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Robot-assisted endoscopic surgery for thyroid cancer: experience with the first 100 patients

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Abstract
Background Various robotic surgical procedures have been performed in recent years, and most reports have proved that the application of robotic technology for surgery is technically feasible and safe. This study aimed to introduce the authors' technique of robot-assisted endoscopic thyroid surgery and to demonstrate its applicability in the surgical management of thyroid cancer.
Methods From 4 October 2007 through 14 March 2008, 100 patients with papillary thyroid cancer underwent robot-assisted endoscopic thyroid surgery using a gasless transaxillary approach. This novel robotic surgical approach allowed adequate endoscopic access for thyroid surgeries. All the procedures were completed successfully using the da Vinci S surgical robot system. Four robotic arms were used with this system: a 12-mm telescope and three 8-mm instruments. The three-dimensional magnified visualization obtained by the dual-channel endoscope and the tremor-free instruments controlled by the robotic systems allowed surgeons to perform sharp and precise endoscopic dissections.
Results Ipsilateral central compartment node dissection was used for 84 less-than-total and 16 total thyroidectomies. The mean operation time was 136.5 min (range, 79–267 min). The actual time for thyroidectomy with lymphadenectomy (console time) was 60 min (range, 25–157 min). The average number of lymph nodes resected was 5.3 (range, 1–28). No serious complications occurred. Most of the patients could return home within 3 days after surgery.
Conclusions The technique of robot-assisted endoscopic thyroid surgery using a gasless transaxillary approach is a feasible, safe, and effective method for selected patients with thyroid cancer. The authors suggest that application of robotic technology for endoscopic thyroid surgeries could overcome the limitations of conventional endoscopic surgeries in the surgical management of thyroid cancer.

Keywords Endoscopic thyroid surgery · Gasless · Robot-assisted · Thyroid cancer · Transaxillary approach

Since the first report of endoscopic parathyroidectomy by Gagner [1] in 1996 and video-assisted thyroid lobectomy by Hüscher et al. [2] in 1997, various methods of endoscopic surgery have been introduced with the development of laparoscopic operations and endoscopic instruments during the past decade [3–9]. Recently, the suitability of endoscopic thyroidectomy has been accepted for some benign thyroid tumors, and the applicability of endoscopic thyroidectomy for early thyroid cancer has been investigated in several studies [10–14].

In general, conventional endoscopic surgeries have some limitations in obtaining adequate visualizations and precise, meticulous manipulation of the surgical tissues. These limitations result from the two-dimensional representation and

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the simplicity of the endoscopic instruments used [15]. The da Vinci S surgical robot system (Intuitive Surgical, Sunnyvale, CA, USA) was developed to address these limitations of conventional endoscopic surgery. Indeed, the da Vinci S robot system can provide safe and feasible operational manipulations through a three-dimensional magnified field of view, precise and multi-articulated hand-like motions, a hand-tremor filtering system, and an ergonomically designed operative space [15–19].

In some recent reports, application of the da Vinci S robot system in the abdominal and thoracic surgical fields has shown superior results compared with conventional laparoscopic surgeries [15, 18, 19]. Many surgeons anticipate that the application of robot systems in surgery will improve the techniques of minimally invasive surgery. There also are some reports about endoscopic head and neck surgeries using robotic systems together with several reports discussing the initial experiences of robot-assisted endoscopic thyroid surgery [16, 17]. All these reports, however, are limited to procedures involving mediastinal ectopic goiters or mediastinal metastatic lymph nodes and a few thyroid diseases such as Grave's disease or benign thyroid tumor [16, 17, 20].

Recently, we managed serial cases of endoscopic thyroidectomy with lymph node dissection using the da Vinci S surgical robot system for patients with thyroid cancer. To the best of our knowledge, application of the da Vinci S surgical robot system in thyroid cancer surgery has never been reported previously, and this report aims to demonstrate the applicability of this technique in the current context (Figs. 1, 2, 3).

Fig. 1 The robotic operation. Four robotic arms were placed through the patient's axilla and anterior chest wall trocar

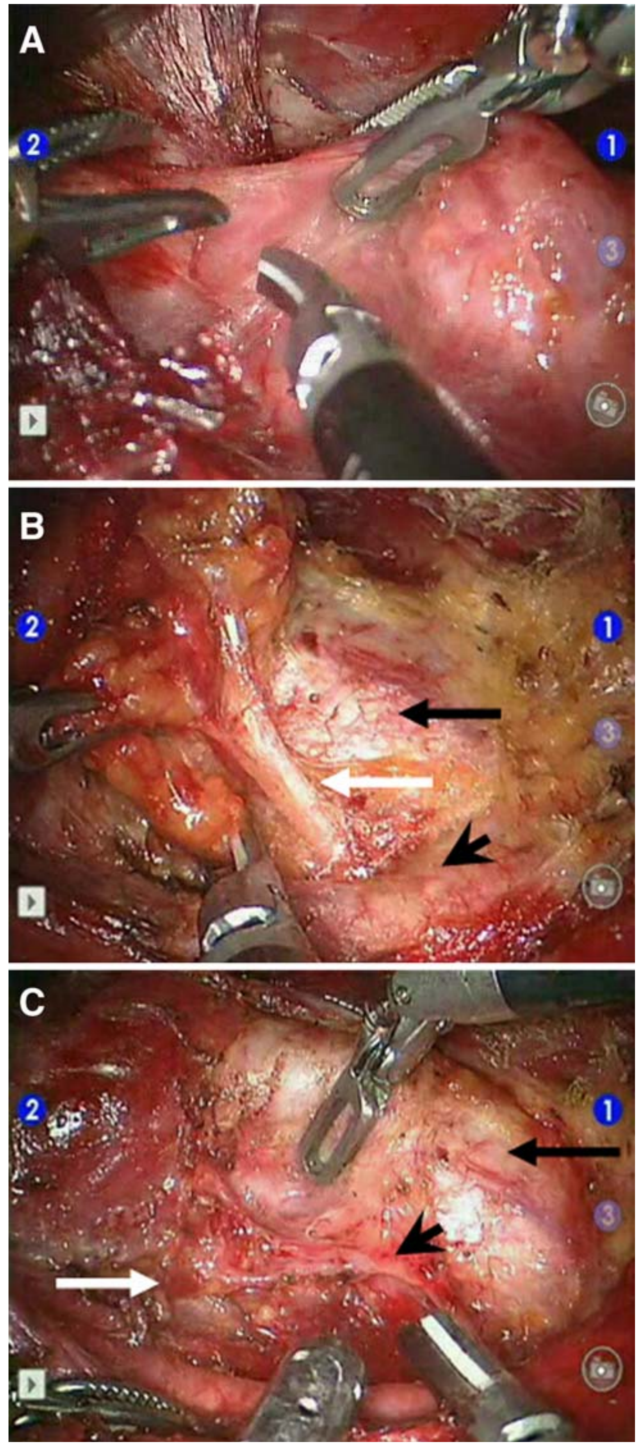

Fig. 2 The robotic-assisted endoscopic thyroidectomy procedure. **A** Dissection of the right upper pole of the thyroid gland by Harmonic curved shears. **B** Paraesophageal lymph node dissection: trachea (*black arrow*), recurrent laryngeal nerve (*white arrow*), and common carotid artery (*arrowhead*). **C** After the specimen delivery: right superior parathyroid gland (*white arrow*), recurrent laryngeal nerve (*arrowhead*), and retracted trachea by the robotic grasper (*black arrow*)

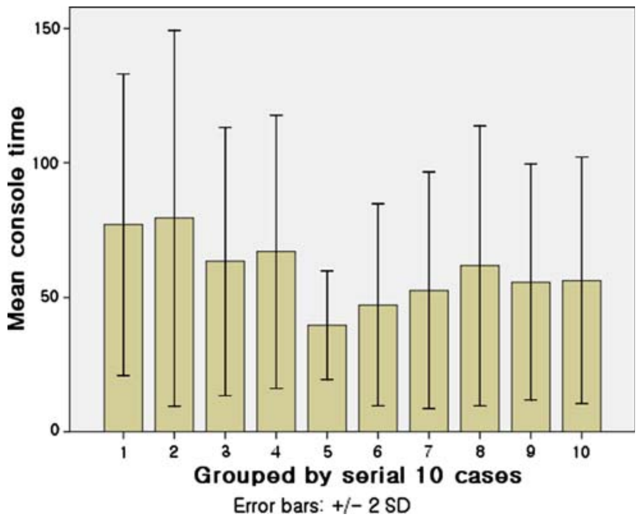

Fig. 3 Changes in actual operation time according to the cases (grouped by 10 serial cases)

Patients and methods

Patients

From 4 October 2007 to 14 March 2008, 100 patients with a preoperative diagnosis of thyroid papillary cancer underwent robot-assisted endoscopic surgery using a gasless transaxillary approach (with informed consent). We have previously reported our novel method of gasless endoscopic thyroidectomy using the transaxillary approach [3]. All the operations were performed with the same approach and endoscopic technique using the da Vinci S surgical robot system.

To evaluate the initial surgical outcome of robot-assisted endoscopic thyroidectomy, we compared the clinicopathologic data of 224 patients who underwent conventional open thyroidectomy for papillary thyroid microcarcinoma (PTMC) with the data for our 80 PTMC patients during the same period. All the operations were performed by one surgeon. We analyzed each patient's clinical characteristics, operation type, operation time, postoperative hospital stay, complications, pathologic characteristics, and tumor-node-metastasis (TNM) stage from the progressively updated thyroid database.

Preoperative diagnoses of the thyroid nodule were determined by ultrasonography-guided fine-needle aspiration biopsy and neck computed tomography (CT). The diagnosis for all the patients was well-differentiated thyroid carcinoma.

After thorough evaluations of tumor size, presence of capsular invasion, multiplicity and bilaterality of the lesion, and lymphatic metastasis, the patients underwent robot-assisted endoscopic thyroid surgery according to the inclusion criteria. The criterion for tumor size required that it be not larger than 2 cm by preoperative ultrasound. The study excluded all patients identified by the preoperative imaging study as having definite extrathyroidal tumor invasion, multiple lateral neck node metastases or perinodal infiltration of metastatic lymph nodes, or distant metastasis. Cases with the lesion located in the posterior capsule area of the thyroid, especially the portion adjacent to the tracheoesophageal groove, also were excluded to prevent injury to the trachea, esophagus, or recurrent laryngeal nerve.

According to the American Thyroid Association guidelines [21], less than a total thyroidectomy was performed for the patients younger than 45 years with a single intrathyroidal lesion not larger than 1 cm and no lymph node metastasis who had no personal history of radiation therapy to the head and neck and no immediate family history of differentiated thyroid cancer. However, patients identified as having multiple, bilateral lesions or thyroid capsular invasion during the operation underwent bilateral total thyroidectomy. Prophylactic ipsilateral central compartment node dissection (CCND) was performed for all the patients.

All the patients were administered levothyroxine for suppression of thyroid-stimulating hormone after the operation, which was regularly followed up with serum thyroglobulin and neck ultrasonography at an interval of 3 or 6 months. The patients who satisfied the indications underwent radioactive iodine (RAI) therapy 4 to 6 weeks after bilateral total thyroidectomy. A ^{131}I whole-body scan was carried out for these patients the second day after RAI therapy, and abnormal RAI uptake was taken into account. The TNM stage was classified according to the 6th edition of AJCC/UICC by the American Joint Committee on Cancer and the International Union Against Cancer [22]. The mean follow up period was 188.5 days (range, 120–280 days).

Operation method

The patients were placed in the supine position under general anesthesia. The neck was slightly extended, and the lesion-side arm was raised and fixed for the shortest distance from the axilla to the anterior neck. A 5- to 6-cm vertical skin incision was made in the axilla, and the subplatysmal skin flap from the axilla to the anterior neck area was dissected over the anterior surface of the pectoralis major muscle and clavicle using an electrical cautery under direct vision.

After the medial border of the sternocleidomastoid muscle (SCM) was exposed, the dissection was approached through the avascular space of the SCM branches (between the sternal and clavicular heads) and beneath the strap muscle until the contralateral lobe of the thyroid was exposed.

Next, to maintain adequate working space, an external retractor was inserted through the skin incision in the axilla and raised using a lifting device. A second skin incision (0.8 cm in length) was made on the medial side of the anterior chest wall for insertion of the fourth robot arm. This incision was 2 cm superior and 6 to 8 cm medial to the nipple.

Four robotic arms were used during the operation. Three arms were inserted through the axillary incision. The dual-channel endoscope was placed on the central arm, and the Harmonic curved shears together with the Maryland dissector was placed on both lateral sides of the scope. A Prograsp forceps was inserted through the anterior chest arm. The operation then proceeded in the same way as a conventional open thyroidectomy.

All the dissections and ligations of vessels were performed using the Harmonic curved shears. Under endoscopic guidance, the upper pole of the thyroid was drawn downward and medially by the Prograsp forceps. The superior thyroid vessels were identified and divided individually close to the thyroid gland. This was done to avoid injury to the external branch of the superior laryngeal nerve by use of the Harmonic curved shears. The lower pole was dissected from the adipose and cervical thymic tissue. The inferior thyroid artery was divided close to the thyroid gland to avoid injuring the inferior parathyroid gland.

The thyroid gland then was retracted medially with the Prograsp forceps, and the perithyroidal fascia was divided and sharply dissected using the Harmonic curved shears and the Maryland dissector. Careful dissection then was performed to identify the inferior thyroid artery and the recurrent laryngeal nerve in their usual anatomic relationship. The inferior thyroid artery was cut close to the thyroid gland using the Harmonic curved shears, and the entire cervical course of the recurrent laryngeal nerve was traced.

The superior parathyroid gland was identified during the dissection and left intact. The thyroid gland then was dissected from the trachea. The contralateral thyroidectomy was performed using the same method applied for medial traction of the thyroid. The resected specimen was extracted through the axillary skin incision. A 3-mm closed suction drain was inserted through a separate skin incision under the axillary skin incision. The wound then was closed. The small incision scar in the axilla remained completely covered when the arm was in its natural position.

Results

The mean age of the patients in this study was 39.9 ± 8.9 years, and the male-to-female ratio was 1:19 (5:95 patients). Less than a total thyroidectomy was performed for 84 patients (41 had ipsilateral total and contralateral partial thyroidectomies and 43 had ipsilateral total and contralateral subtotal thyroidectomies), and a bilateral total thyroidectomy was performed for 16 patients. For all the patients, a prophylactic ipsilateral CCND was added. At no time was conventional open surgery required.

All the patients described in this report were confirmed as having papillary thyroid carcinoma. The multiplicity and bilaterality of the lesions were observed in 23 cases (23%) and 11 cases (11%), respectively. The tumor size was 0.79 ± 0.6 cm (range, 0.1–6.0 cm), and 80 patients (80%) had PTMC. Central compartment node metastasis was found in 31 patients (31%).

The T1 stage in the TNM classification was noted for 52 patients (52%), the T3 stage for 47 patients (47%), and the T4a stage for 1 patient (1%). Among the T3 stage patients, most of the tumors were smaller than 2 cm, but the lesions had invaded the thyroid capsule. One T4a-stage patient showed recurrent laryngeal nerve invasion and underwent a shaving procedure with the Maryland dissector. The N-stage patients included 69 patients (69%) classified as N0 and 31 patients (31%) classified as N1a. No patient had distant metastasis. Thus, stage 1 was noted for 83 (83%) patients, stage 3 for 16 (16%) patients, and stage 4A for 1 (1%) patient (Table 1).

The early surgical outcome for the 80 PTMC patients who underwent a robot-assisted endoscopic thyroidectomy was compared with the data for 224 patients who underwent conventional open thyroidectomy for PTMC during the same period. The mean operation times were 136.5 ± 36.6 min for the robot-assisted endoscopic thyroidectomies (robotic group) and 105.5 ± 41.6 min for the conventional open thyroidectomies (open group).

In the robotic group, the operation time consisted of working space time, docking time, and console time. The mean time for creating adequate working space (flap dissection from the axillar to the anterior neck and connection of the retractor to the external lifting system) was 20.9 ± 8.4 min. The docking time (placement of the robotic arms) was 6.8 ± 3.1 min, and the console time (actual time for thyroid surgery) was 59.9 ± 25.9 min. The postoperative hospital stay was 3.0 ± 0.45 days for the robotic group and 3.3 ± 1.7 days for the open group.

To estimate the degree of postoperative pain, we investigated the mean time of postoperative analgesic use for each procedure. The mean numbers of postoperative analgesic use were 0.75 ± 0.82 in the robotic group and 0.88 ± 0.89 in the open group. The mean numbers of retrieved lymph nodes were 5.3 ± 3.9 in the robotic group and 5.9 ± 4.5 in the open group.

The postoperative complications in the robotic group included one case (1/6, 16.6%) of transient hypocalcemia

Table 1 Clinicopathologic characteristics of the patients

Age: years (range)	39.9 ± 8.9 (16–65)
Sex ratio (male:female)	1:19 (5:95)
Operation type (*n*)	
Total thyroidectomy with CCND	16
Less than total thyroidectomy with CCND	84
Tumor size: cm (range)	0.79 ± 0.6 (range 0.1–6.0)
Multiplicity (*n*)	
Yes	23
No	77
Bilaterality (*n*)	
Yes	11
No	89
TNM stage (*n*)	
T1/T3/T4a	52/47/1
N0/N1a	69/31
Stage 1/3/4a	83/16/1

CCND central compartment node dissection, *TNM* tumor-node-metastasis

and two cases (2.5%) of transient hoarseness. In the open group, temporary hypocalcemia was experienced by 45 patients (45/117, 38.5%), temporary hoarseness by 5 patients (2.2%), seroma by 1 patient (0.4%), and hematoma by 2 patients (0.9%). All the patients with temporary hypocalcemia or temporary hoarseness recovered within 1 month, and no permanent hypocalcemia or permanent recurrent laryngeal nerve palsy occurred in either group (Table 2).

Discussion

Thyroid disease usually is experienced by women, and its occurrence in young women has been increasing recently. Currently, patients are much more interested not only in treatment of the disease but also in postoperative quality of life, which includes such considerations as operative scar, degree of pain, and ability to return rapidly to the work. These interests have focused on the cosmetic result and the noninvasiveness of the operation, resulting in the development of minimally invasive surgical techniques.

Since the first report of endoscopic parathyroid surgeries in 1996 [1], various techniques of endoscopic thyroid surgery have been introduced during the past decade [3–9]. We also have developed our own novel method of gasless endoscopic thyroidectomy using a transaxillary approach [3].

Endoscopic thyroid operations can be classified according to the two methods used to create a viable working space: the continuous carbon dioxide gas insufflation method and the gasless method [5, 6, 8]. Additionally, according to the insertion site of the surgical instruments, endoscopic surgery can be described as a cervical [6, 7], anterior chest wall [8], breast [9], axillary [3–5], or axilla-breast approach [23, 24]. Because all these various techniques for endoscopic thyroidectomy have their own advantages and disadvantages, it has been impossible to discern which technique gives the best outcome when all factors are considered.

Our own transaxillary endoscopic thyroidectomy uses the lateral approach to the thyroid. Because this approach provides a natural operative view, as in open surgery,

Table 2 Data comparing the initial surgical outcomes between the robotic and open groups

	Robotic group ($n = 80$)	Open group ($n = 224$)	*p* Value
Operation type			0.000
Total thyroidectomy with CCND: *n* (%)	6 (7.5)	117 (52.2)	
Less than total thyroidectomy with CCND: *n* (%)	74 (92.5)	107 (47.8)	
Operation time: min (range)	136.5 ± 36.6 (79–267)	105.5 ± 41.6 (47–233)	0.000
Approaching time	20.9 ± 8.4 (6–49)		
Docking time	6.8 ± 3.1 (3–20)		
Console time	59.9 ± 25.9 (25–157)		
Postoperative hospital stay: days (range)	3.0 ± 0.45 (2–5)	3.32 ± 1.7 (1–19)	0.066
Retrieved lymph node: *n* (range)	5.26 ± 3.9 (1–28)	5.96 ± 4.50 (1–27)	0.153
Postoperative analgesics use: *n* (range)	0.75 ± 0.82 (0–4)	0.88 ± 0.89 (0–6)	0.242
Postoperative complications: *n* (%)			0.000
Transient hypocalcemia	1 (1/6, 16.6)	45 (45/117, 38.5)	
Transient hoarseness	2 (2.5)	5 (2.2)	
Seroma	0 (0)	1 (0.4)	
Hematoma	0 (0)	2 (0.9)	

CCND central compartment node dissection easier manipulation of the upper and lower poles of the thyroid than with the inferior approach is ensured. Identification of the recurrent laryngeal nerve and the parathyroid gland also is relatively simple with this method.

However, the most remarkable benefit of this method is in the performance of CCND. With this technique, the surgeon creates a route of approach between the SCM branches and dissects the anterior surface of the carotid sheath, which then is dropped just below the strap muscles. This approach enables the surgeon to conduct a complete ipsilateral CCND from the carotid artery to the substernal notch and the prelaryngeal area. With regard to cosmetic considerations, the results of this approach are favorable compared with the cervical and anterior chest wall approach because the operation scar in the axilla is covered by the arms in their natural position [4, 5].

The gasless operation method also lacks those disruptions within the working space normally associated with air or blood suctioning [8]. Conventional open surgical instruments also can be used during this procedure, in which some of the surgery can be performed with the naked eye [8].

This method, however, has several disadvantages. It is more invasive because of the wide dissection from the axilla to the anterior neck and more time consuming than the conventional open method. Also, it is difficult to approach the contralateral upper pole of the thyroid with this method [3–5]. Some reports, pointing out the limitations of bilateral total thyroidectomy using a one-sided axillary approach, have introduced a bilateral axillary approach [16, 17]. However, such limitations usually are overcome with sufficient experience.

We usually have accomplished full exposure of the thyroid's contralateral lobe through medial traction using Prograsp forceps to conduct subcapsular dissection. The use of a 30° scope enables us to see downward easily, thereby allowing us to identify the contralateral superior pole of the thyroid with little difficulty.

Recently, application of the da Vinci S surgical robot system to various surgical fields has led to a speedy evolution in minimally invasive surgical techniques [15, 18, 19]. Although a few reports describe the application of robot systems in head and neck surgeries, the use of these systems has been limited to benign thyroid diseases [16, 17, 20].

We have applied the da Vinci S surgical robot system to operations for thyroid cancer patients with low risk, using the same approach as with our own endoscopic thyroid surgery technique. In our experience, addition of the da Vinci S surgical robot system to endoscopic thyroidectomies has resolved the difficulties of conventional endoscopic surgery. Such problems include awkward endoscopic instrument angle and manipulation difficulties. Because the operator controls the entire operational procedure, the problems associated with assistant-dependent conventional endoscopic surgery are bypassed. We have found the working space through the axillary route wide enough to perform the operation without interference from each surgical instrument.

Initially with this procedure, the narrow entrance meant that surgical instruments on the robotic arms frequently collided. However, this problem was resolved by setting the camera to different introduction angles for the Harmonic curved shears and the Maryland dissector, respectively. The fourth robot arm (equipped with Prograsp forceps) can replace the role of an assistant and offers stable retraction movement. The operator can control all robotic arms using the swapping system of the three arm controllers.

The da Vinci S surgical robot system provides a three-dimensional field of view and a more accurate sense of perspective [25–27]. Moreover, because this system can magnify target structures, it more easily enables the preservation of the parathyroid and recurrent laryngeal nerves. The robot arm can be driven in multi-angular motions with seven degrees freedom: yaw (side-to-side), pitch (up and down), insertion (in and out), grip, and three additional degrees of freedom provided by the second joint in the instrument tip mimicking the human wrist and finger joints. This enables safe and complete central compartment node dissection in the deep and narrow operation space [28]. The hand-tremor filtration, the fine motion scaling, the negative motion reversal of the robot system (providing minute and precise manipulations of tissue), and the ergonomically designed console means that surgeons experience less fatigue [15, 18, 19].

Despite these various advantages of the da Vinci S surgical robot system, it may prove cost inhibitive when factors such as general cost, fees of disposables, and maintenance are taken into consideration. Additionally, the large room space it requires may be another factor that limits its widespread use in thyroid surgery [19]. However, the total economic expenses can be reduced through the increased cases of robotic operation in various surgical areas [19].

The early surgical outcomes of robot-assisted endoscopic thyroidectomies were compared with the data for conventional open thyroidectomies. As described earlier, this transaxillary approach is a more time-consuming procedure than conventional open thyroidectomy. However, with accumulation of experience, the actual operation time is decreasing. The patients in the robotic group were highly selected for several reasons such as the expected risk group and the expensive operation fee, and the difference in operation method was expected. However, there was little difference in the retrieved lymph node numbers, postoperative hospital stays, and pain between the two groups. Moreover, the postoperative complications in the robotic group were somewhat fewer than in the conventional open thyroidectomy group. From this comparison then, it seems that the initial surgical outcomes for robot-assisted endoscopic thyroidectomy using a gasless, transaxillary approach are satisfactory.

Although robot-assisted endoscopic thyroid surgery showed cosmetic and various technical advantages for surgeons, the major concerns when a new treatment technique for malignant tumors is considered should be the safety and radicalness of the operation to prevent local recurrence and distant metastasis. The relative oncologic safety of endoscopic versus robot-assisted endoscopic thyroid surgery has not yet been established due to the newness of this technology. Recently, however, various surgical applications and the results of endoscopic thyroid surgery for early thyroid cancer with low-risk groups have been reported [10–14].

To prevent cancer cell dissemination and to minimize the possibility of local recurrence during endoscopic thyroidectomy, the safety of the operational methods and the degree of surgical skill are important. We suggest that our gasless transaxillary approach for endoscopic thyroidectomy, with the added technical advantages of robot assistance, is a safe and effective method. Indeed, we are planning a future study to compare the safety and radicalness of open, conventional endoscopic, and robot-assisted endoscopic thyroidectomies. If the safety and radicalness of robotic thyroid surgery as a treatment for papillary thyroid microcarcinoma can be established by the performance of complete thyroidectomies with secure lymphadenectomies, then the application boundaries and development area of this technique can be gradually extended.

Conclusion

Our novel technique of robot-assisted endoscopic thyroid surgery using a gasless transaxillary approach is a feasible and safe method with satisfactory initial surgical outcomes. We suggest that the application of robotic technology in endsocopic thyroid surgeries could overcome the limitations of conventional endoscopic surgeries in the surgical management of selected patients with thyroid cancer.

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