Videofluoroscopic Evaluation in Oropharyngeal Swallowing after Radical Esophagectomy with Lymphadenectomy for Esophageal Cancer

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Abstract. *Background: After esophagectomy a swallowing abnormality is the predominant symptom for esophageal cancer. The aims of this study were to examine (i) oropharyngeal swallowing by comparing pre- and post-operative period, and (ii) the relationship between oropharyngeal swallowing and the alimentary reconstruction route after esophagectomy. Patients and Methods: We studied 27 patients in the upright position using videofluoroscopy in the lateral projection. Each patient was studied during 10 mL barium swallows in the pre- and post-operative period. Results: Of the 27 patients studied, alimentary reconstruction with the retrosternal route (RS group) was performed in 8 patients, that with posterior mediastinal route (PM group) in 8 patients, and the intrathoracic (IT group) esophagogastrostomy inside the posterior mediastinum in 11 patients. With regard to the maximal extent of structural movement, the superior and anterior excursion of the hyoid bone was significantly reduced postoperatively among all groups. The maximal extent of the cricopharyngeal opening was significantly reduced postoperatively in the RS group, but not in the IT group. The changes in the peri-operative structural movement were the lowest in the RS group. Conclusion: A new-onset oropharyngeal swallowing abnormality following retrosternal reconstruction after esophagectomy may have appeared because the change in the peri-operative movement was the lowest. The results of the swallowing evaluation using videofluoroscopy suggest that to avoid oropharyngeal swallowing abnormalities the intrathoracic or cervical anastomosis with posterior mediastinal route should be chosen as reconstruction after esophagectomy if possible.*

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Esophageal carcinoma is considered as one of the most difficult malignancies to cure (1, 2). Esophagectomy is the mainstay of therapy for malignancy of the esophagus (3). Although the whole stomach can be used as an esophageal substitute after esophageal resection, the most general gastric reconstruction after an esophagectomy is the gastric tube (4, 5). The gastric tube is often transposed to the neck where an esophagogastric anastomosis is performed (6-10). Reconstruction in this circumstance can be achieved through a retrosternal or posterior mediastinal route, and the anastomosis is performed at the cervical or high thoracic level. Esophagectomy can be accompanied by early and severe late functional disturbances, with a large impact on quality of life (QOL) (11). However, there are few reports evaluating the quality of swallowing in patients who received esophagectomy because of the reduced number of long-term survivors.

In our previous study, we reported that the interdigestive pyloric motor activity of the gastric tube, on which a pyloroplasty had been performed, begins to recover at 12 months after an esophagectomy (12). Moreover, the interdigestive gastric motility returns towards normal in a progression over time from the pylorus cephalad. In another study, we reported the relationship between anastomotic insufficiency and tissue blood flow in the gastric tube in the perioperative period (13). As regards postoperative swallowing, quality of swallowing has been reported to be quite variable in the perioperative period and in long-term survivors, despite technically precise surgery (14). Previous

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functional studies have suggested that the transposed, intrathoracic stomach retains its gastric identity, with varying rates of gastric emptying and transit times for radiolabelled solids to pass through the cervical esophagus and anastomosis (15). Two recent studies on quality of swallowing after esophageal reconstruction have been published, one reporting videofluoroscopic evidence of increased pharyngeal phase abnormalities in 10 patients after esophagectomy (16), and a second smaller series of eight patients where decreased upper esophageal sphincter (UES) diameter and reduced hyoid excursion were associated with altered swallowing and aspiration in the early postoperative period (17). In the recent study of Koh co-workers (18), sensory and motor functions of the cervical esophagus were analyzed to investigate the oropharyngeal or cervical esophageal swallowing abnormalities after cervical esophagogastrostomy. They demonstrated that a functional etiology of swallowing abnormalities may be explained by hypertensive peristalsis in the cervical esophagus.

However, comparisons of oropharyngeal swallowing and the alimentary reconstruction route after esophagectomy for esophageal cancer have not been reported. The aims of this study were to: (i) characterize oropharyngeal swallowing by comparing pre- and postoperative swallowing patterns in esophageal carcinoma patients, and (ii) analyze the relationship between oropharyngeal swallowing and the alimentary reconstruction route after esophagectomy.

Patients and Methods

Patients. Between January 2004 and September 2005, 27 patients with thoracic esophageal carcinomas who underwent radical esophagectomy without preoperative treatment at the Department of General Surgical Science, Gunma University, Graduate School of Medicine were included in this study. Patients with preoperative severe esophageal stenosis, palliative resection, apparent postoperative residual tumors, and postoperative bilateral recurrent laryngeal paralysis were excluded. Written informed consent was obtained from all patients prior to surgery. The median age of the patients was 64.3 years, with a range of 53 to 78 years. All the patients were male. Patients with limited local metastasis considered by thoracic surgeons to have resectable diseases were included.

Surgical procedure. Two different procedures were used. In suitable cases, a standard esophagectomy was performed according to the McKeown method (right thoracotomy followed by laparotomy and neck incision with a cervical anastomosis) with three-field (thoracoabdominal and cervical; n=16) lymph node dissection. In other cases, an Ivor Lewis method was used (right thoracotomy and laparotomy with anastomosis in the chest) with two-field (thoracoabdominal; n=11) lymph node dissection if indicated (2). The extents of intrathoracic and abdominal lymph node dissection were similar in both surgical procedures. The lymph node around the bilateral recurrent laryngeal nerves and the trachea were included in the upper mediastinal lymph node and were usually dissected at operation. All patients received curative thoracic esophagectomy including the esophagogastric junction, and reconstruction was performed using a gastric tube as an esophageal substitute.

In the McKeown method, the gastric tube was passed up through a retrosternal route (RS group) or a posterior mediastinal route (PM group) and into the neck. The cervical exploration was performed through a low transverse incision curved until the sternocleidomastoid muscle. During the operation the sternocleidomastoid muscle and carotid sheath were retracted laterally. The middle thyroid vein was divided, and the sternohyoid and sternothyroid muscles were retracted medially. If adequate exposure was not gained, these muscles were partially divided. The recurrent laryngeal nerve was avoided by maintaining dissection directly on the esophagus and gently separating the esophagus from the membranous trachea. Secondly, cervical bilateral lymph node dissections included supraclavicle, deep external and deep lateral cervical lymph nodes were performed. After cervical lymph node dissection, a cervical esophagogastrostomy was performed end to side using a suture instrument. The neck was drained with a small Jackson-Pratt drain, which was removed on the 2nd or 3rd postoperative day when drainage was negligible.

In the Ivor Lewis method, the stomach was passed up through the esophageal hiatus, and into the intrathoracic (IT group). Cervical lymph node dissection was not performed in patients of this group. An intrathoracic esophagogastrostomy was performed above the aortic arch using a suture instrument. The posterior mediastinum was drained with a small Jackson-Pratt drain through the hiatus, through the abdominal cavity and outside the abdominal wall, which was removed on the 2nd or 3rd postoperative day when drainage was negligible.

Videofluoroscopic analysis. We studied 27 esophagectomy patients in the upright position using videofluoroscopy in the lateral projection, as described by Logemann *et al.* (19). Each patient was studied during 10 mL barium swallows in the pre- and post-operative period. The first videofluoroscopic swallow study was performed preoperatively and the postoperative study was performed between the 14th and 21st postoperative days. The videofluoroscopic recordings were digitized and subsequently analyzed independently by two individuals. For calibration of videofluoroscopic measurements, before each study, length reference markers (coin: 23 mm diameter; Figure 1) were taped on the skin at the subject's chin.

Videofluoroscopic recordings were obtained at an appropriate collimation so that an image was obtained of the posterior mouth, pharynx and pharyngoesophageal region. Videofluoroscopic images were recorded on a super-VHS videocassette recorder. The computer analysis system used for analyzing the videofluoroscopic data consisted of a Dell-desktop Dimension 5100C (Dell Inc. Round Rock, TX, USA) operating with a Pentium Processor. The computer system includes an analog-to-digital conversion board and program specifically designed for image capture. The image analysis and capture software (PowerDirector, CyberLink, Fremont, CA, USA) allows capture of standard raster scan video images and morphologic analysis of digitized image data. The digitized images are stored as computer files for any subsequent recall or analysis using software (MovieRuler, Photron, San Diego, CA, USA). Videofluoroscopic recordings of biomechanical swallow events were timed using each video frame (1/30 second intervals)

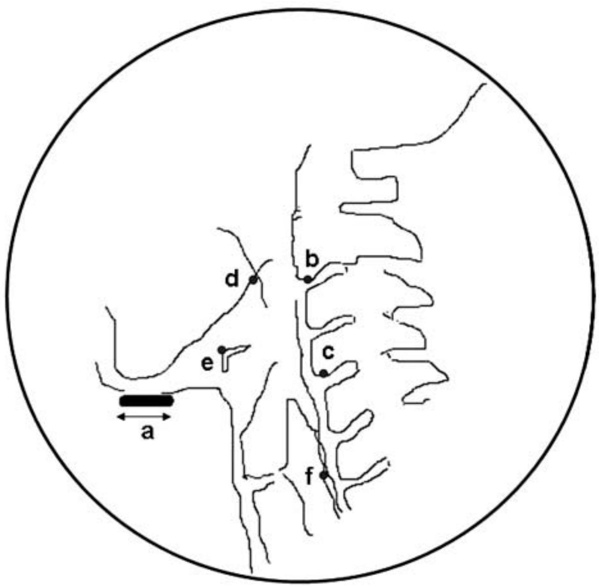

Figure 1. *Tracing of a lateral view from a videofluoroscopic frame. Swallowing study with marked points and lines identified, including: (a) length of reference marker (coin: 23 mm); (b) anchor point marked at the anterior-inferior corner of C2; (c) anchor point marked at the anterior-inferior corner of C4; (d) points where the lower edge of the mandible crosses the tongue base; (e) most anterior-superior aspect of the hyoid bone; (f) criopharyngeal region.*

from each data. To measure the extent of the hyoid bone movement, the anterior corner of the second and fourth cervical vertebra were defined, in all frames, as the two reference points. Figure 1 outlines the swallowing study with marked points and lines identified, including: (a) length of reference marker (coin: 23mm); (b) anchor point marked at the anterior-inferior corner of C2; (c) anchor point marked at the anterior-inferior corner of C4; (d) points where the lower edge of the mandible crosses the tongue base; (e) most anterior-superior aspect of the hyoid bone; (f) criopharyngeal region. These reference points were used to measure the following.

Duration measures (in seconds): (i) Pharyngeal transit duration: the time interval (in seconds) from the bolus head reaching the lower edge of the mandible until the bolus tail passes through the cricopharyngeal sphincter; (ii) duration of maximum superior hyoid elevation: the time interval (in seconds) from the bolus head reaching the lower edge of the mandible until maximum superior elevation of the hyoid; (iii) duration of maximum anterior hyoid movement: the time interval (in seconds) from the bolus head reaching the lower edge of the mandible until maximum anterior movement of the hyoid; (iv) duration of cricopharyngeal opening: the time interval (in seconds) from the bolus head reaching the lower edge of the mandible until the first cricopharyngeal opening.

Maximal extent of structural movement (in mm): (v) extent of cricopharyngeal opening: maximum anterior-posterior width of the cricopharyngeal opening; (vi) extent of superior hyoid elevation: distance of maximum superior elevation of the hyoid; and (vii) extent of anterior hyoid movement: distance of maximum anterior movement of the hyoid. The change in the peri-operative period was calculated as maximal extent of structural movement in post-operative period/maximal extent of structural movement in the pre-operative period. The relationship between the parameters of swallowing measures and peri-operation, and each group were determined using analysis of variance (ANOVA) or Student's *t*-test.

Results

Of the 27 patients studied, alimentary reconstruction with the retrosternal route (RS group) was performed in 8 patients, with posterior mediastinal route (PM group) in 8 patients, and the intrathoracic (IT group) esophagogastrostomy inside the posterior mediastinum in 11 patients.

Swallowing measures from videofluoroscopic images of the all patients in the pre- and post-operative period are summarized in Table I. The results of duration measurements for all groups revealed that there was no significant difference in pharyngeal transit duration, duration of maximum superior hyoid elevation, duration of maximum anterior hyoid movement, or duration of cricopharyngeal opening between groups. With regard to the structural movement in the IT group, maximal extents of superior hyoid elevation and anterior hyoid movement significantly decreased postoperatively. However, there was no significant difference in the maximal extent of cricopharyngeal opening. Regarding the structural movement in the PM group, maximal extents of superior hyoid elevation and anterior hyoid movement significantly decreased postoperatively. In addition, there was a slight difference in the maximal extent of the cricopharyngeal opening. With respect to the structural movement in the RS group, the maximal extent of cricopharyngeal opening, maximal extents of superior hyoid elevation and anterior hyoid movement significantly decreased postoperatively.

The relationship between the changes in the peri-operative period in each group are summarized in Table II. The changes in the peri-operative structural movement in the RS group were significantly lower than those in the IT group. Furthermore, the change in the extent of superior hyoid elevation in the RS group was lower than that in the PM group.

Discussion

A swallowing abnormality is the predominant symptom after esophagectomy for esophageal cancer (16). Swallowing abnormalities after esophagectomy generally result, for example from recurrent laryngeal nerve paralysis, reduced laryngeal movement, cricopharyngeal opening disturbance (11). However, there are few studies of altered swallowing after esophageal resection and reconstruction.

In the present study, we examined (i) oropharyngeal swallowing by comparing that in the pre- and postoperative

Table I. *The relationships between peri-operation and swallowing measures in each group.*

Parameter	Pre-operation		Post-operation		*P*-value
	Average	SD	Average	SD	
IT group (n=11)					
Duration measures(s)					
Pharyngeal transit duration	0.70	0.16	0.66	0.14	0.4855
Duration of maximum superior hyoid elevation	0.23	0.19	0.28	0.22	0.5673
Duration of maximum anterior hyoid movement	0.46	0.21	0.49	0.17	0.7390
Duration of cricopharyngeal opening	0.27	0.12	0.27	0.16	0.9999
Maximal extent of structural movement (mm)					
Extent of cricopharyngeal opening	10.49	1.38	10.14	1.11	0.5090
Extent of superior hyoid elevation	14.00	3.23	10.18	4.21	0.0267
Extent of anterior hyoid movement	11.60	2.57	9.38	2.30	0.0454
PM group (n=8)					
Duration measures(s)					
Pharyngeal transit duration	0.80	0.19	0.78	0.15	0.7158
Duration of maximum superior hyoid elevation	0.32	0.14	0.26	0.12	0.4330
Duration of maximum anterior hyoid movement	0.55	0.15	0.46	0.15	0.2385
Duration of cricopharyngeal opening	0.27	0.21	0.23	0.13	0.6790
Maximal extent of structural movement (mm)					
Extent of cricopharyngeal opening	10.56	1.13	8.89	1.83	0.0501
Extent of superior hyoid elevation	15.18	3.97	10.89	2.65	0.0235
Extent of anterior hyoid movement	10.28	1.70	7.82	1.83	0.0190
RS group (n=8)					
Duration measures(s)					
Pharyngeal transit duration	0.76	0.13	0.85	0.19	0.3054
Duration of maximum superior hyoid elevation	0.37	0.09	0.30	0.18	0.3759
Duration of maximum anterior hyoid movement	0.52	0.09	0.47	0.16	0.4110
Duration of cricopharyngeal opening	0.28	0.08	0.32	0.17	0.5568
Maximal extent of structural movement (mm)					
Extent of cricopharyngeal opening	11.34	1.23	9.03	1.81	0.0099
Extent of superior hyoid elevation	14.92	3.88	8.26	2.30	0.0009
Extent of anterior hyoid movement	11.02	2.78	6.83	2.45	0.0065

SD: Standard deviation; IT group: intrathoracic esophagogastrostomy after esophagectomy; PM group: cervical esophagogastrostomy reconstruction through a posterior mediastinal route after esophagectomy; RS group: cervical esophagogastrostomy reconstruction through a retrosternal route after esophagectomy.

period and (ii) the relation between oropharyngeal swallowing and the alimentary reconstruction route chosen after esophagectomy. The pharyngeal transit duration from videofluoroscopic images in the pre- and postoperative periods were not significantly different between groups. Regarding the maximal extents of structural movement, the superior and anterior excursion of the hyoid bone was significantly reduced postoperatively in all groups. Although cervical management was not undertaken in the IT group, the hyoid movement was also significantly reduced. The reason for the postoperative swallowing abnormalities is a result of postoperative adhesion due to the lymph node dissection, scarring at the anastomosis, adhesion of the gastric tube to the trachea and incarceration of the gastric tube in the thoracic inlet. Regarding the cricopharyngeal opening, the maximal extent of the cricopharyngeal opening was significantly reduced postoperatively in the RS group, but not in the IT group. The changes in the peri-operative structural movement in the RS group were the lowest. This may be due to the adhesiveness of the trachea, since the intrathoracic gastric tube is placed in front of the trachea in the RS group. From these results, the hyoid movements in the post-operative period were shown to be reduced, despite no cervical management of the IT group. New-onset oropharyngeal swallowing abnormality of the retrosternal reconstruction after esophagectomy, such as aspiration, pneumonia, and pharyngeal residue, might have appeared because the changes of the peri-operative movement in the RS group were the lowest. These results of swallowing evaluation using videofluoroscopy suggest that to avoid oropharyngeal

Table II. *The relationship between the changes in the peri-operative structural movement and each group.*

Change in peri-operative period	IT group		PM group		RS group	
	Average	SD	Average	SD	Average	SD
Extent of cricopharyngeal opening	0.98	0.15	0.84	0.14	0.79	0.12
	(IT vs. RS: **)					
Extent of superior hyoid elevation	0.71	0.18	0.74	0.19	0.58	0.18
	(PM vs. RS: *; IT vs. RS: *)					
Extent of anterior hyoid movement	0.83	0.21	0.77	0.21	0.63	0.22
	(IT vs. RS: *)					

*P-value <0.05, **p-value <0.01, SD: standard deviation.
IT group: intrathoracic esophagogastrostomy after esophagectomy; PM group: cervical esophagogastrostomy reconstruction through a posterior mediastinal route after esophagectomy; RS group: cervical esophagogastrostomy reconstruction through a retrosternal route after esophagectomy.

swallowing abnormalities, the intrathoracic or cervical anastomosis with the posterior mediastinal route should be preferred as the reconstruction route after esophagectomy.

Previous studies have reported oropharyngeal swallowing abnormalities following transhiatal esophagectomy (16, 17, 20). Heitmiller and Jones (20) reported at least one new-onset swallowing abnormality in 67% of patients one week after transhiatal esophagectomy. Although these abnormalities resolved or improved within the first postoperative month in most cases, two patients judged to have significant preoperative swallowing disorders had long-term postoperative dysphagia. The swallowing abnormalities, including aspiration, deficient airway protection and reduced laryngeal movement, have been attributed to surgical damage during esophagectomy (20). Easterling and colleagues (17) found that dysphagia in posttranshiatal esophagectomy patients is associated with a significant reduction in upper esophageal sphincter (UES) opening and hyoid bone excursion. Resolution of these symptoms as well as postdeglutitive aspiration in these patients are associated with a significant increase in cricopharyngeal opening diameter of the UES and hyoid bone excursion. In a study by Martin *et al.* (16), kinematic analyses indicated that oropharyngeal stage swallow-related laryngeal movement, as reflected in hyoid movement, was significantly reduced postoperatively in almost all cases. This suggests that reduced laryngeal movement, as reported in the above studies (17, 20), may represent a long-term deficit. New-onset oropharyngeal dysphagia has been attributed to surgical damage of the innervation of the swallowing mechanism. Oropharyngeal swallowing deficits following esophagectomy have also been interpreted as resulting from inadvertent damage to the pharyngeal plexus and other nerves mediating swallowing (16, 17, 20). The recent study of Koh *et al.* (18) demonstrated that swallowing abnormalities after cervical esophagogastrostomy may be caused by hypertensive peristalsis in the cervical esophagus. They suggested that abnormalities of intrinsic neural pathways of the cervical esophagus which are responsible for peristalsis occur; possibly afferent sensory disruption results from mobilization of the cervical esophagus during surgery.

Our present study gave similar results in that the oropharyngeal stage hyoid movement was significantly reduced postoperatively. However, the surgical procedures differ considerably between the present and previous studies. The surgical procedure in the present study was transthoracic esophagectomy with intrathoracic lymph node dissection, whereas all previous studies were transhiatal esophagectomy. Therefore, swallowing abnormalities may be caused by the damage of the neural pathway of the pharyngeal or cervical esophagus in the previous studies. However, we suggested that the reason may be a surgical effect, such as adhesion formation, scarring at the anastomosis, and inflammation, rather than neural damage by intraoperative manipulation during esophagectomy since the hyoid movements were reduced postoperatively in spite of no cervical management of the IT group.

Furthermore, the present study, which compared pre- and postoperative swallowing deficits in detail, showed no extension of the pharyngeal transit duration. From these results, we suggest that reduced hyoid movement resulting from surgical damage may be recovered by rehabilitation. Moreover swallowing abnormalities may be diminished by earlier postoperative swallowing rehabilitation to prevent adhesion formation. On the other hand, a surgical method, such as laryngeal suspension, may produce reduced swallowing abnormalities. During cervical surgical manipulation, reduced laryngeal movement may be compensated for by dissecting inferior traction muscles of the hyoid and larynx, such as sternohyoid muscle, sternothyroid muscle and omohyoid muscle. In the future, it will be necessary to determine using videofluoroscopy whether or not swallowing abnormalities are reduced by this surgical method.

This detailed analysis of oropharyngeal swallowing deficits and the alimentary reconstruction route reveals the novel finding that deficits were the highest in retrosternal reconstruction after esophagectomy. To our knowledge, this is the first report of videofluoroscopic analysis of swallowing abnormalities and the alimentary reconstruction route after esophagectomy. The results suggest that, if possible, retrosternal reconstruction should be avoided. Finally, it is worth considering that other factors, such as peristaltic disorder and low clearance of the remnant esophagus and surgical anastomosis method (hand-sewn or stapled anastomosis) may also be influenced. Videofluoroscopic analysis of long-term postoperative swallowing abnormalities will be required in the future.

In conclusion, we suggest that a new-onset oropharyngeal swallowing abnormalities following retrosternal reconstruction after esophagectomy, such as aspiration, pneumonia, pharyngeal residue, appear because postoperative structural movement is poor. Results of the swallowing evaluation using videofluoroscopy suggest that to avoid oropharyngeal swallowing abnormalities, the intrathoracic or cervical anastomosis with posterior mediastinal route should be chosen as reconstruction after esophagectomy.

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