Annals of Otology, Rhinology & Laryngology 122(2):73-84.

Clinical Outcomes of Transoral Robotic Surgery for Head and Neck Tumors

Young Min Park, MD; Won Shik Kim, MD; Hyung Kwon Byeon, MD; Armando De Virgilio, MD; Sei Young Lee, MD; Se-Heon Kim, MD, PhD

Objectives: In order to reduce treatment-related morbidity rates and increase patients' quality of life, robot-assisted surgery using the da Vinci surgical system (Intuitive Surgical Inc, Sunnyvale, California) has been studied actively in the field of head and neck surgery. This study analyzes our experiences therewith in order to evaluate the feasibility and efficacy of robot-assisted surgery via a transoral approach in the head and neck area.

Methods: Between April 2008 and December 2011, 141 patients were treated with robot-assisted surgery via a transoral approach.

Results: Robot-assisted surgeries were successfully completed via a transoral approach in all patients. The mean robotic operative time was 69.3 minutes, and the mean time for setup of the robotic system was 10.4 minutes. The average blood loss during the operation was 29.6 mL (range, 0 to 300 mL). Patients who underwent robot-assisted surgery were satisfied with their cosmetic results and treatment outcomes.

Conclusions: Robot-assisted surgery via a transoral approach was confirmed to be feasible and efficient in the field of head and neck surgery. Further research is needed to investigate the long-term functional and oncological results of robot-assisted surgery.

Key Words: head and neck neoplasm, minimally invasive surgical procedure, robotics, transoral robotic surgery.

INTRODUCTION

The newest paradigm in surgery has been minimally invasive surgery using sophisticated endoscopic techniques. Compared to open surgery, endoscopic surgery shows better results in terms of hospital stay, postoperative pain, period of recovery to normal life, and immunologic response, because damage to collateral tissues is reduced.[1-4] However, endoscopic surgery has not been widely used in head and neck surgery because of several limitations. It is difficult to perform delicate surgical operations in a narrow and deep working space with 2-dimensional visualization and long and non-flexible instruments that are not diverse enough to suit the needs of endoscopic surgery of the head and neck. Robot-assisted surgery using the da Vinci surgical system (Intuitive Surgical Inc, Sunnyvale, California) has been studied in a search to overcome the limitations of endoscopic surgery in the field of head and neck surgery.

Surgical resection of upper aerodigestive tract tumors requires an incision on the face or neck and leaves a visible scar. Also, invasive procedures such as a transcervical or transmandibular approach are often used to remove tumors of the upper aerodigestive tract. These invasive procedures have disadvantages in that they can end in poor cosmetic results and also in poor functional results affecting swallowing and speech. To overcome these problems, a few studies have researched methods for removing lesions via a transoral approach using robotic surgical systems without face or neck incisions. Weinstein et al[5] defined this procedure as transoral robotic surgery (TORS), which progresses by insertion of at least 3 robotic arms through the oral cavity. We have performed robot-assisted surgery using the da Vinci surgical system on diseases of the upper aerodigestive tract through a transoral approach. This prospective study analyzes these experiences, evaluating the feasibility and efficacy of robot-assisted surgery via a transoral approach in the head and neck area.

MATERIALS AND METHODS

Patients. The Institutional Review Board of Yonsei University authorized this prospective study. In-

From the Department of Otorhinolaryngology, Yonsei University College of Medicine (Park, W. S. Kim, Byeon, S.-H. Kim), and the Department of Otorhinolaryngology, Chung-Ang University College of Medicine (Lee), Seoul, Korea, and the Department of Otorhinolaryngology, Sapienza University of Rome, Rome, Italy (De Virgilio).

Correspondence: Se-Heon Kim, MD, PhD, Dept of Otorhinolaryngology, Yonsei University College of Medicine, 50 Yonsei-ro, Seodaemun-gu, Seoul 120-752, Korea.

TABLE 1. TRANSORAL ROBOTIC SURGERY PROCEDURES ACCORDING TO HEAD AND NECK REGION

Anatomic Region (Patients)	*Subsite (Patients)*	*Disease (Patients)*	*Mean Setup Time (min)*	*Mean Robotic Operation Time (min)*	*Mean Time to Return to Swallowing (d)*	*Mean Blood Loss (mL)*
Oral cavity (7)	Tongue (5) Floor of mouth (2)	Malignancy (7)	11.7	79.0	4.0	115.0
Oropharynx (55)	Tonsil (31) Base of tongue (20) Retromolar trigone (2) Soft palate (2)	Malignancy (39) Benign diseases (16)	8.4	73.2	6.1	12.7
Hypopharynx (30)	Pyriform sinus (24) Posterior pharyngeal wall (5) Postcricoid area (1)	Malignancy (28) Benign diseases (2)	14.2	65.7	8.6	15.0
Larynx (36)	Glottis (26) Supraglottis (10)	Malignancy (31) Benign diseases (5)	11.2	50.6	4.8	8.0
Parapharynx (11)		Benign diseases (11)	10.4	80.7	5.3	9.7
Nasopharynx (2)		Benign diseases (2)	10.0	20.0	3.0	50.0

formed consent was obtained from all patients before their operations. The study included 141 patients who all underwent operation between April 2008 and December 2011. The patients were divided into 2 different categories. The first group of patients underwent TORS for the treatment of disease in the upper aerodigestive tract (oral cavity, nasopharynx, oropharynx, hypopharynx, or larynx). The second group underwent robotic resection of a parapharyngeal tumor via a transoral or transoral-transparotid approach.

A total of 130 patients underwent TORS for the treatment of disease in the upper aerodigestive tract. The average age of these patients was 58.4 years (range, 19 to 78 years); 105 patients were male and 25 patients were female. The primary sites of lesions were in the oral cavity in 7 patients, the oropharynx in 55 patients, the hypopharynx in 30 patients, the larynx in 36 patients, and the nasopharynx in 2 patients (Table 1). The inclusion criteria for TORS were 1) age greater than 18 years and 2) disease of the oral cavity, oropharynx, hypopharynx, larynx, or nasopharynx that required surgical treatment. Cases in which a through-and-through defect was expected after wide surgical resection were excluded, as were patients with inadequate exposure due to inadequate mouth opening or retrognathia.

Robotic resection of a parapharyngeal tumor was performed in 11 patients via a transoral or transoral-transparotid approach. The average age of these patients was 42.2 years (range, 24 to 61 years). Eight patients were male and 3 were female. Their diagnoses were pleomorphic adenoma in 6, schwannoma in 2, chondroid tumor in 1, and other in 2. If patients had a suspected malignant neoplasm before the operation, they were excluded from this study.

Robotic Surgical System. The da Vinci surgical system comprises 3 elements. First, the surgeon's console, at which the operator is located, controls robotic arms that are attached to a manipulator cart. The ergonomic design of the console helps the operator feel less fatigue, even during long operations. Second, 1 endoscopic arm and 3 instrument arms are attached to the manipulator cart. A 0°, 30° face-up, or 30° face-down endoscope can be installed on the endoscopic arm, and these endoscopes are equipped with 2 integrated cameras that offer a 3-dimensional (3-D) visual field. The instrument arms can be equipped with 8-mm instruments for adults or 5-mm instruments for children. Multiplanar resection is made possible in a limited working space by the EndoWrist of the robotic instruments, and delicate procedures such as suturing or tying down are possible.

General anesthesia was attained once the patient was placed in a supine position on the surgical cart. A tracheotomy was performed in cases of malignant tumors to prevent possible airway obstruction by postoperative edema or bleeding that may follow wide resection. Endotracheal intubation was performed in cases of benign disease. For approaching the larynx and hypopharynx, the FK-WO retractor (Gyrus Medical Inc, Maple Grove, Minnesota) was used with patients placed in the Boyce position. The Dingman and Crowe-Davis retractors were used to expose the oropharynx and parapharynx. The surgical cart was turned around so that the foot side of the surgical cart was located at 180° to the anesthesia team. The patient's head was then placed on the foot side of the surgical cart. The manipulator unit was placed on the patient's right side so that it could form an angle of 30° with the surgical cart (Fig 1A).

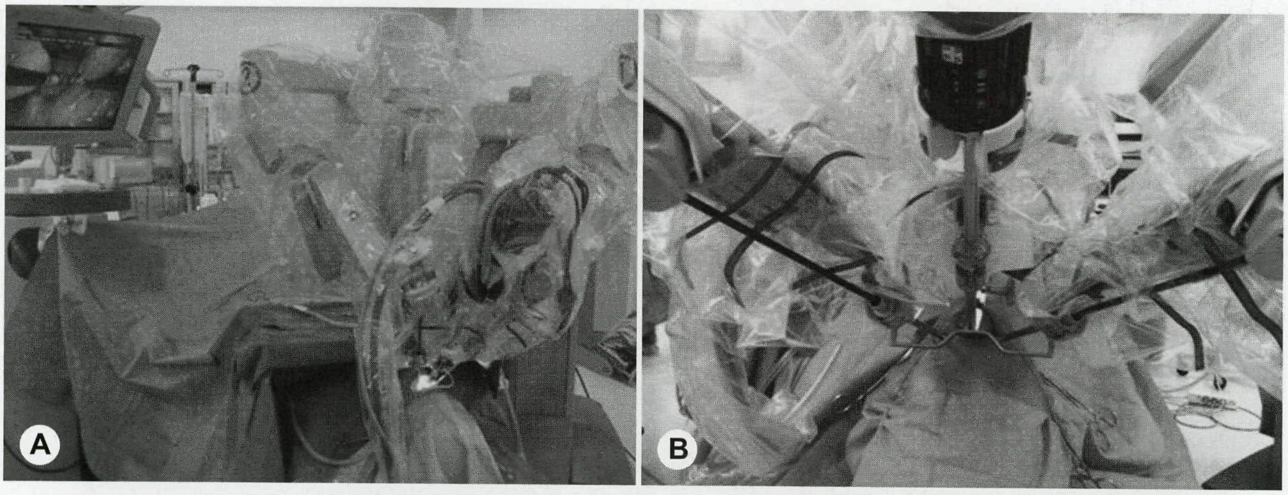


Fig 1. A) Manipulator unit was placed on patient's right side so that it could form 30° angle with surgical cart. **B)** Endoscopic arm was placed at center of oral cavity, and 2 instrument arms were placed laterally to each side to form 30° angle with endoscopic arm.

The endoscopic arm was placed at the center of the oral cavity, and the 2 instrument arms were placed to each side to form an angle of 30° with the endoscopic arm (Fig 1B). An adequate surgical view was obtained by installing a 0°, 30° face-up, or 30° face-down endoscope, depending on the circumstances. A 5-mm monopolar cautery, a Maryland dissector, or a needle driver was attached to the instrument arm to perform the operations.

Various surgical techniques were applied for the surgical treatment of lesions in various anatomic regions in the upper aerodigestive tract. Gaining more and more experience with TORS, we were able to

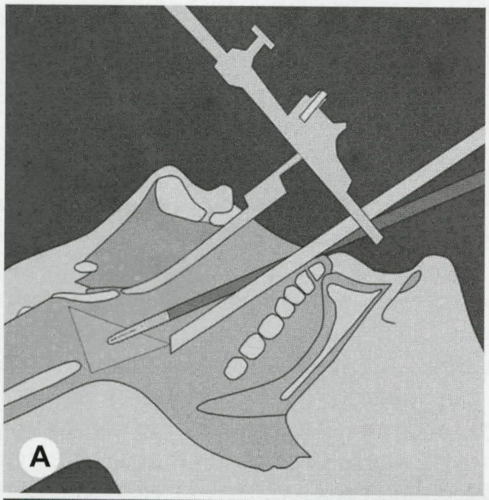
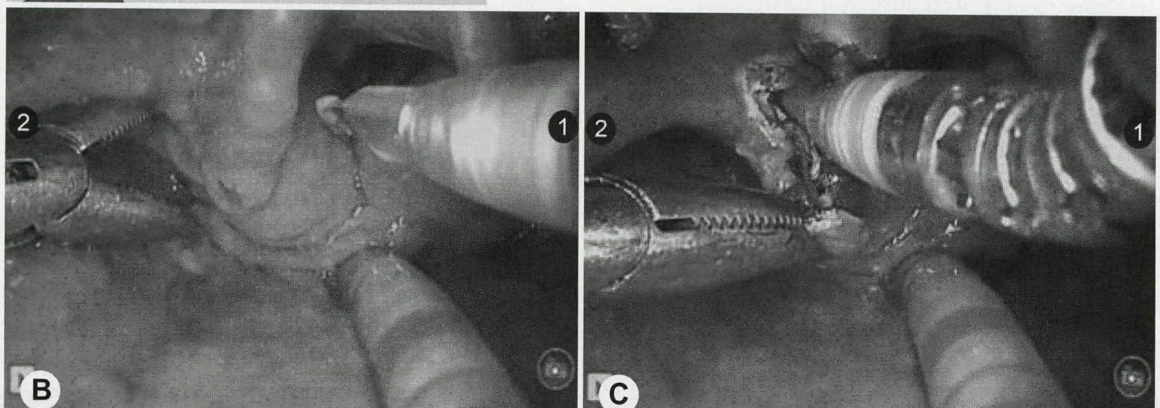


Fig 2. A) Endoscopic arm equipped with 30° face-up endoscope was positioned to form acute angle with surgical bed. Tip of endoscopic arm was located close to posterior wall. In contrast, 2 instrument arms were positioned to form obtuse angle with surgical bed. Instrument arms could then move in other plane without collision with robotic endoscopic arm. **B)** Flaccid epiglottis or retropulsion of epiglottis impeded exposure of surgical field. **C)** Additional view was gained after partial epiglottectomy.



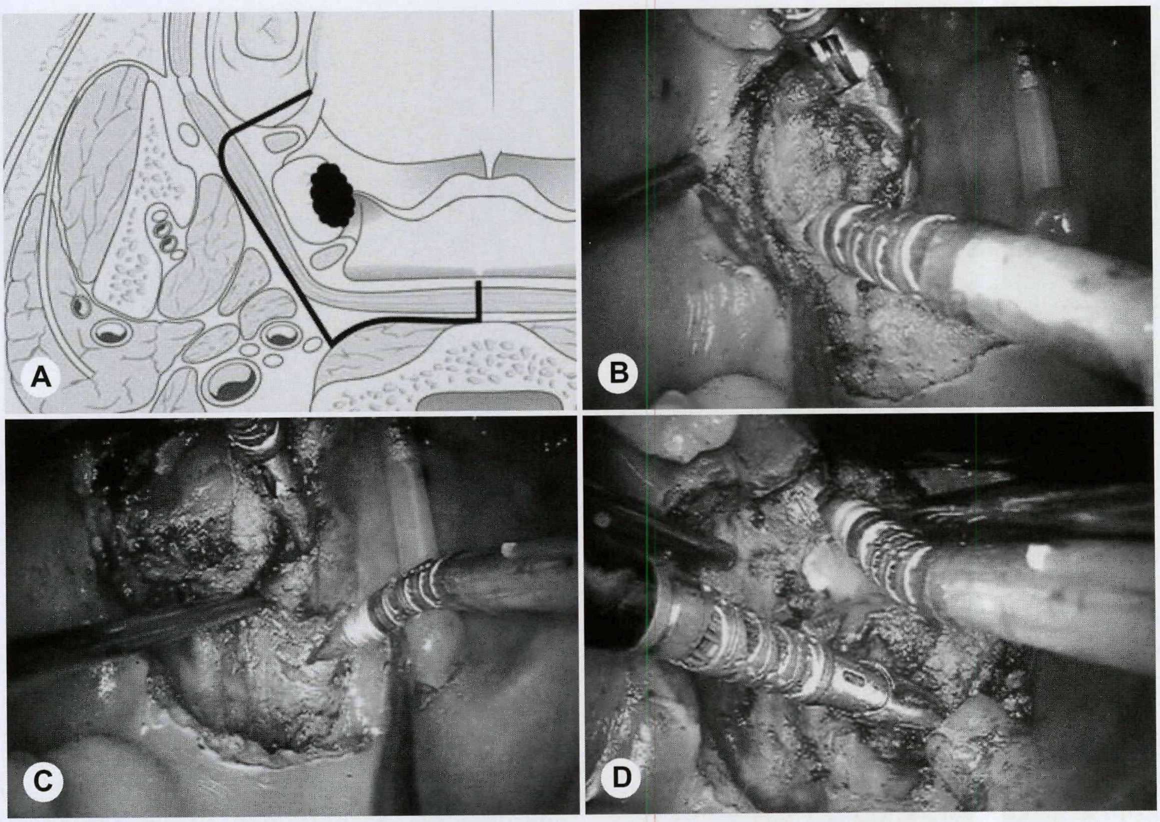


Fig 3. A) Schematic view of transoral lateral oropharyngectomy. Black line — dissection plane. **B)** Resection margin was marked on mucosa with monopolar cautery. **C)** During lateral dissection, parapharyngeal fat pad, medial pterygoid muscle, and pulsation of carotid artery were easily confirmed. **D)** Finally, base of tongue area was resected and lesion was removed en bloc.

standardize the surgical techniques as transoral lateral oropharyngectomy for tonsillar cancer and total pyriform sinus resection for hypopharyngeal cancer. We described these techniques in previous reports.[6-8]

Adequacy of Exposure. On the basis of our experiences with TORS in patients with laryngeal and hypopharyngeal cancer, we established several strategies to obtain sufficient exposure. First, during general anesthesia for acquiring a biopsy specimen, we applied an FK-WO retractor and ensured that sufficient exposure could be obtained. We did not perform TORS in cases in which a sufficient view could not be obtained because of inadequate mouth opening or a retrognathic mandible. Second, an FK retractor with a Wollenberg laryngeal blade is usually used to create working space in laryngeal and hypopharyngeal surgeries; however, because tongue blades are wider than Wollenberg laryngeal blades, we preferred to use tongue blades to expose laryngeal and hypopharyngeal lesions in this study. Third, temporary tracheotomy was performed. This procedure provided the surgeon with a better view of the operative field and working space. Also, it helped to reduce the risk of airway obstruction from swelling and bleeding that might follow a wide resection. Therefore, it was not necessary to admit patients to the intensive care unit during the postoperative period. Fourth, the endoscopic arm equipped with a 30° face-up endoscope was positioned to form an acute angle to the patient. The tip of the endoscopic arm was placed toward the posterior pharyngeal wall. In contrast, the 2 instrument arms were positioned to form an obtuse angle to the patient (Fig 2A). This allowed the instrument arms to move in another plane so that they did not collide with the robotic endoscopic arm. Finally, under general anesthesia, the base of the tongue or epiglottis could be pulled back over the surgical field. In this situation, using an FK retractor with a tongue blade and performing a partial epiglottectomy provided the surgeon with a sufficient view of the operative field (Fig 2B,C).

Use in Oral Cavity and Oropharynx. The method of transoral lateral oropharyngectomy described by Holsinger et al[9] and Weinstein et al[10] was applied to the resection of tonsillar cancer. The lesion was exposed with a Dingman or a Crowe-Davis retractor. Instrument arms were equipped with a 5-mm monopolar cautery and a Maryland dissector. Resection margins were marked on the oral mucosa, including at least 1 cm of normal healthy tissue for

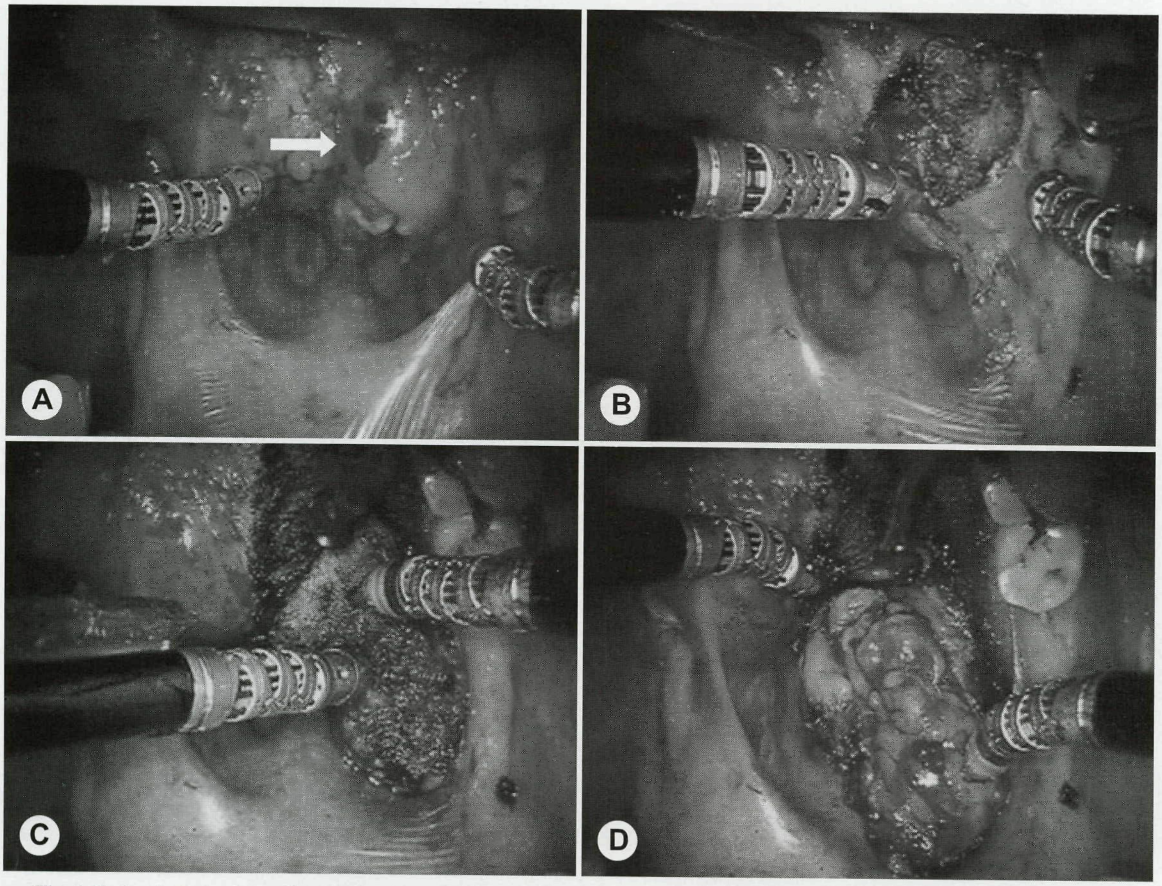


Fig 4. Robotic resection of base of tongue. **A)** About 1.5 × 2 cm of protruding tumor (arrow) was observed in base of tongue. **B,C)** Resection was performed around lesion circumferentially, maintaining direction of tip of spatula cautery toward hyoid bone. **D)** Lesion was removed en bloc with at least 1 cm of normal mucosal tissue.

a safe margin (Fig 3). Dissection of the buccal mucosa was performed first. After the buccal mucosa was vertically incised with a monopolar cautery, the pterygomandibular raphe in which the buccinator muscle and the superior constrictor muscle meet was confirmed. The dissection was conducted under the buccopharyngeal fascia as the lateral margin of the lateral oropharyngectomy. The dissection was carefully performed with multiarticulated hand-like robotic arms after identification of the parapharyngeal fat pad and pulsation of the carotid artery. During the procedure, the articulated robotic arms were positioned, forming an obtuse angle with the carotid artery, to minimize the risk of damaging it. The soft palate was then resected, the posterior wall was dissected from the prevertebral fascia, and the tongue base was resected as the last procedure of the en bloc tumor removal. A hemoclip was used to control bleeding from the lingual artery. Because the base of the tongue is not easily visualized with the naked eye and a classic retractor, it is difficult to resect lesions of the tongue base in conventional transoral surgery. However, we were able to obtain good visualization with a 30° face-up endoscope in this series; it helped in securing the inferior safe margins of the tumor.

Robotic resection of tongue base cancer was done with the da Vinci surgical system. The robotic surgical system was set up by the same method used in the transoral lateral oropharyngotomy procedure. The surgeon marked the resection margin by using a spatula cautery around the lesion. The resection margin was designed to include at least 1 cm of healthy mucosa. Resection was performed along the resection margin circumferentially, maintaining the direction of the tip of the spatula cautery toward the hyoid bone (Fig 4). This technique helped the surgeon obtain a sufficiently deep margin. Also, significant bleeding from the lingual artery may occur during the dissection of the base of the tongue. If such bleeding occurs during the procedure, it would impede the view of the operative field and would make it difficult to control bleeding. Therefore, the surgeon should be careful not to injure the lingual artery and should use a laryngeal hemoclip to control bleeding if it happens.

Use in Larynx. A partial laryngectomy was performed by use of the robotic surgical system for the treatment of glottic carcinoma. The FK retractor

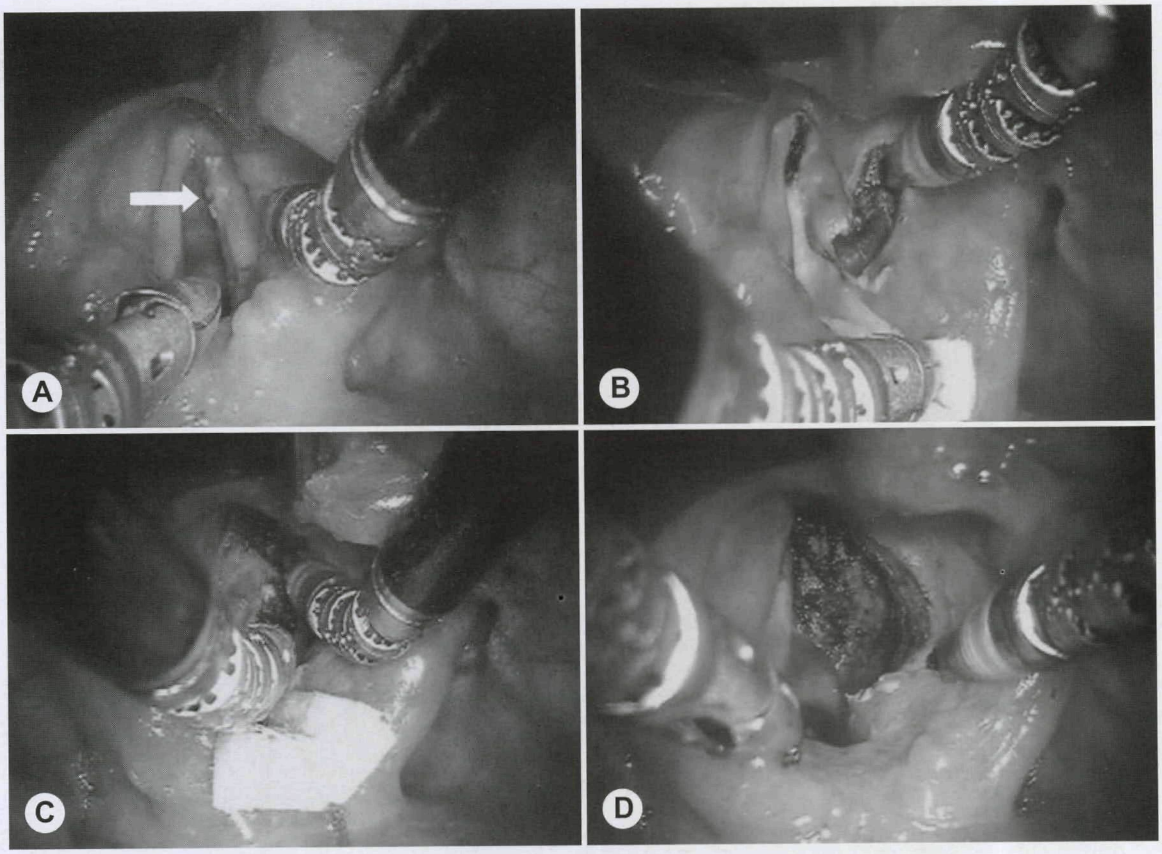


Fig 5. A) Partial laryngectomy was performed with robotic surgical system for treatment of glottic carcinoma (arrow). **B)** Dissection proceeded toward anterior commissure from vocal process of ipsilateral arytenoid cartilage, including part of paraglottic space, with inner surface of thyroid cartilage as lateral margin. **C)** At anterior commissure, resection was performed cephalocaudally after sufficient surgical view was obtained with 30° face-up endoscope. **D)** Tumor was removed en bloc, including ipsilateral paraglottic space.

was used to expose the lesion. The instrument arms were equipped with a 5-mm monopolar cautery and the Maryland dissector. Dissection began from the anterior portion of the contralateral vocal fold and proceeded toward the anterior commissure along the inner surface of the thyroid cartilage (Fig 5). Dissection then proceeded toward the anterior commissure from the vocal process of the ipsilateral arytenoid cartilage, including a part of the paraglottic space, with the inner surface of the thyroid cartilage as a lateral margin. At the anterior commissure, resection was performed cephalocaudally after a sufficient surgical view was obtained with a 30° face-up endoscope. When the tumor involved the anterior commissure, dissection proceeded as close as possible to the inner surface of the thyroid cartilage. Thereafter, tumors were removed en bloc.

Use in Hypopharynx. The entire pyriform sinus was resected in a cone shape for the en bloc removal of pyriform sinus carcinoma. The FK retractor was used to expose the lesion. The instrument arms were equipped with a 5-mm monopolar cautery and the Maryland dissector. The dissection was performed by proceeding anteriorly along the lateral side of the aryepiglottic fold on the side with the lesion up to the thyroid cartilage, and then laterally following the inner surface of the thyroid cartilage (Fig 6). The lateral wall of the pyriform sinus comprised only mucosa and submucosa; therefore, it was difficult to obtain a sufficient safe margin in the anterolateral portion. However, the inner perichondrium of the thyroid cartilage, which is a strong barrier against the spread of tumor, was able to be peeled off to secure an additional lateral safe margin. These procedures are impossible in conventional endoscopic surgery with laser and conventional instruments. The apex of the pyriform sinus was resected afterward, and en bloc resection of the tumor was achieved.

Use in Parapharynx. We adopted 1 of 3 different surgical techniques, depending on the location and dimension of the parapharyngeal tumor. We performed TORS alone in patients with a small tumor that did not extend toward the stylomandibular tunnel (Fig 7A). The parapharynx was exposed with a Crowe-Davis retractor. A vertical incision was made on the oropharyngeal mucosa overlying the tumor, after the tumor boundary was confirmed by digital palpation (Fig 7D). Careful dissection was

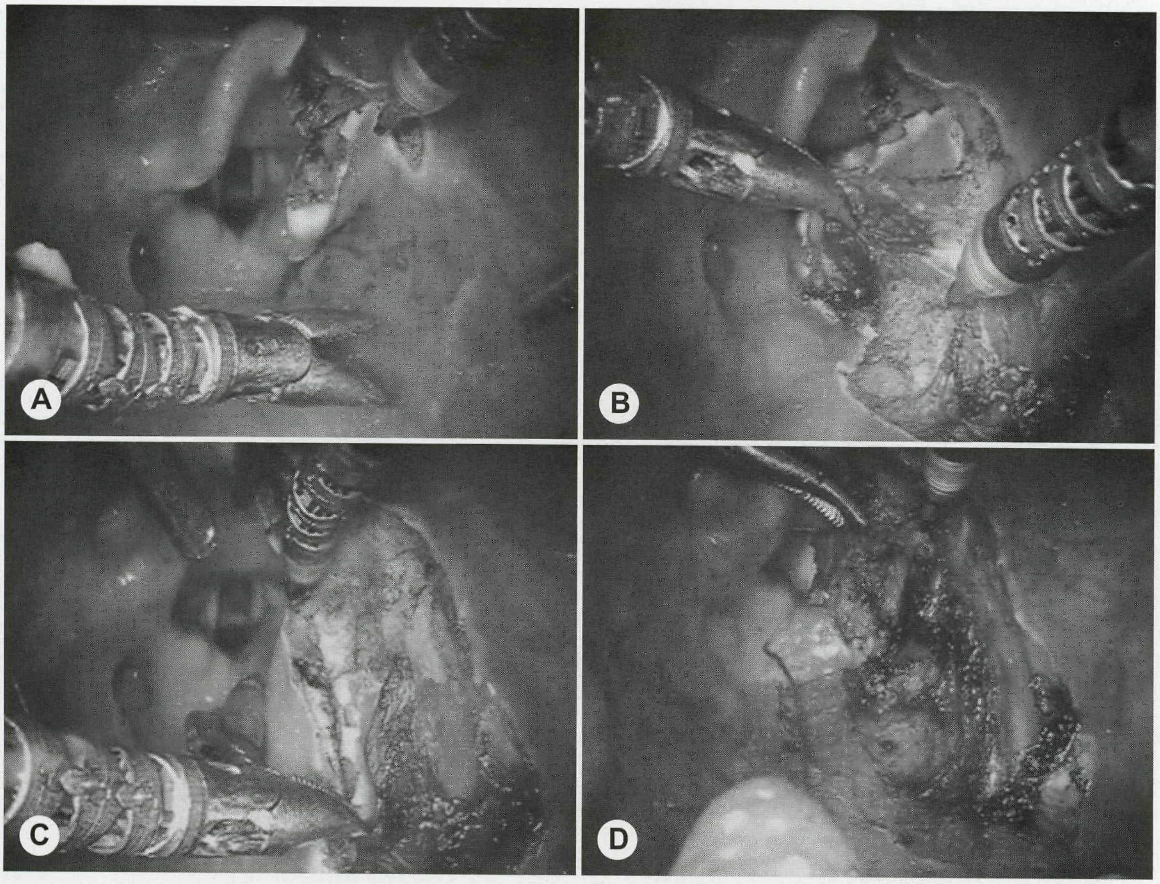


Fig 6. A) Because epiglottis obscured operative field, partial epiglottectomy was done. **B)** Dissection then proceeded in anterior direction along inner side of thyroid cartilage. **C)** Medial dissection was done along aryepiglottic fold. **D)** Appearance of operative field after pyriform sinus resection.

performed around the tumor to reduce the risk of damage to the cranial nerves and major vessels (Fig 7E). The resection was performed with monopolar cautery after identifying important structures under the surgical plane by dissecting surrounding tissues with the Maryland dissector. The axes of the articulated robotic arms were positioned to form an obtuse angle with the carotid artery to avoid damaging it. A needle driver was used with Vicryl to suture the incision site after removal of the tumor (Fig 7F).

We performed TORS with a debrider (Osseoduo 120, Bien-Air Surgery, Le Noirmont, Switzerland) in patients with a large tumor extending toward the stylomandibular tunnel (Fig 7B). At first, the tumor capsule was incised and the curved tip of the debrider was inserted into the central portion of the tumor. After debulking the central compartment of the tumor using a debrider, the surgeon could remove the remnant of tumor transorally with the da Vinci surgical system.

We performed TORS combined with a transparotid approach in patients with a dumbbell-shaped tumor originating from the deep lobe of the parotid gland (Fig 7C). After dissecting the medial portion of the tumor transorally with the da Vinci surgical system, we performed partial parotidectomy through a modified Blair incision. The tumor was then removed through an external incision (a modified Blair incision) with preservation of the facial nerve.

RESULTS

Operative Outcomes. Surgical operations were successfully performed in all patients by use of the robotic surgical system. The robotic operative time was 61.5 minutes on average, and the average docking time of the robotic surgical system was 11 minutes. The mean blood loss was 33.6 mL (range, 5 to 300 mL). Blood transfusion due to significant bleeding was not required in any case, and there were no cases in which conversion to open surgery was needed for hemostasis (Table 1).

Postoperative Outcomes. Thirty-five of the 36 patients (97%) who underwent TORS for the surgical treatment of benign disease in the upper aerodigestive tract were extubated successfully immediately after the operation. One patient underwent transoral resection using the robotic surgical system to resect a chordoma of the nasopharynx, and a planned tra-

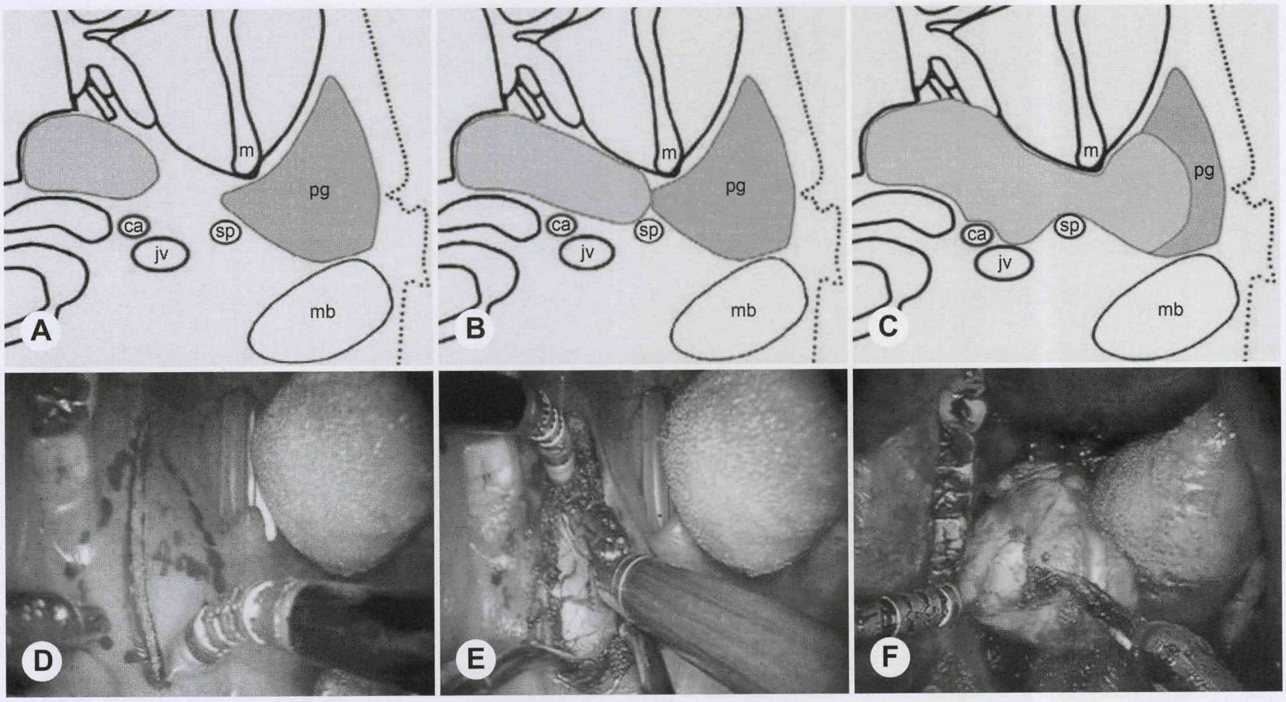


Fig 7. We adopted 1 of 3 different surgical techniques, depending on location and dimension of parapharyngeal tumor. ca — carotid artery; m — mandibular ramus; jv — jugular vein; sp — styloid process; pg — parotid gland; mb — mastoid bone. **A)** Transoral robotic surgery (TORS) alone was performed in patients with small tumor that did not extend toward stylomandibular tunnel. **B)** TORS with debrider (Osseoduo 120, Bien-Air Surgery, Le Noirmont, Switzerland) was used in patients with large tumor that extended toward stylomandibular tunnel. **C)** TORS combined with transparotid approach was used in patients with dumbbell-shaped tumor originating from deep lobe of parotid gland. **D)** Vertical incision was imposed on oropharyngeal mucosa. **E)** Resection progressed carefully along margin of tumor with use of Maryland dissector and monopolar cautery. **F)** After extirpation of tumor, incision site was sutured with Vicryl and needle driver.

cheotomy was performed to prepare for possible airway obstruction from swelling and bleeding. Decannulation was performed on the third day after the operation. In cases of TORS performed on the upper aerodigestive tract, short-term nasal tube feeding was performed to prevent infection of the operative site and aspiration. An average of 5.3 days (range, 3 to 14 days) was required for the removal of nasal feeding tubes, which was performed after confirming that there was no aspiration and that the patient tolerated a normal diet.

One 70-year-old male patient who underwent TORS for resection of a base-of-tongue carcinoma (T2 N0 M0) was treated for aspiration pneumonia in the postoperative period. He died 2 weeks later of respiratory failure. He had had chronic obstructive lung disease with lowered lung function before the procedure and was unable to recover in the intensive care unit with ventilator care. A 76-year-old male patient who underwent TORS for hypopharyngeal cancer (T4a N0 M0) was treated for postoperative dysphagia. Otherwise, there were no cases in which an emergency operation was required for postoperative airway obstruction or bleeding, and there were no complications.

Oncological Outcomes. One hundred five patients underwent TORS for the treatment of malignant neoplasms in the upper aerodigestive tract. The average age of the patients was 47.5 years (range, 28 to 78 years); 91 patients were male and 14 patients were female. The primary sites of the tumors were the oral cavity in 7 patients, oropharynx in 39 patients, hypopharynx in 28 patients, and larynx in 31 patients. Squamous cell carcinoma was diagnosed in 92 patients, adenoid cystic carcinoma in 8 patients, lymphoma in 2 patients, neuroendocrine carcinoma in 1 patient, metastatic adenocarcinoma in 1 patient, and malignant melanoma in 1 patient. Most patients underwent TORS as the primary treatment, but 2 patients underwent TORS as salvage surgery after chemoradiation failure. The final pathology reports were negative for malignancy upon evaluation of the tumor margins in 96% of the patients. Other information is shown in Tables 2 and 3. In general, TORS was carried out to resect T1 (41%) and T2 (42%) tumors. Fifteen patients (17%) with stage T3 and T4 tumors underwent TORS, as invasion of the surrounding tissue was not severe or deep and transoral resection was thought to be possible. Forty-seven percent of patients had early-stage disease (stage I or II), and 53% of patients had advanced-

TABLE 2. DATA ON 105 PATIENTS WITH MALIGNANT NEOPLASMS WHO UNDERWENT TRANSORAL ROBOTIC SURGERY

Characteristics	*Patients* No.	*Patients* %
Primary site		
Oral cavity	7	7
Oropharynx	39	37
Hypopharynx	28	27
Larynx	31	30
Disease		
Squamous cell carcinoma	92	88
Adenoid cystic carcinoma	8	8
Lymphoma	2	2
Malignant melanoma	1	1
Neuroendocrine carcinoma	1	1
Metastatic adenocarcinoma	1	1
T classification*		
T1	38	41
T2	39	42
T3	7	8
T4	8	9
Resection margin		
Positive	4	4
Negative	101	96
Neck dissection		
None	27	26
Unilateral	68	65
Bilateral	10	9
Adjuvant treatment		
None	49	47
Radiotherapy alone	44	42
Concurrent chemoradiation	12	11

*Includes only patients with squamous cell carcinoma.

stage disease (stage III or IV).

The mean follow-up period was 18.2 months (range, 6 to 43 months). During the follow-up period, 5 patients had recurrent disease: 1 local recurrence, 1 regional recurrence, and 3 distant metastases. At the last outpatient department visit, 100 patients showed no evidence of disease, 2 patients had died of distant metastasis, 1 patient had died of other disease, and 2 patients were alive with disease. On Kaplan-Meier analysis, the overall survival rate at 2 years was 96%, and the disease-free survival rate was 91% (Fig 8). An oral diet was tolerated at an average of 6.2 days, and decannulation was performed at an average of 5.5 days. Seventy-eight patients (74%) underwent neck dissection: unilateral in 87% and bilateral in 13%. Postoperative fistula was not observed in any case with concurrent neck dissection. Adjuvant treatment was performed in cases (53%) that were positive for malignancy in resection margins, extracapsular nodal spread, or greater than N2b disease according to National Comprehensive Cancer Network guidelines.

TABLE 3. TNM CLASSIFICATION OF 92 PATIENTS WITH SQUAMOUS CELL CARCINOMA WHO UNDERWENT TRANSORAL ROBOTIC SURGERY

	N0	*N1*	*N2a*	*N2b*	*N2c*	*Total*
T1	25	2	0	10	1	38
T2	18	10	0	10	1	39
T3	1	1	0	4	1	7
T4	3	0	0	3	2	8
Total	47	13	0	27	5	92

Percentage of patients with each disease stage: stage I, 27%; stage II, 20%; stage III, 15%; stage IV, 38%.

Advantages of TORS in Oral Cavity and Oropharynx. Surgery was successfully completed without any injury to major vessels, and the transoral lateral oropharyngectomy technique was performed in patients with tonsillar cancer. The risk of damage to the carotid artery was minimized by use of the articulated robotic arms. The risk increased when the robotic arms were positioned at an acute angle with the carotid artery. Accordingly, the robotic arms were arranged to form an obtuse angle with the carotid artery during dissection of the posterior wall.

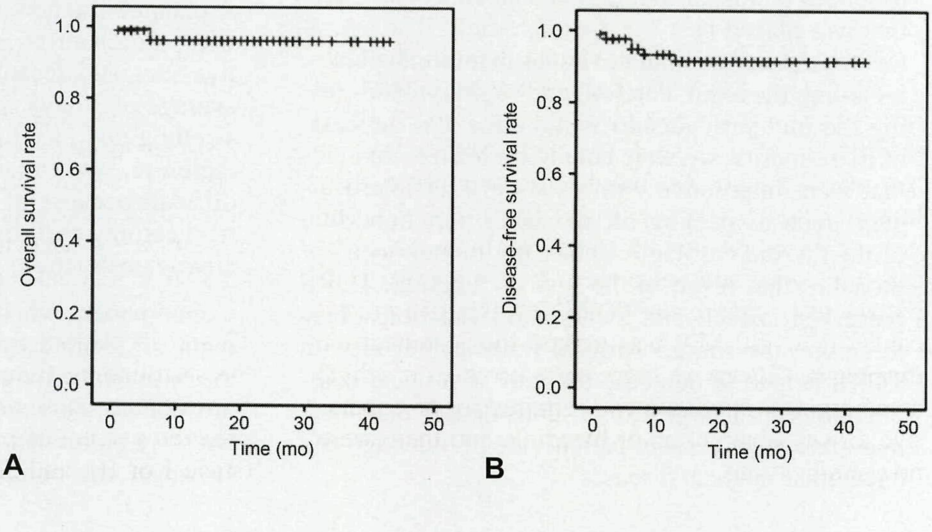


Fig 8. A) Overall survival rate and **B)** disease-free survival rate of patients with malignant tumors who underwent TORS.

A 3-D view of the tongue base region, which was obtained by 2 integrated cameras on the endoscopic arm, helped achieve a sufficient safe margin of the inferior portion. TORS was also successful in a case of tongue cancer with oropharyngeal extension, and a safe margin of the posterior portion was obtained. Deep lesions of the floor of the mouth were successfully removed under a 3-D magnified view with minimal injury to the nerves and vessels. Volume reduction of the base of the tongue was also successfully performed with the robotic surgical system in a patient with sleep apnea.

Advantages of TORS in Larynx. Conventional endoscopic cordectomy is ideal for the treatment of glottic carcinoma limited to one vocal fold because of the "line of limitation" that comes with it. This procedure cannot be performed if lesions are not well visualized with an endoscope. The tumor is removed en bloc via endoscopic cordectomy. On the other hand, TORS incorporates a robotic surgical system that can geometrically analyze and resect lesions of the larynx using a magnified 3-D view and multiarticulated robotic arms. The operator can manipulate the lesion through a bimanual technique aided by 2 instrument arms. Thanks to these advantages, tumors were resected en bloc without our having to cut through tissues.

Advantages of TORS in Hypopharynx. The hypopharynx is located deeper than the oral cavity and is made up of complex anatomic structures. To expose the lesions, we used an FK-WO retractor connected with a laryngeal blade and some of the instruments that were used in laryngeal microsurgery. It was not technically easy, as the robotic arms were required to operate in the narrow laryngeal lumen; however, effective resection was possible with use of Maryland forceps and a 5-mm spatula cautery. A magnified 3-D view of the lesion was obtained with endoscopes of various degrees and an endoscopic arm that was placed near the operative field. The operator was able to manipulate tissues in multiple planes, including the axial, coronal, and sagittal planes, using the multiarticulated robotic arms. On the basis of these merits, we were able to perform techniques that were impossible with existing laser microsurgery, such as peeling off the inner perichondrium of the thyroid cartilage. Unlike traditional open approaches that result in the loss of function, TORS preserved speech and swallowing functions. Furthermore, the shorter surgical times achieved with TORS helped to decrease the rate of surgical complications to a large extent, considering that most hypopharyngeal cancer patients are of older age and have other medical diseases.

Advantages of TORS in Parapharynx. Tumor extirpation was achieved without leaving an external scar on patients with parapharyngeal tumors. A magnified 3-D view enabled the operator to identify pulsation of the carotid artery, the pterygomandibular raphe, and the medial pterygoid muscle, which are difficult to differentiate with the naked eye; this advantage allowed the operator to keep track of anatomic landmarks throughout the operation. Thereby, injury to important neurovascular bundles in the parapharynx was minimized.

DISCUSSION

A transcervical approach with or without mandibulotomy or a lip-splitting incision is often used to resect neoplasms that occur in the upper aerodigestive tract. Such an invasive procedure is accompanied by a high morbidity rate and can lead to problems in swallowing or speech functions after the operation.[11-13] On the other hand, transoral resection can reduce the morbidity rate and preserve these functions. Because of these advantages, a study of transoral surgery using a robotic system was started. Early studies showed that TORS was feasible for resection of base-of-tongue and supraglottic carcinomas.[14] Subsequent studies were carried out to prove that TORS is feasible for lesions in the oral cavity, oropharynx, hypopharynx, and larynx.[6-8,15,16] In our study, TORS was carried out successfully for the treatment of lesions in various regions of the head and neck, and the feasibility thereof was confirmed.

Patients who underwent TORS were able to tolerate an oral diet at an average of 5.3 days after surgery and rapidly recovered their normal swallowing function. All patients who underwent endotracheal intubation were successfully extubated after the operation. Although other studies have reported instances of reintubation due to airway swelling, none of our patients required reintubation after extubation.[15] A planned tracheotomy was performed on patients with malignant neoplasms in the upper aerodigestive tract, and decannulation was performed after an average of 3 days. Airway obstruction due to tissue swelling and bleeding can cause serious problems; therefore, when maintaining airway patency seems difficult because of extensive resection, a planned tracheotomy performed in advance can help prevent airway obstruction.

One patient who underwent TORS for the treatment of adenoid cystic carcinoma (T2 N0 M0) of the base of the tongue experienced respiratory failure due to aspiration combined with chronic obstructive pulmonary disease, and he ultimately died. However, this complication was not directly related to the TORS procedure. No serious bleeding or complications occurred in other cases. Seventy-eight patients underwent neck dissection for the treatment of malignant nodal disease. These patients underwent concurrent neck dissection with TORS. Orocervical fistula related to concurrent neck dissection did not occur, nor did any other complications. This study confirms the relative safety of TORS and concurrent neck dissection in selected patients, despite the risk of fistula occurrence.

When performing TORS, it is important to secure suitable exposure, because the robotic arms must move in narrow and deep spaces. The oral cavity, oropharynx, and parapharynx can easily be exposed with the Dingman retractor or the Crowe-Davis retractor. For the larynx and hypopharynx, the FK-WO retractor should be used. Previous studies have found that retrognathia, aberrant dentition, and inadequate mouth opening are associated with inadequate exposure.[15,16] Upon preoperative physical examination in our study, when inadequate mouth opening was observed or when retrognathia was observed, the patients were excluded as targets of TORS. This practice helped achieve a higher success rate of TORS. In our study, there were no cases in which the operation was discontinued because of an inappropriate visual field. Because 1 endoscopic arm and 2 instrument arms move in a confined working space, they can collide with each other. Collision of the instrument arms was observed in the initial period of our study; however, as the surgeon gained more experience, the procedure was performed without instrument collision.

The final pathology report of the specimen was negative for malignancy in 96% of patients. Reports positive for malignancy were given for 4 patients, 2 of whom underwent TORS as salvage surgery after chemoradiation failure. Although all gross lesions in the salvage cases were removed with TORS, cancer cells were detected on histologic examination. On Kaplan-Meier analysis, the overall survival rate at 2 years was 96%, and the disease-free survival rate was 91%. Although long-term follow-up is required to validate these oncological results, the oncological results of TORS appear quite acceptable in our study.

These patients were able to tolerate an oral diet at an average of 6.2 days and were decannulated at an average of 5.5 days. They also recovered normal swallowing and speech function within 1 week. Because the constrictor muscles and pharyngeal nerve plexus were preserved during the TORS procedure, the patients were able to rapidly recover normal swallowing function without dysphagia or aspiration.

The parapharyngeal space is a complex anatomic area, because it contains significant neurovascular structures. A transcervical or transparotid approach is usually used to remove small tumors of the parapharyngeal space. In cases with a large tumor, a transmandibular approach is required to obtain a wide exposure of the operative field. However, these kinds of invasive approaches leave a visible scar on the face or neck and have a high morbidity rate. In this study, we performed various TORS techniques to resect parapharyngeal tumors. TORS was successfully performed in all patients, with good cosmetic results, and they showed a rapid recovery of swallowing function in the postoperative period. Using the maneuverability of robotic arms, the surgeons could control bleeding, preserve major vessels and cranial nerves, and completely extirpate the tumors.

CONCLUSIONS

The feasibility and efficacy of TORS were verified in the field of head and neck surgery. Transoral robotic surgery has the advantages of 3-D visualization, tremor filtration, and free movement of the instrument arms. Within a narrow working space, various procedures that are impossible to perform with instruments used in conventional endoscopic surgery were able to be performed, removing lesions and preserving surrounding healthy structures maximally for maintenance of function. However, this surgery was disadvantageous with respect to the limited instrument type, the high cost of the robotic system, and the lack of an exclusive retractor for obtaining working space. In the future, robot technology must be developed to overcome these disadvantages, and further research is needed to investigate the long-term functional and oncological results.

REFERENCES

1. Franklin ME Jr, Rosenthal D, Abrego-Medina D, et al. Prospective comparison of open vs. laparoscopic colon surgery for carcinoma. Five-year results. Dis Colon Rectum 1996;39 (suppl):S35-S46.

2. Cuschieri A, Dubois F, Mouiel J, et al. The European experience with laparoscopic cholecystectomy. Am J Surg 1991; 161:385-7.

3. Allendorf JD, Bessler M, Whelan RL, et al. Postoperative immune function varies inversely with the degree of surgical trauma in a murine model. Surg Endosc 1997;11:427-30.

4. Clinical Outcomes of Surgical Therapy Study Group. A comparison of laparoscopically assisted and open colectomy for colon cancer. N Engl J Med 2004;350:2050-9.

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

6. Park YM, Lee WJ, Lee JG, et al. Transoral robotic surgery (TORS) in laryngeal and hypopharyngeal cancer. J Laparoendosc Adv Surg Tech A 2009;19:361-8.

7. Park YM, Lee JG, Lee WS, Choi EC, Chung SM, Kim SH. Feasibility of transoral lateral oropharyngectomy using a robotic surgical system for tonsillar cancer. Oral Oncol 2009;45: e62-e66.

8. Park YM, Kim WS, Byeon HK, De Virgilio A, Jung JS, Kim SH. Feasibility of transoral robotic hypopharyngectomy for early-stage hypopharyngeal carcinoma. Oral Oncol 2010;46: 597-602.

9. Holsinger FC, McWhorter AJ, Ménard M, Garcia D, Laccourreye O. Transoral lateral oropharyngectomy for squamous cell carcinoma of the tonsillar region: I. Technique, complications, and functional results. Arch Otolaryngol Head Neck Surg 2005;131:583-91.

10. Weinstein GS, O'Malley BW Jr, Snyder W, Sherman E, Quon H. Transoral robotic surgery: radical tonsillectomy. Arch Otolaryngol Head Neck Surg 2007;133:1220-6.

11. Nam W, Kim HJ, Choi EC, Kim MK, Lee EW, Cha IH. Contributing factors to mandibulotomy complications: a retrospective study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;101:e65-e70.

12. Wang CC, Cheng MH, Hao SP, Wu CC, Huang SS. Osteoradionecrosis with combined mandibulotomy and marginal mandibulectomy. Laryngoscope 2005;115:1963-7.

13. Reiter D. Complications of mandibulotomy. Otolaryngol Head Neck Surg 2004;131:339.

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

15. Boudreaux BA, Rosenthal EL, Magnuson JS, et al. Robot-assisted surgery for upper aerodigestive tract neoplasms. Arch Otolaryngol Head Neck Surg 2009;135:397-401.

16. Genden EM, Desai S, Sung CK. Transoral robotic surgery for the management of head and neck cancer: a preliminary experience. Head Neck 2009;31:283-9.