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ORIGINAL ARTICLE

Short-term outcomes and one surgeon's learning curve for thoracoscopic esophagectomy performed with the patient in the prone position

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Abstract
Purpose Thoracoscopic esophagectomy with the patient in the prone position (TEP) is now being performed as minimally invasive esophagectomy for esophageal cancer. This study examines the short-term outcomes and the learning curve associated with TEP.
Methods One surgeon ("Surgeon A") performed TEP on 100 consecutive patients assigned to three periods based on treatment order. Each group consisted of 33 or 34 patients. The outcomes of the three groups were compared to define the influence of surgeon expertise.
Results Outcomes improved as Surgeon A gained experience in performing this operation, as evidenced by reduced thoracic operative times between periods 1 and 2, and then between periods 2 and 3 ($p = 0.0033$ and $p = 0.0326$, respectively); an increased number of retrieved chest nodes between periods 1 and 2 ($p = 0.0070$); and a decline in recurrent laryngeal nerve (RLN) palsy between periods 2 and 3 ($p = 0.0450$). Period 2 was the pivotal period for each learning curve.
Conclusions An individual surgeon's learning curve over the course of 100 TEP procedures had three outcomes: a shortened operative time, a higher number of retrieved chest nodes, and a decreased rate of RLN palsy. Approximately 30–60 cases were needed to reach a plateau in the TEP procedure and a reduction in the morbidity rate.

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Keywords Thoracoscopic esophagectomy in the prone position · Short-term outcome · Learning curve

Introduction

Esophageal cancer, one of the deadliest cancers in the world, is most common in Asia and East Africa [1]. In Japan, esophagectomy with extended lymphadenectomy improves the prognosis of patients with resectable esophageal cancer [2], but it is associated with high morbidity and mortality [3]. Previous studies have demonstrated that a minimally invasive esophagectomy (MIE) is technically feasible, surgically safe, and oncologically adequate, with potentially faster postoperative recovery times and reduced trauma [4, 5]. In fact, a risk model for esophagectomy using a nationwide Japanese web-based database that compared MIE and open esophagectomy (OE) found that the duration of surgery was significantly longer and blood loss was much less in the MIE group [5]. These findings are consistent with those of other reports [6–8]. Interestingly, overall morbidity was significantly higher in the MIE group than in the OE group (44.3 versus 40.8 %, $p = 0.016$) [5]. One potential explanation for this difference is that the MIE cases in that risk-model study included thoracoscopic esophagectomy with the patient in the prone position (TEP) and in the left lateral decubitus position (TELLD). The majority of reports that have addressed the feasibility, safety, and learning curve of MIE have pertained to TELLD [4, 9–11]. However, reports on the short-term outcome and learning curve for TEP are lacking; probably due to a lack of extensive experience with TEP, which was introduced worldwide only in 2006 [12]. A review of the current decade of data should aid in clarifying these issues. Specifically, a surgeon's experience is thought to influence the outcome of esophagectomy significantly [13]. Therefore, the level of experience required for a surgeon to be considered competent in thoracoscopic esophagectomy and extensive lymphadenectomy in TEP needs to be established. Another pertinent question is how surgical outcomes and morbidity improve with increased surgeon experience. This study assesses the short-term outcomes of TEP and evaluates a single surgeon's learning curve with a focus on surgical outcomes and morbidities.

Methods

Patient population

This was a single-institution, non-randomized, retrospective study of 100 patients with esophageal cancer who underwent esophagectomy at the Hyogo Cancer Centre between July, 2010 and March, 2015. All patients were staged preoperatively using endoscopy and enhanced computed tomography. The diagnosis of esophageal cancer was based on the seventh edition of the American Joint Committee on Cancer (AJCC) Staging Manual [14].

At our institution, TEP was performed for all surgical candidates with esophageal cancers, the majority (89 %) of which were squamous cell carcinoma. There were no alternatives in the form of OE without conversion or TELLD. Prior to surgery, two cycles of cisplatin/5-fluorouracil were administered as neoadjuvant chemotherapy to patients with c-Stage II and III disease. None of the patients received neoadjuvant chemoradiotherapy. Three-field (neck, chest, and abdomen) lymph node dissection was performed for cT2 or cT3 tumors in the upper or middle esophagus. Patients with metastases to the supraclavicular lymph nodes (LNs) were also treated surgically.

One attending surgeon (T. Oshikiri: "Surgeon A") performed the procedures independently. Surgeon A had had sufficient previous experience of performing more than 50 OEs as the operator or assistant and more than 300 laparoscopic procedures before the study. He had more than 15 years' experience of performing esophagectomy and had spent time gaining experience at an institute specializing in TEP. Moreover, he had done training using a motion video of TEP repeatedly. He initially performed TEP with a specialist in general thoracic surgery who had established expertise in open esophagectomy and video-assisted thoracoscopic surgery. The 100 consecutive patients who underwent TEP performed by Surgeon A alone were assigned to three periods based on their treatment order. Period 1 included cases 1–33, period 2 included cases 34–66, and period 3 included the final 34 cases. The outcomes of the three groups were compared to analyze the effects of expertise development.

In this study, the inclusion criteria were an age of 18–80 years; cT1–3 or cN0–3 disease [14]; no cognitive impairment or problems with communication; and an ability to independently complete questionnaires. The study was approved by the Institutional Review Board and the Ethics Committee of the Hyogo Cancer Centre. Informed consent was obtained from all patients who met the inclusion criteria.

Surgical procedures

Thoracic procedure

All patients underwent a radical esophagectomy with total mediastinal (extended 2-field) lymphadenectomy or 3-field lymph node dissection with TEP. To permit easy retraction of the trachea, a single-lumen tracheal tube was inserted into the trachea, and a blocker was inserted into the right bronchus for one-lung anesthesia prior to the procedure. The patient was initially placed in the prone position. A total of five 5- or 12-mm ports were inserted in the following intercostal spaces (ICS): the third ICS, behind the midaxillary line; the fifth and seventh ICS, in the posterior axillary line; the eighth ICS, in the midaxillary line; and the ninth ICS, in the scapular angle line. The chest cavity was inflated with a CO_2 insufflation pressure of 6 mmHg using the ports. The endoscope was inserted through the ninth ICS. The azygos arch was divided with an endoscopic stapler. The middle and lower esophagus was mobilized from the aorta, pericardium, and left mediastinal pleura. The thoracic duct was preserved unless direct tumor extension was suspected. The paraesophageal and subcarinal nodes were removed en bloc, taking care to preserve the left bronchial arteries (sacrificing the right bronchial arteries) and the pulmonary branches of the bilateral vagus nerves. The right recurrent laryngeal nerve (RLN) was identified at the intersection between the right vagus nerve and the right subclavian artery and pursued cranially to remove the lymph nodes along the nerve. After the upper portion of the esophagus was separated from the membranous trachea, the esophagus was divided at one level (above the azygos arch or diaphragm) with an endoscopic stapler and the left RLN was skeletonized from the level of the aortic arch to the thoracic inlet to remove the left paratracheal nodes. The cut esophageal ends were connected with a thread, and a chest drain was inserted.

Abdominal and neck procedure

The abdominal procedure was performed with hand-assisted laparoscopic surgery or open laparotomy through a 15–18 cm abdominal incision. After gastric mobilization, abdominal lymphadenectomy was done around the

Table 1 Demographic and clinical characteristics of the 100 patients who underwent thoracoscopic esophagectomy in the prone position

	Total ($n = 100$)	Period 1 ($n = 33$)	Period 2 ($n = 33$)	Period 3 ($n = 34$)	p[a]
Gender (male/female)	85/15	27/6	30/3	28/6	0.4832
Age (years)	64.6	63.9	65.2	64.6	0.8031[b]
Tumor location (upper/middle/lower)	31/35/34	12/9/12	12/11/10	7/15/12	0.4750
Depth of tumor invasion (cT1/T2/T3/T4)	32/29/39/0	10/15/8/0	11/8/14/0	11/6/17/0	0.0953
Lymph node metastasis (cN0/N1/N2/N3)	56/37/6/1	23/8/1/1	15/15/3/0	18/14/2/0	0.2810
AJCC c-stage (I/II/III/IV)	39/37/22/2	18/11/4/0	11/12/9/1	10/14/9/1	0.2946
Histology (scc/adenocarcinoma/other)	89/3/8	28/0/5	30/1/2	31/2/1	0.1929
Preoperative therapy (yes/no)	48/52	18/15	15/18	15/19	0.6512
Conduit (stomach/others)	91/9	31/2	30/3	30/4	0.7112
Reconstruction route (posterior mediastinum/retrosternum/presternum)	90/1/9	30/0/3	29/0/4	31/1/2	0.5707
Lymph node dissection (extended 2-field/3-field)	64/36	20/13	21/12	23/11	0.8723

AJCC American Joint Committee on Cancer, *scc* squamous cell carcinoma

[a] χ^2 test unless otherwise indicated

[b] One-way analysis of variance (ANOVA) test

left gastric pedicle and the celiac axis with excision of the entire isolated thoracic esophageal specimen and lymph node dissection through the esophageal hiatus. A gastric conduit, 3–4 cm wide, was created outside the wound and raised via the posterior mediastinum. If the gastric conduit could not be created because of gastric cancer or a history of gastrectomy, antethoracic colon or pedicled jejunum reconstructions were performed. After removing the third rib cartilage, the right internal mammary artery and vein were isolated for microvascular anastomosis using the jejunal conduit. Revascularization was performed by a plastic surgeon.

The neck was the site of the anastomosis. For 3-field lymph nodes, the cervical nodes were dissected through a collar incision. The bilateral RLNs were identified to remove the cervical paraesophageal nodes. A supraclavicular lymphadenectomy was also performed.

Evaluation of the postoperative clinical course

The following parameters were analyzed: operative times for the entire procedure and the thoracic component; estimated blood loss during the thoracic procedure; number of retrieved lymph nodes during the thoracic procedure; conversion frequency and reasons for open thoracotomy; residual tumor frequency; and duration of postoperative hospital stay. Postoperative mortality and morbidity were analyzed according to the Clavien-Dindo classification [15].

Assessment of laryngopharyngeal function

Hoarseness was judged by auditory impression. Aspiration was assessed by videofluorography or clinical condition during ingestion. Each patient was referred to the Department of Otolaryngology for evaluation of vocal cord mobility with flexible laryngoscopy.

Statistical analysis

Differences between variables were analyzed using a χ^2 test, Kruskal–Wallis test, or Student's t test, as appropriate. A one-way analysis of variance (ANOVA) was used to compare the quantitative variables between the three groups. p values less than 0.05 were considered significant. All statistical calculations were performed using JMP® 11 (SAS Institute Inc., Cary, NC, USA).

Results

Patient demographics and clinical characteristics

Table 1 summarizes the patient and tumor characteristics. There were no significant differences in gender, age, location, depth of tumor invasion, status of lymph node metastasis, stage, histology of the main tumor, preoperative therapy, conduit for reconstruction, reconstruction route, or type of lymph node dissection among the three groups.

Outcomes of surgery performed by Surgeon A

The operative times for the total and thoracoscopic procedures were 527.9 ± 95.1 and 282.3 ± 52.6 min, respectively. The estimated blood loss was 36.2 ± 34.8 ml. The number of retrieved thoracic lymph nodes was 27.4 ± 11.6. Conversion to OE was required for only one patient

Table 2 Period-to-period comparisons of surgical outcomes for Surgeon A

	Total ($n = 100$)	Period 1 ($n = 33$)	Period 2 ($n = 33$)	Period 3 ($n = 34$)	p[a]
Operative time (min)					
Total	527.9 ± 95.1	556.7 ± 94.4	541.4 ± 85.6	485.3 ± 92.6	0.0048[b]
Thoracic procedure	282.3 ± 52.6	314.0 ± 57.6	279.4 ± 42.9	253.5 ± 37.8	<.0001[b]
Blood loss during the thoracic procedure (ml)	36.2 ± 34.8	45.3 ± 43.1	32.2 ± 28.6	31.1 ± 30.1	0.1805[b]
Number of retrieved nodes (chest)	27.4 ± 11.6	22.5 ± 8.1	30.0 ± 13.9	29.4 ± 10.8	0.0129[b]
Reasons for conversion to open thoracotomy					
Dense pleural adhesion	0	0	0	0	>0.999
Massive hemorrhage	0	0	0	0	>0.999
Bulky tumor	1	1	0	0	0.3266
Residual tumor (R0/R1–2)	96/4	31/2	33/0	32/2	0.1934
Postoperative hospital stay (days)[c]	18	20	18	15	0.6226[d]

Data are expressed as the mean ± SD unless otherwise indicated

[a] χ^2 test unless otherwise indicated

[b] One-way analysis of variance (ANOVA) test

[c] Data are expressed as the median

[d] Kruskal–Wallis test

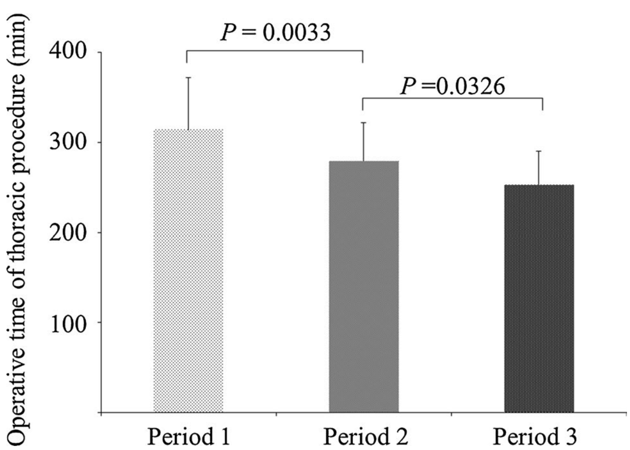

Fig. 1 Relationship between surgeon experience and operative time. The operative time for the thoracic procedure significantly decreased between periods 1 and 2 and periods 2 and 3 (basic step). A Student's *t* test was used to compare groups

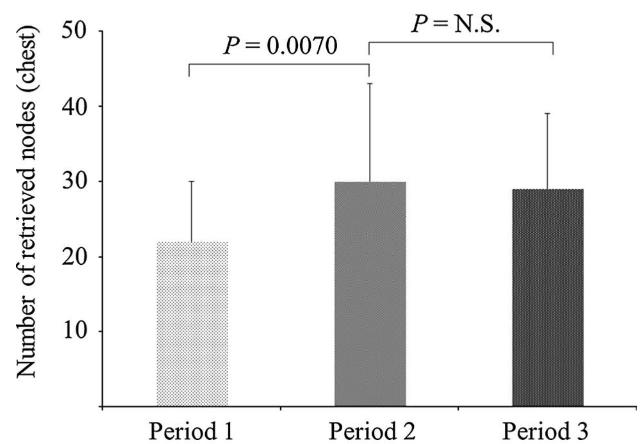

Fig. 2 Relationship between surgeon experience and number of retrieved nodes in the chest. The number of retrieved nodes in the chest significantly increased between periods 1 and 2 (intermediate step). A Student's *t* test was used to compare groups. *N.S.* not significant

(1 %), the complete resection rate was 96 %, and the average length of the postoperative hospital stay was 18 days (Table 2).

As Surgeon A continued to perform the TEP procedure, there were significant reductions in the total and thoracic operative times ($p = 0.0048$ and $p < 0.0001$, respectively; Table 2). A significant reduction in the mean thoracic operative time was observed between periods 1 and 2 (Fig. 1, $p = 0.0033$) and again between periods 2 and 3 (Fig. 1, $p = 0.0326$). The turning point in the thoracic operative times was noted in the 44th case (data not shown). Similarly, an increase in the number of retrieved nodes in the chest was observed as additional procedures were completed, when compared with period 1 ($p = 0.0129$) (Table 2). The first significant increase occurred between periods 1 and 2 (Fig. 2, $p = 0.0070$). No significant intergroup differences were observed in the conversion to OE, the number of residual tumors, or the duration of the postoperative hospital stay.

Table 3 Period-to-period comparisons of postoperative mortality and morbidity after thoracoscopic esophagectomy with the patient in the prone position performed by Surgeon A

	Total ($n = 100$)	Period 1 ($n = 33$)	Period 2 ($n = 33$)	Period 3 ($n = 34$)	p[a]
Mortality	2	1[c]	0	1[d]	0.4311
Complications					
Pneumonia					
Grade[b] II/IIIa/IIIb/IV	2/4/0/0 (6 %)	1/1/0/0 (6 %)	0/2/0/0 (6 %)	1/1/0/0 (6 %)	0.9994
Anastomotic leakage					
Grade[b] II/IIIa/IIIb/IV	6/6/1/0 (13 %)	2/1/1/0 (12 %)	2/3/0/0 (15 %)	2/2/0/0 (12 %)	0.9051
Recurrent laryngeal nerve palsy					
Grade[b] I/II/IIIa/IIIb/IV	10/7/4/0/0 (21 %)	3/3/3/0/0 (27 %)	5/3/1/0/0 (27 %)	2/1/0/0/0 (9 %)	0.0761
Chylothorax	0	0	0	0	>0.999
ARDS	1	1	0	0	0.3266
Gastric conduit necrosis					
Grade[b] II/IIIa/IIIb/IV	0/0/2/0 (2 %)	0/0/1/0 (3 %)	0/0/1/0 (3 %)	0	0.4311
Gastrotracheal fistula					
Grade[b] II/IIIa/IIIb/IV	1/1/0/0 (2 %)	0	1/0/0/0 (3 %)	0/1/0/0 (3 %)	0.4443

ARDS acute respiratory distress syndrome

[a] χ^2 test unless otherwise indicated

[b] Postoperative mortality and morbidity were analyzed according to the Clavien-Dindo classification

[c] Patient died of ARDS

[d] Patient died because of blast crisis of myelogenous leukemia

Postoperative mortality and morbidity of Surgeon A's patients

There were two operative deaths: one in period 1 and one in period 3. The first patient died of adult respiratory distress syndrome, and the second patient died following a blast crisis of myelogenous leukemia. The incidences of postoperative pneumonia, anastomotic leakage, and recurrent laryngeal nerve palsy in 100 patients were 6, 13, and 21 %, respectively (Table 3). The incidence of postoperative pneumonia was 6 % in each period with no significant difference among the groups. There was no significant difference in the incidences of anastomotic leakage, at 12, 15, and 12 % in periods 1, 2, and 3, respectively. In contrast, the rate of RLN palsy decreased over time, being 27, 27, and 9 % in periods 1, 2, and 3, respectively (Table 3). There was a significant decrease in the rate of RLN palsy from period 2 to period 3 (Fig. 3, $p = 0.0450$). No significant differences in other complications were observed among the groups.

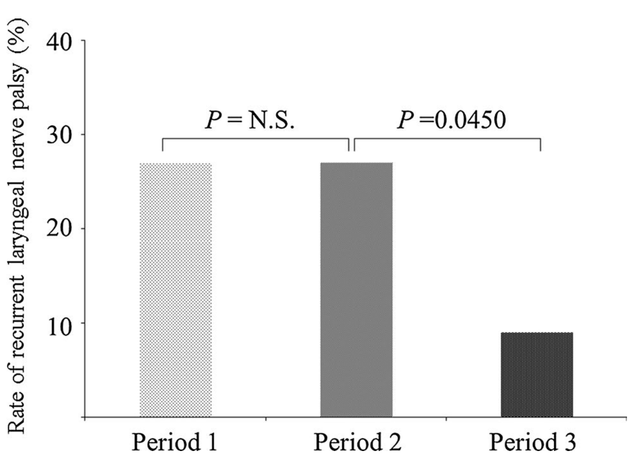

Fig. 3 Relationship between surgeon experience and rate of recurrent laryngeal nerve palsy. The rate of recurrent laryngeal nerve palsy significantly decreased between periods 2 and 3 (advanced step). A χ^2 test was used to compare groups. *N.S.* not significant

Oncologic long-term outcomes

At the time of analysis, the median follow up period was 37 months. Recurrent disease had developed in 23 patients, 6 of whom had locoregional lymph node recurrence.

Discussion

The theoretical advantages of performing esophagectomy with the patient in the prone position include better operative exposure, improved surgeon ergonomics, lower risk of pulmonary complications, and less blood loss [16]. In our study, the improved operative exposure and surgeon ergonomics during TEP may have contributed to the low rate of conversion to OE, high rate of complete resection, and low rate of operative mortality. The operative time, number of retrieved nodes (chest), and incidence of recurrent laryngeal nerve palsy are similar to those of other reports [7, 17]. Palanivelu et al. analyzed 130 cases of TEP and reported a total operating time for esophagectomy of 220 min and an RLN palsy rate of 1.54 % [12]. These results were superior to those of the present study; however, the mean number of retrieved lymph nodes reported by Palanivelu et al. was 18 for both the thoracic and abdominal procedures, whereas it was 27 for the thoracic procedures in the present study. The incidence of squamous cell carcinoma in esophageal cancer patients is high in East Asia and low in North America and Europe [18]. This difference may account for the disparity in the degree of mediastinum lymphadenectomy; thus, the operative time, numbers of harvested lymph nodes, and RLN palsy rate may not be comparable. Moreover, the evaluation method for RLN palsy may vary among institutes. Regarding pulmonary complications, only 6 % of our patients had pneumonia, in accordance with the findings of Biere et al. who reported that pulmonary infection was significantly lower for MIE versus OE [6].

As Surgeon A gained more experience, an improvement in operative and postoperative parameters became evident. There were three components to the learning curve of Surgeon A: a shortened operative time (basic step), an increased number of retrieved nodes in the chest (intermediate step), and a decreased rate of RLN palsy (advanced step). These parameters correspond to improvements in hand movement, oncological treatment, and functional preservation, respectively. These steps are not independent, but interrelate with each other.

Improvement in hand movement leads to habituation, achieved through experience, and results in shortened operative times. Concerning the intermediate and advanced improvements, oncological treatment often conflicts with functional preservation in surgery. Specifically, dissection around the RLN lymph nodes increases the risk of complications, particularly RLN palsy [19–21]. RLN palsy has been reported as a risk factor for hoarseness and aspiration pneumonia [19–21]. Conversely, avoiding lymphadenectomy around the RLN lymph nodes can prevent RLN palsy but result in the spread of metastatic lymph nodes. Lymph nodes along the RLN are thought to be highly involved in esophageal cancer; thus complete dissection of these lymph nodes is recommended [22–24]. Realistically, dissection around the RLN lymph nodes as oncological treatment should take precedence over preserving the RLN. The habituation of hand movements contributes to an increased number of retrieved nodes in the chest, while preserving the RLN. Finally, the sophistication of the procedure is based on data about the surgeon's experience, including in relation to the prevalence of RLN palsy and how it improved. To assess RLN palsy, the Japan Clinical Oncology Group postoperative complications criteria may be more suitable than the Clavien-Dindo classification because of their accuracy [15, 25]. Concerning the quality of lymph node dissection, the fact that lymph node recurrence in the mediastinum was seen in only six patients suggests that our procedure for TEP is adequate for effective lymph node dissection.

The major limitations of this study relate to its retrospective and single-center design. After consideration of these limitations, our results indicate that each learning curve developed during period 2. Specifically, 30–60 cases were needed to reach a plateau in the TEP procedure and a reduction in the morbidity rate. Guo et al. also reported that at least 30 cases were needed to reach general competence in TELLD, and 60 cases were necessary to reach a sufficient proficiency to improve postoperative variables [10]. Our TEP data support their results.

Conclusion

In summary, we analyzed the short-term outcomes of TEP and concluded that the learning curve for the procedure consisted of three steps: a shortening of the operative time, an increase in the number of retrieved nodes in the chest, and a decrease in the rate of RLN palsy. Approximately 30–60 cases were needed to reach a plateau in the TEP procedure and a reduction in the morbidity rate.

Compliance with ethical standards

Funding This study was not funded.

Conflict of interest We do not have a financial relationship with the organization that sponsored the research or any other conflict of interest.

Ethical approval All procedures performed in studies involving human participants were carried out in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. This article does not contain any reference to studies with animals performed by any of the authors.

Informed consent Informed consent was obtained from all participants included in the study.

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