in the midline. A Dingman retractor was inserted into the oral cavity, resulting in no more than 4 cm of oral opening. Two red rubber catheters were inserted through the nose, brought out laterally through the mouth, and clamped in position to maximize retraction of the uvula and soft palate. The da Vinci robot was positioned at the top of the table, cranial to the patient's head, to optimize the angle of the 3 robotic arms as they were directed anterior-posterior/inferior-superior in the oral cavity. This arrangement is unique to transoral surgery of the skull base; transoral robotic surgery for the glottis and hypopharynx requires a different arrangement. We refined these important details during our cadaver work [13], in which we more fully describe them. The binocular endoscope arm was brought in on the midline with the 2 articulating arms entering laterally without compression of the buccal skin folds. A 12-mm 0-degree endoscope was initially used, providing excellent visualization to the mid-clivus above the arch of C_1. It proved effective for the bulk of the procedure, but the 30-degree angled endoscope was also needed at times to look either superiorly or inferiorly. A Maryland articulated dissector was placed in the left arm and a monopolar, spatula-type electrocauterizer in the right. A C-arm fluoroscope was positioned lateral to the patient's neck to provide real-time imaging of the bony anatomy, and it was moved towards the foot of the bed when not in use (fig. 2).

The operating head and neck surgeon sat at the da Vinci console and began with a midline incision in the posterior pharyngeal mucosa. An assistant, observing the view of the surgeon on

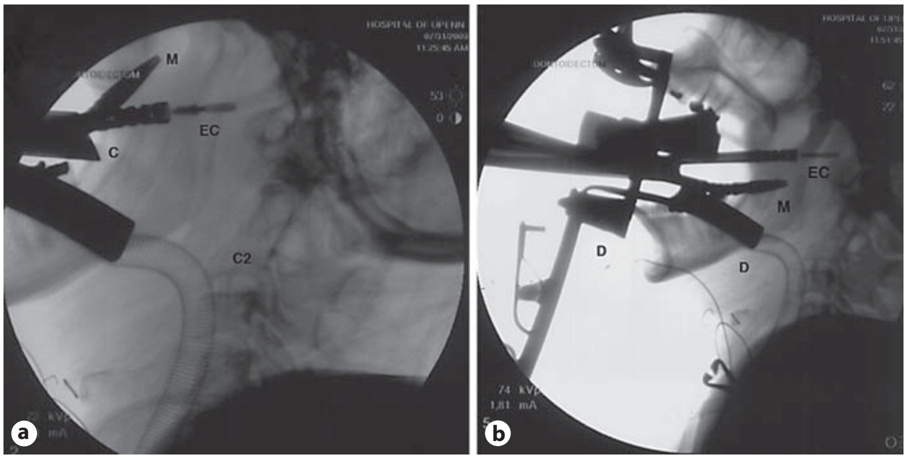

Fig. 3. Lateral fluoroscopic intraoperative view. **a** Close-up view of the spine anatomy included. C2 = C_2 vertebral body; C = transoral Crockard retractor that was used as well. **b** A view of the setup. D = Dingman retractor; M = 5-mm Endowrist Maryland dissector robotic da Vinci arm; EC = 5-mm Endowrist monopolar electrocautery arm.

an adjacent monitor, provided suction and monitored contact between the robotic arms and the structures of the oral cavity, to avoid inadvertent injury. The assistant stood to the right of the patient at the level of the thorax, as we described previously [in press]. The anterior ring of C_1 and the body of C_2 were identified and confirmed on lateral fluoroscopy (fig. 3). The eustachian tubes, a source of significant morbidity if injured, were clearly identified and carefully avoided. Dissection proceeded quickly as the articulated Maryland dissector maintained tension on the mucosa and the electrocauter dissected through layers down to the ring of C_1 and then inferiorly to the body of C_2, with the location confirmed on fluoroscopy. The anterior longitudinal ligament was taken down in the same fashion, exposing the anterior atlanto-occipital membrane superiorly, the arch of C_1, the dens and the body of C_2. This dissection was controlled at the console by the operating surgeon with only minimal assistance from the bedside surgeon.

Once the soft tissue dissection was complete, the next stage required the neurosurgeon to stand at the bedside for the bony dissection. The robotic da Vinci arms were removed from the field, but the endoscopic camera was left in place to perform the procedure as an endoscope-assisted procedure. The transoral Crockard retractor was placed to retract the mucosa and muscle. Next, since there is no drill attachment for the robotic da Vinci arm, the neurosurgeon completed the drilling using a standard Midas Rex drill with a matchstick burr (AM-8). The neurosurgeon was able to visualize the scene on the 2-dimensional flat panel screen with superior illumination. The surgeon seated at the remote robotic console was able to see in 3 dimensions and to assist and guide the bone and ligament removal adjacent to the dura. A neurosurgeon, who is familiar with the anatomy of the bony structures of the cervical spine, is more helpful as an assistant than a cooperating otolaryngologist for this portion of the procedure.

The C_1 arch was removed with the drill by creating 2 troughs no more than 16 mm in maximum width (e.g. medial border of the lateral mass of C_1) [14]. Upon completion of the removal of the C_1 arch, the apical ligament was identified. Final removal of the residual bone of the dens and the apical and alar ligaments was accomplished using a Kerrison punch and curette in the hands of the neurosurgeon. Corrections in placement of instruments and direction for dissection were provided by the assistant seated at the console who benefited from the 3-dimensional view available with the binocular endoscope. The odontoidectomy was completed in this manner, exposing the underlying dura, and thus completing the standard extradural decompression of the congenital basilar invagination.

Once the bone work was complete, the primary otolaryngologist sat at the remote robotic console and began the closure of the muscle and mucosa, performed with tremor-free precision using the robotic arms. Using 2 articulated needle drivers, the seated surgeon closed the muscle and mucosa with the da Vinci robotic arms. A single layer suture with 3-0 vicryl was performed, and all suture ties were made from the operating surgeon console utilizing the articulated hands of the robot. The upper sutures required the 30-degree endoscope, whereas the middle of the incision could be closed with the 0-degree instrument. A postdecompression CT scan demonstrated excellent decompression of the craniocervical junction (fig. 4).

This procedure was then followed by the posterior cervical stabilization procedure which involved an occiput-to-C_2 fusion using the Depuy fusion hardware. C_1 lateral mass screws and C_2 pars screws were placed using standard techniques as described by Harms and Melcher [15]. The patient was kept in a halo device and was kept intubated overnight. She was extubated the next day. Once swallowing function was deemed to be satisfactory, she was allowed to resume a normal diet within 1 week and was discharged to rehabilitation.

Discussion

A transoral robot-assisted decompression of the craniocervical junction is technically feasible, but it could not have been performed without the significant amount of work that our group has already done with the transoral robotic resection of tumors in patients with head and neck cancer [7]. We followed this work with cadaver

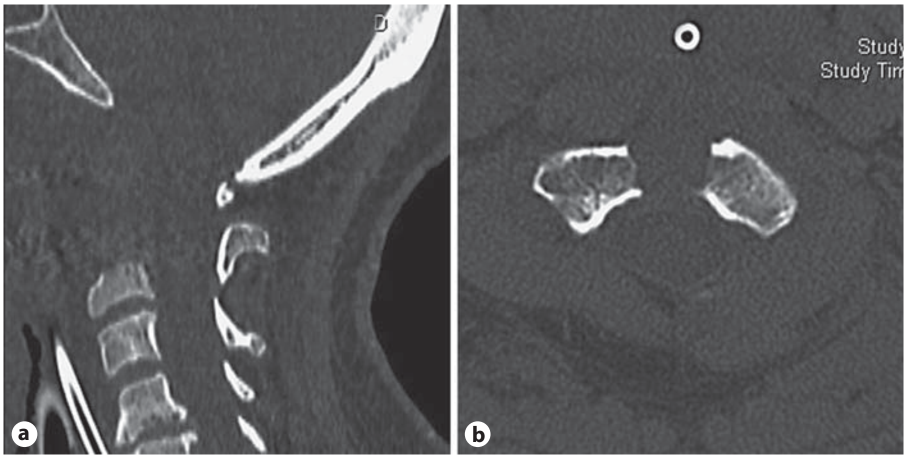

Fig. 4. CT scan performed after the decompression demonstrates excellent decompression of the bony elements. **a** CT scan that demonstrates no remnant bone from the odontoid to the base of C_2. **b** The axial CT scan on the right demonstrates the width of the decompression and the missing pathological odontoid.

work in the spine [13] and then proceeded with this case under an IRB protocol. In addition, our group has carefully used the da Vinci robot in applications in the lumbar spine as well [16]. The experience of this surgery, invaluable as a source of improvements and ideas, has clarified limitations of the da Vinci robot and highlighted its capabilities. Our discussion focuses first on its advantage, followed by a discussion of persistent limitations and finally we offer suggestions for how these might be overcome in the future.

Superb visualization of the operative field is the first advantage the da Vinci robot offers. The narrowness of the working channel and depth of the field have let other surgeons be faced with the problem to develop elaborate approaches requiring splitting of the mandible or a labored upward reach from an retropharyngeal exposure [17]. The illumination and especially the depth perception that the binocular camera provides make the dissection accurate and precise. Unlike a conventional endoscope, the precise depth and orientation of the da Vinci camera are controlled by the operating surgeon, with hands-free controls, no untoward motion and a wide field of view. These advantages became especially apparent during the initial dissection, when the eustachian tubes were identified and avoided. The bony structures underlying the mucosa, including the C_1 ring and the clivus, were identifiable prior to mucosal incision. Most importantly, the occipitocervical joint capsule and the interface between the dura and the posterior longitudinal ligament were visualized, and subtle corrections were communicated from the surgeon seated at the console (with a 3-dimensional view) to the operating surgeon at the bedside.

Control at depth in a narrow, geometrically limited working space is another advantage of the da Vinci system. This proved necessary to achieve a good closure of the oral mucosa at the end of the procedure, and it was useful during the exposure. While no durotomy occurred during this case, we have previously demonstrated the ability of the da Vinci system to perform dural closure after odontoidectomy using the robotic dissectors and needle drivers. This control far exceeds that available using conventional endoscopic techniques and is more flexible than with microscopic techniques. The wristed dissectors also permit the robotic arms to make acute-angled reaches around anatomic roadblocks. Specifically, if a patient's dens axis sits unusually high, conventional transoral approaches may reach their limits without exposing the entire length of the dens to the basion. This may, for example, necessitate a combined transnasal/transoral surgery [18–20]. The da Vinci robot suffers fewer such limitations because it is capable of retaining significant freedom of movement at depth in the surgical field, permitting it to reach around the hard palate and access structures more superiorly.

Our group has described some of the da Vinci system's disadvantages based on our previous, preclinical work [13, 16], but the details of its current limitations came into clearer view after our first attempt at a clinical intervention. The lack of instruments for bony dissection is the first limitation. Because conventional instruments have to be used to remove the odontoid and other bony structures, the operating surgeon must stand at the bedside in an ergonomically deleterious position, working around the robotic endoscope, using a 2-dimensional display to guide his dissection. While the corrections offered by the assistant based on his 3-dimensional view are helpful, the true benefits of the da Vinci system will only manifest themselves once the surgery can be performed completely by the operating surgeon while seated at the robotic console. Similarly, the necessity of a bedside assistant, even for the early stages of the operation, will require a system that allows him or her to benefit from the possibility of a 3-dimensional view of the surgical site. Such technology exists but is not widely available.

As this was the first human robotic skull base surgery, it suffered from a number of inefficiencies of space utilization and arrangement of equipment. Ultimately, the case took longer than a standard microscopic or endoscopic transoral odontoidectomy. Specifically, docking the da Vinci robot required 15 min. The initial pharyngeal dissection took 1 h. The decompression itself lasted 1.5 h, and the closure required another additional hour. The total surgical time was 4 h. However, we expect that it will diminish considerably as all personnel involved become more familiar with the requisite protocols. Also, we feel that if a durotomy were to occur, it could be closed much more quickly with robotic than conventional techniques.

Conclusion

This paper describes the first clinical application of the da Vinci robotic system to the craniocervical junction and skull base as performed via a transoral robot-assisted odontoidectomy. A fully robotic surgery will require the development of new tools for the da Vinci robotic arms, and the company has signaled some interest in this direction with their publication [21]. Specifically, high-speed air drills, Kerrison punches and curettes for bony dissection are still required. Nevertheless, the unique advantages of robotic surgery will prompt otolaryngologists and neurosurgeons to further refine and perfect its use and application to the difficult problems of skull base surgery. Given the recent FDA approval of the transoral robotic surgical procedure for head and neck cancer in the USA, we anticipate progressive and gradual steps directed towards the skull base.

References

1 Crockard HA, Essigman WK, Stevens JM, Pozo JL, Ransford AO, Kendall BE: Surgical treatment of cervical cord compression in rheumatoid arthritis. Ann Rheum Dis 1985; 44:809–816.

2 Hadley MN, Dickman CA, Browner CM, Sonntag VK: Acute axis fractures: a review of 229 cases. J Neurosurg 1989;71:642–647.

3 Menezes AH, Van Gilder JC: Transoral-transpharyngeal approach to the anterior craniocervical junction: ten-year experience with 72 patients. J Neurosurg 1988;69:895–903.

4 Menezes AH, Van Gilder JC, Graf CJ, McDonnell DE: Craniocervical abnormalities: a comprehensive surgical approach. J Neurosurg 1980;53:444–455.

5 Hockstein NG, O'Malley BW Jr, Weinstein GS: Assessment of intraoperative safety in transoral robotic surgery. Laryngoscope 2006;116:165–168.

6 O'Malley BW Jr, Weinstein GS: Robotic anterior and midline skull base surgery: preclinical investigations. Int J Radiat Oncol Biol Phys 2007;69:S125–S128.

7 O'Malley BW Jr, Weinstein GS: Robotic skull base surgery: preclinical investigations to human clinical application. Arch Otolaryngol Head Neck Surg 2007;133:1215–1219.

8 O'Malley BW Jr, Weinstein GS, Hockstein NG: Transoral robotic surgery (TORS): glottic microsurgery in a canine model. J Voice 2006;20:263–268.

9 Weinstein GS, O'Malley BW Jr, Hockstein NG: Transoral robotic surgery: supraglottic laryngectomy in a canine model. Laryngoscope 2005;115:1315–1319.

10 O'Malley BW Jr, Weinstein GS, Snyder W, Hockstein NG: Transoral robotic surgery (TORS) for base of tongue neoplasms. Laryngoscope 2006;116:1465–1472.

11 Weinstein GS, O'Malley BW Jr, Snyder W, Hockstein NG: Transoral robotic surgery: supraglottic partial laryngectomy. Ann Otol Rhinol Laryngol 2007;116:19–23.

12 Weinstein GS, O'Malley BW Jr, Snyder W, Sherman E, Quon H: Transoral robotic surgery: radical tonsillectomy. Arch Otolaryngol Head Neck Surg 2007;133:1220–1226.

13 Lee JY, O'Malley BW Jr, Newman JG, Weinstein GS, Lega B, Diaz J, Grady MS: Transoral robotic surgery of craniocervical junction and atlantoaxial spine: a cadaveric study. J Neurosurg Spine 2010;12:13–18.

14 Tun K, Kaptanoglu E, Cemil B, Karahan ST, Esmer AF, Elhan A: A neurosurgical view of anatomical evaluation of anterior C_1–C_2 for safer transoral odontoidectomy. Eur Spine J 2008;17:853–856.

15 Harms J, Melcher RP: Posterior C_1–C_2 fusion with polyaxial screw and rod fixation. Spine (Phila Pa 1976) 2001;26:2467–2471.

16 Kim MJ, Ha Y, Yang MS, Yoon DH, Kim KN, Kim H, et al: Robot-assisted anterior lumbar interbody fusion (ALIF) using retroperitoneal approach. Acta Neurochir (Wien) 2009, E-pub ahead of print.

17 Vender JR, Harrison SJ, McDonnell DE: Fusion and instrumentation at C_{1-3} via the high anterior cervical approach. J Neurosurg 2000;92:24–29.

18 Messina A, Bruno MC, Decq P, Coste A, Cavallo LM, de Divittis E, et al: Pure endoscopic endonasal odontoidectomy: anatomical study. Neurosurg Rev 2007;30:189–194, discussion 194.

19 Welch WC, Kassam A: Endoscopically assisted transoral-transpharyngeal approach to the craniovertebral junction. Neurosurgery 2003;52:1511–1512.

20 Wu JC, Huang WC, Cheng H, Liang ML, Ho CY, Wong TT, et al: Endoscopic transnasal transclival odontoidectomy: a new approach to decompression: technical case report. Neurosurgery 2008;63:ONSE92–94, discussion ONSE94.

21 Ponnusamy K, Chewning S, Mohr C: Robotic approaches to the posterior spine. Spine (Phila Pa 1976) 2009;34:2104–2109.