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ORIGINAL SCIENTIFIC REPORT

Yonsei Experience of 5000 Gasless Transaxillary Robotic Thyroidectomies

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Abstract

Background Since the use of robot systems in thyroid surgery was introduced in 2007, we have advanced a novel method of robotic thyroidectomy (RT) using a gasless transaxillary approach (TAA). We report our experience with this technique and detail the surgical outcome of 5000 robotic thyroidectomies.

Methods From October 2007 to May 2016, we successfully performed 5000 robotic thyroidectomies using a gasless TAA at the Department of Surgery, Yonsei University Health System. The medical records of the patients are reviewed retrospectively, and the details of clinicopathologic characteristics, operation times, perioperative complications, and oncologic outcomes are analyzed.

Results The 5000 patients with thyroid tumor (4804 with cancer and 196 with benign tumor) underwent RT using a gasless TAA. Mean operation time was 134.5 ± 122.0 min. The most common histologic subtype of thyroid cancer was papillary (98%), and the mean tumor size was 8.0 ± 6.0 mm. Stage I was found in 85.4% patients regarding tumor nodes metastasis staging. The 196 benign tumors consisted of 104 adenomatous hyperplasias (53.0%), 43 follicular adenomas (21.9%), 30 Graves' diseases (15.3%), and 19 others (9.7%). Postoperative complication occurred in 24.1% without any serious one, and overall morbidity tended to decrease over time. No disease-specific mortality was observed during the follow-up period. Locoregional recurrence was developed in 26 patients (0.5%).

Conclusion The authors have tried to improve RT technique using gasless TAA and achieved acceptable surgical outcomes. The rapid evolution of surgical robot technology and our constant effort to advance RT technique using gasless TAA would make it possible to reduce the perioperative morbidity and gain the best possible operative and oncologic outcomes.

Introduction

The incidence of thyroid cancer has increased worldwide during the last decade, with thyroid surgery becoming one of the most common surgical procedures. Conventional open thyroid surgery leaves a scar on the anterior neck, which can be a cosmetic issue for some patients.

Desire for the lack of visible scars has led to the introduction of endoscopic surgeries in the late nineteenth century. Endoscopic cervical approaches to the thyroid and parathyroid glands were initiated by Gagner [1] and Huscher et al. [2]. The endoscopic technique has subsequently been augmented with various approaches such as anterior chest, axillary, breast, and cervical approaches [3–5]. At our institution, Chung et al. [6] invented the new endoscopic thyroidectomy (ET) technique using a gasless transaxillary approach (TAA) in November 2001.

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However, ET showed several limitations, including restricted vision, difficulty in instrument handling, and lack of tactile perception [7, 8].

The disadvantages of endoscopic surgery necessitated more technical advancements, and the concept of using a "robot" in surgery was introduced. Robotic surgery was developed to overcome the limitations of the ET technique and to enhance the capabilities of surgeons. Since the da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA, USA) was approved by the US Food and Drug Administration in 2000 for certain laparoscopic procedures, its application has rapidly become more widespread [9]. However, since the conventional approach is safe and time-honored, robotic thyroidectomy (RT) remains controversial especially in the West including the USA, where the FDA has revoked approval on the use of robotic thyroidectomy and parathyroidectomy in 2011 [10].

Our institution utilized the robot system in thyroid surgery, and first introduced the RT technique using gasless TAA in October 2007 [7]. We have made constant effort to advance our RT technique since then. As robotic experience accumulated, we could change the surgical incision from double incision to single axillary incision, developing a less invasive RT technique using gasless TAA while maintaining surgical outcomes. Until May 2016, we have performed 5000 cases of RT using a gasless TAA. We herein report our experience and detail the surgical outcome of the total 5000 patients.

Materials and methods

Patients

From October 2007 to May 2016, 5000 patients with thyroid tumor underwent RT using a gasless TAA at the Department of Surgery, Yonsei University Health System. Of these, 4804 patients (96%) had thyroid cancer and 196 (4%) had a benign tumor. All operations were performed with the da Vinci S, Si, or Xi surgical robotic system (Intuitive Surgical).

Less than total thyroidectomy (LTT) was performed in 3123 patients (62.5%), and bilateral total thyroidectomy (BTT) was conducted in 1543 (30.9%). LTT was defined as total resection on one lobe of the thyroid and partial or subtotal resection on the opposite lobe. Robotic modified radical neck dissection (MRND) was performed in 334 patients (6.7%) with lateral neck node metastases. All patients with thyroid cancer underwent prophylactic ipsilateral central compartment neck dissection.

The eligibility criteria for RT were as follows: (1) follicular proliferation with tumor size $\leq$5cm, and (2) differentiated thyroid cancer without contraindications to RT. The exclusion criteria were (1) previous head-and-neck surgery or irradiation, (2) definite tumor invasion to an adjacent organ (recurrent laryngeal nerve [RLN], esophagus, or trachea), (3) multiple lateral neck node metastases or perinodal metastatic lymph node infiltration, and (4) distant metastasis.

Patients with thyroid tumor were divided into four groups according to operation dates: first period (October 2007–November 2011, $n = 1033$), second period (December 2011–January 2012, $n = 1367$), third period (February 2012–March 2014, $n = 1489$), and fourth period (April 2014–May 2016, $n = 904$). Details of clinicopathologic characteristics, operation times, perioperative complications, and oncologic outcomes were reviewed retrospectively. This study was approved by the Institutional Review Board of Yonsei University Health System (4–2015–1163).

For benign tumors, surgical management was indicated as follows: (1) follicular/Hürthle cell lesions of diameter <5 cm, (2) nodules with indefinite suspicious ultrasonographic findings, (3) nodules with fine needle aspiration biopsy (FNAB) findings suspicious for malignancy, and (4) Graves' disease (GD). Among patients with GD, those who were intractable to medical treatment and had contraindications to radioactive iodine (RAI) therapy, those with severe exophthalmoses, and those seeking pregnancy within 1 year were included. Frozen sections were obtained from all suspicious lesions with inconclusive FNAB results. When a lesion was considered malignant, treatment was provided according to ATA guidelines [11].

Operative methods

We have previously described the procedures for RT and robotic MRND [7, 12–14]. We started RT using a gasless TAA with two separate incisions: one in the axilla and one in the anterior chest. After performing >750 cases of RT, we modified our technique by using a single incision on the axilla, from September 2009 for RT and from March 2013 for robotic MRND.

Outcome assessment

All patients were administered with levothyroxine for thyroid-stimulating hormone (TSH) suppression immediately after surgery. To evaluate postoperative morbidity, the parathyroid function was assessed by measuring serum calcium and intact parathyroid hormone (iPTH) concentrations preoperatively, and at 1 week and 3 months postoperatively. Hypoparathyroidism was defined as a reduction in serum iPTH concentration below the normal limit, regardless of hypocalcemic symptoms [15]. Postoperative laryngoscopy was performed in patients with

transient hoarseness after surgery. Permanent hypoparathyroidism and RLN palsy were defined as non-recovery within 6 months.

Thyroid function tests (TSH, fT3, and fT4) and serum calcium levels were determined at 1, 3, and 6 months postoperatively. TSH-suppressed serum thyroglobulin (Tg) levels were measured, and ultrasonography (US) was performed at 3- or 6-month intervals. RAI ablation was performed based on stage and risk factors, according to ATA guidelines, at 4–12 weeks after surgery [11]. The patients underwent posttherapy whole-body scans and diagnostic whole-body scans 2–5 days after RAI ablation, and abnormal RAI uptakes were investigated [16].

To evaluate the long-term oncologic outcomes, suppressed serum Tg concentration was measured annually, and all patients underwent regular follow-up US. Patients with evidence of recurrence or distant metastasis were assessed with other imaging modalities, such as neck computed tomography (CT) and/or positron emission tomography-CT. Regional neck node recurrence was confirmed with US-guided FNAB.

Overall survival was defined as the time from the date of initial surgery to the date of last follow-up or death. Recurrence-free survival (RFS) was defined as the time from the date of surgery to the date of detection of the first recurrence on imaging.

Study endpoints

The primary endpoint of the study was to review clinicopathologic characteristics and surgical outcomes of 5000 patients with thyroid tumor. The second endpoint was to demonstrate feasibility and safety of RT technique using gasless TAA by comparing the rate of perioperative morbidities according to the periods.

Statistical analysis

Categorical data were reported as rates and proportions, while the median and ranges were calculated for continuous data. To compare the rate of perioperative complications according to operation period, patients were regrouped into two groups: patients of the first, second, and third periods; and patients of the fourth period. Surgical complications and complication rates were assessed for each group, and among-group comparisons were expressed as numbers and proportions. Differences in categorical variables were compared by Chi square test and Fisher's exact test, as appropriate. A P value of <0.05 was considered statistically significant. Statistical analyses were performed using IBM SPSS Statistics for Windows, version 23.0 (IBM Corp., Armonk, NY).

Results

The clinical characteristics of 5000 patients (558 men and 4442 women; mean age, 38.3 ± 9.3 years) were reviewed. Primary operations were performed on 4963 patients (4767 with cancer and 196 with benign tumor). The mean total operation time was 134.5 ± 122.0 min (Table 1). No case was converted to conventional open surgery.

Concerning the 196 benign tumors, the mean tumor size was 2.1 ± 1.4 cm. Adenomatous hyperplasia was the most common finding (104 patients). Forty-three lesions were diagnosed as follicular adenoma. GD was indicated for surgery in 30 cases (Table 2).

Table 3 shows the histopathologic characteristics of 4804 patients with thyroid cancer. The mean tumor diameter was 0.8 ± 0.6 cm. Papillary thyroid carcinoma (PTC) was the most common histologic type (4751 patients [98.9%]). Multiple or bilateral lesions were observed in 1188 (24.7%) and 598 cases (12.4%), respectively.

According to the tumor node metastasis stage classification, 2530 patients (52.9%) had T1 cancer lesions, followed by 2171 patients (45.4%) with T3 lesions. In 25 patients with T4a lesions, direct cancer invasion into adjacent organs was noted, as follows: 15 RLN, 6 trachea (perichondrium), 1 esophagus (longitudinal muscle layer), and 1 internal jugular vein (tunica adventitia) invasions. In 20 patients, the invaded organs were successfully preserved after shaving with robotic scissors; however, the RLN was sacrificed in four patients owing to complete tumor invasion of the nerve core. The remaining one patient had a widely invasive follicular carcinoma. Concerning N stage, central neck node metastases (N1a) and lateral neck metastases (N1b) were found in 1407 (29.3%) and 363 (7.6%) patients, respectively. No patient had distant metastasis (Table 3).

For 334 patients with lateral neck metastasis, BTT with MRND was performed in 311 patients, and redo operations consisting of 8 completion total thyroidectomy with MRNDs and 15 MRNDs were conducted in 23 patients with tumor recurrence. The mean tumor size was 1.3 ± 0.7 cm. The mean numbers of retrieved central and lateral lymph nodes were 6.3 ± 5.1 and 34.1 ± 17.5, respectively (Table 4).

To figure out changing trends in our RT experience, patients were organized into four groups according to their operation dates and then re-evaluated. The trends of RT with experience showed several changes in clinical performance status. Specifically, BTT with MRND cases increased and total operation times decreased (Table 5).

In terms of postoperative complications, 884 patients (48.1% of BTT cases) experienced transient hypocalcemia, which resolved within 3 months. Twenty-five patients

Table 1 Clinical characteristics of patients

Variables	$N = 5000$
Age (years)	38.3 ± 9.3
Sex ratio (male:female)	558:4442 (ratio 1:8.0)
Pathologic type, malignant:benign (*n*, %)	4804 (96%):196 (4%)
Operation type, primary:redo (*n*, %)	4963 (99%):37 (1%)
Operation time (min)	134.5 ± 122.0 (range 53–635)
Postoperative hospital stay (days)	3.3 ± 3.0 (range 2–7)

Table 2 Pathologic characteristics of patients with benign tumors

Variables	$n = 196$
Mean tumor size (cm)	2.1 ± 1.4
Pathology (*n*)	
Adenomatous hyperplasia	104
Follicular adenoma	43
Hürthle cell adenoma	11
Lymphocytic thyroiditis	10
Graves' disease	30
Others	5[a]

[a] Hyalinizing trabecular tumor: two cases, maltoma: one case, bronchogenic cyst: one case, and neurofibroma: one case

(1.3% of BTT cases) were found to have permanent hypocalcemia. Transient hoarseness appeared in 126 patients (2.5%), which resolved within 3 months. Most cases of chyle leakage were successfully managed conservatively; however, three patients had massive chyle leakage requiring reoperation.

There were 18 cases (0.4%) of RLN injury, 7 cases (0.1%) of tracheal wall injury, and 2 cases (0.04%) of vessel injuries (carotid artery or brachiocephalic vein). All RLN injuries were treated by using injection laryngoplasty with Rofilan. Tracheal wall and vessel injuries were managed through primary repair by using robotic instruments.

Horner's syndrome occurred in four patients. Three patients underwent lateral neck dissection due to extensive lateral neck node metastases. The remaining one patient had isthmus cancer with extrathyroidal extension and central LN metastases. Extensive manipulation and dissection of tissues around the carotid sheath would have led to compression of the cervical plexus. The symptoms spontaneously resolved within 2 months.

The technique-related complications that were seen exclusively in RT were axillary skin flap perforation in eight patients (0.2%) and transient brachial nerve paralysis in four patients (0.1%). Transient brachial nerve paralysis occurred owing to the hyperextension of the lesion side arm, and all patients spontaneously recovered within 2 months (Table 6).

Moreover, accumulation of robotic experience resulted in a smaller overall morbidity rate in the fourth period. Comparative analyses revealed that patients of the fourth period experienced significantly less transient hypocalcemia, permanent hypocalcemia, and overall morbidity compared to previous periods (Table 7).

Of 1863 thyroid cancer patients who had BTT, 1460 (80.0%) underwent adjuvant RAI therapy, and no abnormal uptake was seen in 1380 patients (94.5%) according to diagnostic whole-body scans. At 3 months after surgery, the serum TSH-suppressed Tg level was less than 1 ng/mL in 1038 patients (55.7%). During the follow-up, tumor recurrence was detected by imaging and confirmed in 26 patients (0.5%) (Table 8).

Patients with tumor recurrence consisted of 15 patients who had hemithyroidectomy and 11 patients who had total thyroidectomy. Despite the fact that the latter group had all received RAI ablation, five patients had serum Tg $\geq$ 1 ng/mL after 5 years of surgery. Patients who had no RAI treatment showed higher percentages of persistent serum Tg elevation. However, no structural recurrence was found in these patients during follow-up.

The most common sites of recurrence were the lateral neck nodes (14 patients). Recurrence in the contralateral thyroid and in the central neck node was found in nine and three patients, respectively. No recurrence was detected in distant organs. All patients with recurrence underwent reoperation (robotic surgery in 15 and conventional open method in 11). The median RFS of these patients was 39.5 ± 30.0 months.

No disease-specific mortality was observed during the follow-up period. The median RFS of 4804 thyroid cancer patients was 52.5 ± 27.1 months.

Discussion

In the current study, the trends in our RT tended to include more advanced cases with less invasive method, shorter operation time, and less perioperative complications over time. These can be explained by the rapid evolution of robot technology. Moreover, accumulation of robotic

Table 3 Pathologic characteristics of patients with thyroid cancer

Variables	$n = 4804$
Tumor size (cm)	0.8 ± 0.6 (range 0.1–11)
Pathology, *n*(%)	
Papillary carcinoma	4751 (98.9%)
(papillary microcarcinoma)	(3617 [75.3%])
Follicular carcinoma	38 (0.79%)
Papillary carcinoma + follicular carcinoma	4 (0.08%)
Medullary carcinoma	9 (0.19%)
Papillary carcinoma + medullary carcinoma	1 (0.02%)
Hürthle cell carcinoma	1 (0.02%)
Multiplicity, *n* (%)	1188 (24.7%)
Bilaterality, *n* (%)	598 (12.4%)
Retrieved lymph node, *n*	
Central neck node	4.9 ± 4.0 (range 0–40)
Lateral node	27.8 ± 19.8 (range 1–146)
T stage, *n* (%)	
T1/T2/T3/T4	2530 (25.9)/57 (1.2)/2171 (45.4)/25 (0.5)
N stage, *n* (%)	
N0/N1a/N1b	3034 (63.1)/1407 (29.3)/363 (7.6)
TNM stage, *n* (%)	
I/II/III/IV	4102 (85.4)/7 (0.2)/622 (12.9)/73 (1.5)

Table 4 Pathologic characteristics of patients with lateral neck metastasis

Variables	$n = 334$
Tumor size (cm)	1.3 ± 0.7 (range 0.1–11)
Extracapsular invasion, *n* (%)	258 (77.9%)
Multiplicity, *n* (%)	143 (43.2%)
Bilaterality, *n* (%)	100 (30.2%)
Retrieved lymph node, *n*	
Central neck node	6.3 ± 5.1 (range 0–40)
Lateral node	34.1 ± 17.5 (range 1–146)
T stage, *n* (%)	
T1/T2/T3/T4	59 (17.8)/8 (2.4)/236 (71.2)/8 (2.4)
TNM stage, *n* (%)	
I/IV	273 (82.4)/58 (17.5)

experience and constant efforts to develop more effective techniques may have led to preferable outcomes.

Robotic surgery is an innovative and new technique representing minimally invasive surgery in the current surgical trends. The outstanding advantages of robotic surgery are overcoming the technical limitations of endoscopic surgery and providing three-dimensional imaging, motion scaling, tremor elimination, and additional degrees of freedom [9, 17, 18].

The application of robot technology in thyroid surgery has provided a safe and feasible approach for preexisting ET. Several institutions subsequently substantiated the technical efficiency and positive potential of RT, and reported their successful experience with this technique [8, 19]. Considering the advantages of RT, many thyroid surgeons performed >6000 RTs with or without neck dissection in South Korea between 2007 and 2011 [13, 14, 20, 21].

At our institution, we have performed >650 ETs using a gasless TAA from 2001. Our RT technique using gasless TAA is based on the feasibility of ET in papillary microcarcinoma of the thyroid, which is defined as PTC with diameter ≤1 cm [6]; however, the first application of robotics to thyroid surgery was limited to well-differentiated thyroid carcinoma with tumor size ≤2 cm without definite extrathyroidal tumor invasion, or to follicular neoplasms with tumor size ≤5 cm [8]. We have continued to refine the surgical techniques in RT based on the principles and protocols described for the indication.

As robotic experience accumulated, we were able to successfully manage unexpected advanced cases, such as those with definite adjacent muscle invasion or perinodal infiltration. The indications for RT have expanded, including more aggressive disease, with more technical advancements and increase in the skill of surgeons over time (Table 5). Superficial invasion to adjacent organs such as the trachea, RLN, and neck vessels became manageable by using the technique of shaving with robotic scissors. Currently, the only contraindication of RT at our institution

Table 5 Clinicopathologic characteristics of patients with thyroid cancer according to period ($n = 4804$)

	First period ($n = 1036$)	Second period ($n = 1370$)	Third period ($n = 1492$)	Fourth period ($n = 906$)
Operation type, *n* (%)				
LTT	644 (62.2)	787 (57.4)	906 (60.7)	624 (68.9)
BTT	352 (34.0)	484 (35.3)	480 (32.2)	199 (21.9)
Additional MRND	40 (3.8)	99 (7.2)	106 (7.1)	83 (9.2)
Total operation time				
LTT	121.4 ± 29.7	108.2 ± 25.1	117.4 ± 30.0	105.7 ± 29.5
BTT	143.7 ± 31.0	140.3 ± 32.7	144.5 ± 33.3	139.4 ± 39.4
Additional MRND	276.0 ± 46.3	296.1 ± 63.2	289.5 ± 57.5	282.2 ± 92.8
Working space time				
LTT	31.4 ± 12.8	36.5 ± 13.2	39.8 ± 13.2	35.3 ± 14.3
BTT	32.6 ± 12.0	38.4 ± 14.0	42.5 ± 14.3	40.1 ± 18.1
Additional MRND	59.2 ± 20.8	62.3 ± 20.0	68.7 ± 25.7	72.1 ± 36.2
Docking time				
LTT	5.6 ± 2.8	4.6 ± 2.7	4.6 ± 2.5	4.0 ± 1.8
BTT	5.4 ± 2.7	4.4 ± 1.8	4.6 ± 1.8	3.9 ± 1.5
Additional MRND	5.3 ± 1.8	9.0 ± 3.2	9.6 ± 4.4	8.2 ± 3.9
Console time				
LTT	47.8 ± 19.3	42.1 ± 19.3	39.6 ± 14.4	37.1 ± 17.6
BTT	68.1 ± 21.8	61.3 ± 21.7	61.5 ± 21.2	62.7 ± 21.3
Additional MRND	109.2 ± 56.9	150.4 ± 44.5	138.1 ± 36.4	135.6 ± 54.8
Positive nodes				
Central nodes	0.9 ± 1.8	0.9 ± 1.9	0.9 ± 1.8	1.2 ± 2.2
Lateral nodes	3.0 ± 3.6	4.2 ± 3.8	3.5 ± 3.9	4.6 ± 4.8
T stage, *n* (%)				
T1	527 (50.9)	727 (53.1)	813 (54.5)	480 (53.0)
T2	11 (1.0)	15 (1.1)	18 (1.2)	19 (2.1)
T3	492 (47.5)	625 (45.6)	652 (43.7)	397 (43.8)
T4	6 (0.6)	3 (0.2)	9 (0.6)	10 (1.1)
N stage, *n* (%)				
N0	651 (62.8)	896 (65.4)	976 (65.4)	526 (58.1)
N1a	344 (33.2)	375 (27.4)	407 (27.3)	293 (32.3)
N1b	41 (4.0)	99 (7.2)	109 (7.3)	87 (9.6)
TNM stage, *n* (%)				
I	873 (84.3)	1150 (84.0)	1290 (86.5)	776 (85.7)
II	0 (0)	2 (0.1)	4 (0.2)	2 (0.2)
III	154 (14.8)	193 (14.1)	177 (11.9)	111(12.2)
IV	9 (0.9)	25 (1.8)	21 (1.4)	17 (1.9)

LTT less than total thyroidectomy, *BTT* bilateral total thyroidectomy, *MRND* modified radical neck dissection

is deep tumor infiltration to adjacent structures requiring extensive resection of the trachea or neck vessels. Our experience resulted in >300 cases of MRND with acceptable perioperative outcomes and excellent cosmesis [22].

Furthermore, the robotic technique enabled the management of GD and multinodular goiter, which were difficult to manage with an endoscopic method owing to the large volume of engorged fragile thyroid tissue. Surgeons with experience in RT can successfully extract large thyroid glands with excellent cosmesis, without increasing the complication rates [23].

Through the application of the robotic technique in thyroid surgery, our institution aimed to achieve comparable postoperative outcomes and enhance patient

Table 6 Perioperative complications of the 5000 total patients according to period

Complication (*n*, %)	First period ($n = 1052$)	Second period ($n = 1421$)	Third period ($n = 1563$)	Fourth period ($n = 964$)	Total ($N = 5000$)
Transient hypocalcemia (*n*/BTT, %)	161 (161/393, 41.0)	256 (256/579, 44.2)	372 (372/589, 63.2)	95 (95/276, 34.4)	884 (884/1837, 48.1)
Permanent hypocalcemia (*n*/BTT, %)	5 (5/393, 1.3)	10 (10/579, 1.7)	10 (10/589, 1.6)	0 (0/964, 0)	25 (25/1837, 1.3)
Transient voice change	56 (5.3)	18 (1.3)	27 (1.7)	25 (2.6)	126 (2.5)
Seroma	23 (2.2)	23 (1.6)	23 (1.5)	6 (0.6)	75 (1.5)
Hematoma [reoperation]	6 [1] (0.6)	5 [1] (0.4)	5 [2] (0.3)	5 [1] (0.5)	21 [5] (0.4)
Chyle leak [reoperation]	5 [1] (0.5)	11 [0] (0.8)	9 [0] (0.6)	4 [2] (0.4)	29 [3] (0.6)
RLN injury	6 (0.6)	4 (0.3)	6 (0.4)	2 (0.2)	18 (0.4)
Horner syndrome	1 (0.1)	0 (0)	2 (0.1)	1 (0.1)	4 (0.1)
Trachea injury	4 (0.44)	1 (0.1)	2 (0.1)	0 (0)	7 (0.1)
Vessel injury (carotid artery, brachiocephalic vein)	0 (0)	1 (0.1)	1(0.1)	0 (0)	2 (0.04)
Flap injury (burn)	2 (0.2)	1 (0.1)	2 (0.1)	3 (0.3)	8 (0.2)
Traction injury of lesion side arm	2 (0.2)	0 (0)	2 (0.1)	0 (0)	4 (0.1)
SAN injury	0 (0)	0 (0)	0 (0)	1 (0.1)	1 (0.02)
Overall morbidity	271 (25.8)	330 (23.2)	461(29.5)	142 (14.7)	1204 (24.1)

BTT bilateral total thyroidectomy, *RLN* recurrent laryngeal nerve, *SAN* spinal accessory nerve

Table 7 Comparative analyses of perioperative complications of the 5000 patients at different periods

Complication (*n*, %)	First + Second + Third Period ($N = 4036$)	Fourth Period ($N = 964$)	*P* value
Transient hypocalcemia (*n*/BTT, %)	789 (789/1561,50.5)	95 (95/276,34.4)	<0.001
Permanent hypocalcemia (*n*/BTT, %)	25 (25/1561,0.1)	0 (0/964,0)	<0.001
Transient voice change	101 (2.5)	25 (2.6)	0.820
Seroma	69 (1.7)	6 (0.6)	0.035
Hematoma [reoperation]	16 [4] (0.3)	5 [1] (0.5)	0.529
Chyle leak [reoperation]	25 [1] (0.6)	4 [2] (0.4)	0.637
RLN injury	16 (0.3)	2 (0.2)	>0.999
Horner syndrome	3 (0.1)	1 (0.1)	>0.999
Trachea injury	6 (0.1)	1 (0.1)	>0.999
Vessel injury (carotid artery, brachiocephalic vein)	2 (0.04)	0 (0)	>0.999
Flap injury (burn)	4 (0.1)	3 (0.3)	0.187
Traction injury of lesion side arm	4 (0.1)	0 (0)	>0.999
SAN injury	0 (0)	1 (0.1)	0.348
Overall Morbidity	1062 (26.3)	142 (14.7)	<0.001

BTT bilateral total thyroidectomy, *RLN* recurrent laryngeal nerve, *SAN* spinal accessory nerve

satisfaction after surgery. We conducted comparative studies between RT and open thyroidectomy or ET to evaluate the oncologic and functional outcomes, technical efficiency, and safety. We retrospectively reviewed the medical records of patients undergoing RT, and single- and multicenter trials were also conducted.

Our constant efforts in developing surgical techniques and training programs have resulted in similar postoperative complications and surgical completeness, as well as comparable 5-year oncologic outcomes [16, 22, 24, 25]. According to our prospective functional study, less sensory change in the neck, less swallowing difficulty, and much

Table 8 Treatment outcomes of patients with thyroid cancer

Study patients, *n* (%)	LTT ($n = 2941$)	TT (±MRND) ($n = 1863$)
Postoperative RAI ablation		1460 (78.3%)
Ablation success based on DxWBS		1380 (94.5%)
Serum Tg < 1.0 ng/mL after 3 months (without TSH↑)		1038 (55.7%)
Recurrence	15 (0.3%)	11 (0.2%)

LTT less than total thyroidectomy, *TT* total thyroidectomy, *MRND* modified radical neck dissection, *RAI* radioactive iodine, *DxWBS* diagnostic whole-body scan, *Tg* thyroglobulin

better cosmetic satisfaction were observed in patients who underwent RT [26].

RT is a complex and sophisticated surgical procedure and needs a longer total operation time than open or endoscopic surgery. The operation time gradually decreased with increasing surgeon skill and reached steady states after 35–40 cases for RT and after 55–60 cases for ET [27]. The advantages of RT may be due to the three-dimensional magnified camera vision, use of multiarticulated instruments, and the fine coordination of robotic hands, resulting in more ergonomically favorable conditions [18].

Although large numbers of results have already been reported, the technical reproducibility of RT remains unproven. Most studies have been nonrandomized retrospective studies, which is the limitation in this field. Prospective studies in large numbers of patients are needed to accurately assess the effects of RT in terms of various postoperative outcomes. Despite the limitations, our institution has accomplished the first 5000 cases of RT using gasless TAA worldwide. Our results may provide a good starting point to guide future studies with a longer follow-up.

RT is a revolutionary technology; however, the robotic equipment and the operative field have a learning curve. RT requires complete understanding of the robotic instruments, approach routes, and neck anatomy, which can lead to a dexterous and sophisticated technique in performing the procedure. Thus, sufficient training is essential, and careful observation of an expert's technique and animal or cadaveric studies are required. Surgeons should also consider the patient factors affecting outcomes in RT, including age, body habitus, disease aggressiveness, associated comorbidities, and safety. The stepwise extension of surgical methods and indications after proper training and sufficient experience will lead to the ideal application of robotic thyroid surgery.

Over the last nine years, the authors tried to improve RT technique using gasless TAA and achieved acceptable surgical outcomes. We believe that the rapid evolution of surgical robot technology, in addition to our constant efforts to advance RT technique using gasless TAA, would help reduce perioperative morbidity and gain the best possible operative and oncologic outcomes.

Compliance with ethical standards

Conflict of interest There are no conflicts of interest or financial ties to disclose.

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