For patients undergoing esophagectomy, the stomach is the organ that is most commonly used to restore continuity in the gastrointestinal tract. As a consequence of changes in stomach shape and location, patients in the postoperative period usually experience disturbed motility of the upper gastrointestinal tract of variable intensity.

The aim of the study was to assess the motility of esophageal substitutes and the emptying rate of a narrowed stomach (in particular its prepyloric portion) using scintigraphy in patients undergoing esophageal resection compared to those in healthy controls.

Material and methods. Between 2000 and 2006, 297 patients (105 women, 192 men) underwent surgical treatment for esophageal cancer in the Clinic of Gastrointestinal Surgery. Ten patients (average age 59; range 54 to 67 years) who underwent an attempted curative esophageal resection were selected into the study group. Patients from this group underwent scintigraphic assessment of gastric emptying between three to 11 months after the surgical procedure (an average 7 months). Furthermore, ten healthy volunteers (average age 28; range 19 to 43 years) constituted the control group.

Results. The average radiotracer retention after two hours was 44.7±6.5% in the study group and 51.1–7.4% (p>0.2) in the control group. Frequency of contractions of the whole prepyloric segment, as well as its distal fragment, in the subsequent periods of examination was comparable in both groups. Correlation among the frequency of contractions, contraction duration and duration of relaxation of the whole prepyloric segment and its distal fragment was high for the control group (correlation coefficients 0.71 p<0.001; 0.71 p=0; and 0.63 p=0, respectively). In the study group, correlation between the frequency of contractions and contraction duration was poor (coefficients of correlation 0.03 p>0.8 and –0.02 p>0.9), while correlation between duration of relaxation of the whole prepyloric segment and its distal fragment was moderate (coefficient of correlation 0.34 p<0.06).

Conclusions. Formation of a gastric substitute after its narrowing and denervation (truncal vagotomy) does not abolish gastric contractility. Frequency, amplitude, duration of contraction, and relaxation duration of the prepyloric portion of the ectopic substitute do not differ significantly from the patterns of motility of the upper gastrointestinal tract in healthy volunteers.

Key words: gastric emptying, esophageal substitute, truncal vagotomy

Among malignancies, cancer of the esophagus is the 6th most common cause of death in males and the 9th most common cause in females (1). Despite advanced surgical techni-
ques and the development of other therapeutic methods, esophageal cancer still remains a disease with very poor prognosis (2, 3). One- and five-year survival rates after operation are approximately 58% and 25%, respectively (4). The method of esophageal reconstruction after esophagectomy plays an important role in the postoperative period. Proper functioning of the esophageal substitute is a prerequisite for proper evacuative function, which ensures a rapid increase in body weight and normalization of vital signs during postoperative periods. Proper activity of the esophageal substitute also minimizes potential gastroesophageal reflux (5, 6).

Both the stomach and the large intestine can be used to restore gastrointestinal continuity in the group of patients undergoing esophageal resection. However, the stomach is most commonly used for this purpose due to the lower incidence of postoperative complications and the simpler surgical technique in such cases (7-10). In this procedure, the stomach is narrowed from the lesser curvature, and after its “tube-like” formation, it is moved to the anterior or posterior mediastinum (11, 12, 13). Due to the significantly lower mortality and incidence of cardiovascular and respiratory complications, the narrowed stomach is most commonly moved to the posterior mediastinum (11, 14). According to other studies, a retrosternal location of the substitute decreased the probability of gastroesophageal reflux (15). Moreover, in the event of local tumor relapse, retrosternal positioning protected the substitute against infiltration and obstruction (14, 16).

As a consequence, changes in shape and location during the postoperative period may lead to disturbed motility in the upper gastrointestinal tract. This may result in ingestion of inadequate amounts of food and inhibition of normal body weight increase in cachectic patients. The requirement for truncal vagotomy could also result in incomplete relaxation of the substitute, which, along with low capacity of the translocated gastric portion, limits the volume of ingested food. Some authors reported that total vagotomy resulted in gastric atony (17, 18), while others claimed that the organ contractility continued unabated despite denervation of the organ (19, 20, 21). Symptoms reported by patients, such as rapid satiety and regurgitation even after a small meal may thus result from improper emptying of a gastric substitute and its decreased capacity. Passage of fluid and semi-fluid foods is more rapid than that of solid foods, while the force of gravity is believed to play a major role in the emptying process (22, 23, 24). Dynamic scintigraphy seems to be the most convenient method to assess the evacuative activity and function of the substitute (24, 25). This examination is simple to conduct, minimally invasive and safe for the patient. It allows for functional assessment of a narrowed stomach, and with other diagnostic modalities (such as endoscopy, x-ray, electrogastrography or manometry), provides a more complete picture of the functioning of the substitute.

The aim of the study was to assess the motor function of the esophageal substitute, in particular the prepyloric portion of the translocated stomach after a test meal, and to assess the emptying of the narrowed stomach.

**MATERIAL AND METHODS**

Between 2000 and 2006, 297 patients (105 women, 192 men) underwent surgical treatment for esophageal cancer in the Clinic of Gastrointestinal Surgery. Ten patients (average age 59; range 54 to 67 years) who underwent an attempted curative esophageal resection were selected into the study group. Patients from this group underwent scintigraphic assessment of gastric emptying between three to 11 months after the surgical procedure (an average 7 months). Furthermore, ten healthy volunteers (average age 28; range 19 to 43 years) constituted the control group.

Malignancy was the indication for esophageal resection in the study group, including eight cases of squamous cell carcinoma and two cases of adenocarcinoma (six patients – stage II in TNM scale; four patients – stage III in TNM scale). All patients in this group underwent video-assisted trans-hiatal esophagectomy, and the esophagus was replaced by a narrowed gastric fragment formed out of the greater curvature. Esophageal substitutes were formed with a gastric tube after its partial resection from the lesser curvature and longitudinal suturing with a bilayered continuous suture. The duodenum was mobilized with the Kocher maneuver; no pyloroplasty or nutritive micro-jejunostomy was performed. After the
substitute was moved to the posterior mediastinum, end-to-end esophagogastronomy was performed with the cervical approach along the left sternocleidomastoid muscle. The anastomosis was supported by a gastric probe that was left in the substitute for 3 – 5 days. The gastrointestinal tract was tested for leakage on day 5 after the surgery. If the test was normal, the probe was removed and oral feeding was started, beginning with fluids and switching to solid foods from day 10 on.

Scintigraphic examination of gastric emptying was performed at the Department of Isotope Diagnostics, Medical University of Silesia in Katowice, during a routine follow-up of patients in the late postoperative period.

After a 12-hour fast, patients ingested solid test meals composed of thermally denatured single egg with 5 grams of butter, half a roll and 100 ml of 2% milk. Amberlite IRA-410 resin labeled with pertechnetate 99mTc (3 mCi) was added to the test meal. After ingestion of the test meal, each patient then sat in front of a collimator of gamma camera DIACAM (Siemens) with ICON software to radiotracer migration through the esophageal substitute using the frame mode method.

One-minute image sequences were recorded for 120 minutes. Additionally, at every 30 minutes, a three minute recording of high dynamic imaging composed of one-second images was performed. The following areas of interest were selected for analysis: the whole stomach, the prepyloric portion and its distal fragment.

Radioactivity curves versus time were subsequently generated over respective areas of interest. Total gastric curve required correction due to radioisotope decay (T1/2 99mTc – six hours), while high dynamic imaging did not require correction. Analysis was performed using NMS and Matlab software.

The following parameters were selected for analysis:
- degree of gastric emptying and radiotracer retention as % of maximal value in 120th minute of examination,
- average amplitude of contraction of the whole prepyloric part and its distal fragment, as % curve deviation from the mean,
- average frequency of contractions of the whole prepyloric part and its distal fragment in respective periods of the high dynamic imaging (1/s),
- average contraction and relaxation duration of the whole prepyloric part and its distal fragment in seconds.

A T-test for independent samples was used in the statistical analysis. p<0.05 was considered statistically significant. Furthermore, the Pearson linear correlation coefficient was estimated for respective parameters in both groups. Correlation was considered good if an absolute correlation coefficient exceeded 0.5, very good if it exceeded 0.7, moderate if it was in the range of 0.3 – 0.5 and poor if it was lower than 0.3.

RESULTS

Table 1 shows test results as % of radiotracer retention in respective time points relative to maximal value. After two hours, the average retention was 44.7±6.5% and 51.1±7.4% in the study and control groups, respectively. This difference was not statistically significant (p>0.2). Two patients demonstrated very rapid evacuative gastric function, manifested as a significant decrease in radioactivity in the projection of the substitute relative to the maximal value (9% and 23%). The lowest retention in the control group was 17% and 27%.

In order to establish a relation between the degree of radiotracer retention and gastric evacuation function in the study and control groups, and to demonstrate differences in the emptying of narrowed and denervated organs versus the normal stomachs, the correlation coefficients between the respective parameters were calculated. There was no correlation between the degree of radiotracer retention and the other parameters analyzed in the control group (linear correlation coefficients were in

<table>
<thead>
<tr>
<th></th>
<th>30 min</th>
<th>60 min</th>
<th>90 min</th>
<th>120 min</th>
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</thead>
<tbody>
<tr>
<td>Study group</td>
<td>74.5±6.4%</td>
<td>63.9±6.6%</td>
<td>52.4±6.5%</td>
<td>44.7±6.5%</td>
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<tr>
<td>Control group</td>
<td>84.1±2.5%</td>
<td>68.0±4.9%</td>
<td>57.7±6.35%</td>
<td>51.1±7.4%</td>
</tr>
<tr>
<td>Significance level</td>
<td>&gt;0.09</td>
<td>&gt;0.3</td>
<td>&gt;0.1</td>
<td>&gt;0.2</td>
</tr>
</tbody>
</table>

Table 1. Average % radiotracer retention
the range of 0 to 0.2; \( p > 0.2 \)). In the study group, an average correlation coefficient between the degree of radiotracer retention and duration of contraction of the distal pyloric part was 0.42 (\( p < 0.03 \)), whereas the correlation coefficient between radiotracer retention and duration of relaxation of the distal pyloric part was 0.45 (\( p < 0.02 \)). There was no correlation between other analyzed parameters and radiotracer retention in the study group (correlation coefficients <0.2; \( p > 0.2 \)).

Table 2 shows the results of contraction amplitude of the whole prepyloric part and its distal fragment, as % of the curve deviation from the mean in respective time points. The analysis revealed that contraction amplitudes of both the whole prepyloric part as well as its distal fragment were higher in the study group compared to those in the control group. Large scattering of obtained results is worth emphasizing, in particular in the distal fragment of the pyloric part for both the study and control groups.

Assessment of the contraction frequencies of the whole prepyloric part and its distal fragment, expressed as number of peristaltic contractions per minute, in the respective high dynamic study periods is presented in Table 3. Frequency of contractions of the whole prepyloric part and its distal fragment was comparable in both analyzed groups.

Average duration of contraction and relaxation of the whole prepyloric part and its distal fragment is presented in tab. 4 and 5. Significant differences were demonstrated between the study group and the control group with regard to linear correlation coefficients for the functioning of the whole prepyloric portion and its distal fragment. The scatter plots below illustrate the relation between the respective parameters (graphs 1-3). Based on estimated Pearson correlation coefficients, differences were established between the narrowed plus denervated stomach and the normal organ with respect to their contraction. Good correlation was demonstrated in the study group with contraction frequency, contraction duration and relaxation duration of the whole prepyloric part and its distal fragment (correlation coefficients 0.71 \( p < 0.001 \); 0.71 \( p = 0 \); 0.63

<table>
<thead>
<tr>
<th>Time point</th>
<th>28-30 min</th>
<th>58-60 min</th>
<th>88-90 min</th>
<th>28-30 min</th>
<th>58-60 min</th>
<th>88-90 min</th>
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<tbody>
<tr>
<td>Study group</td>
<td>14.3±2.8</td>
<td>14.8±3.3</td>
<td>14.3±3.7</td>
<td>51.4±6.9</td>
<td>49.2±9.3</td>
<td>46.0±9.1</td>
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<tr>
<td>Control group</td>
<td>10.8±1.7</td>
<td>12.1±2.8</td>
<td>11.5±2.45</td>
<td>38.8±6.2</td>
<td>33.9±6.3</td>
<td>28.9±4.9</td>
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<tr>
<td>Significance level</td>
<td>&gt;0.1</td>
<td>&gt;0.2</td>
<td>&gt;0.2</td>
<td>&gt;0.09</td>
<td>&gt;0.09</td>
<td>&gt;0.06</td>
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</table>

Table 3. Average frequency of contractions of the whole prepyloric part and its distal fragment in the respective high dynamic study periods (1/s)

<table>
<thead>
<tr>
<th>Time point</th>
<th>28-30 min</th>
<th>58-60 min</th>
<th>88-90 min</th>
<th>28-30 min</th>
<th>58-60 min</th>
<th>88-90 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study group</td>
<td>3.3±0.1</td>
<td>3.1±0.1</td>
<td>3.5±0.3</td>
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<td>3.2±0.1</td>
<td>3.2±0.2</td>
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<tr>
<td>Control group</td>
<td>3.3±0.1</td>
<td>3.4±0.2</td>
<td>3.5±0.1</td>
<td>3.1±0.1</td>
<td>3.4±0.2</td>
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<tr>
<td>Significance level</td>
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<td>&gt;0.03</td>
<td>&gt;0.4</td>
<td>&gt;0.1</td>
<td>&gt;0.1</td>
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</tbody>
</table>

Table 4. Average duration of contraction of the whole prepyloric part and its distal fragment in seconds

<table>
<thead>
<tr>
<th>Time point</th>
<th>28-30 min</th>
<th>58-60 min</th>
<th>88-90 min</th>
<th>28-30 min</th>
<th>58-60 min</th>
<th>88-90 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study group</td>
<td>9.8±0.4</td>
<td>9.9±0.5</td>
<td>9.3±0.7</td>
<td>10.4±0.4</td>
<td>10.1±0.5</td>
<td>9.9±0.7</td>
</tr>
<tr>
<td>Control group</td>
<td>9.3±0.2</td>
<td>9.1±0.3</td>
<td>8.7±0.3</td>
<td>9.8±0.3</td>
<td>9.3±0.4</td>
<td>8.8±0.3</td>
</tr>
<tr>
<td>Significance level</td>
<td>&gt;0.1</td>
<td>&gt;0.07</td>
<td>&gt;0.2</td>
<td>&gt;0.1</td>
<td>&gt;0.08</td>
<td>&gt;0.09</td>
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</table>
Table 5. Average duration of relaxation of the whole prepyloric part and its distal fragment in seconds

<table>
<thead>
<tr>
<th>Time point</th>
<th>Duration of relaxation of the whole prepyloric part (s)</th>
<th>Duration of relaxation of the distal fragment of prepyloric part (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>28-30 min 58-60 min 88-90 min</td>
<td>28-30 min 58-60 min 88-90 min</td>
</tr>
<tr>
<td>Study group</td>
<td>9.7±0.5 9.5±0.3 8.5±0.4</td>
<td>9.8±0.4 9.0±0.2 9.1±0.4</td>
</tr>
<tr>
<td>Control group</td>
<td>9.2±0.2 8.7±0.3 8.9±0.2</td>
<td>9.5±0.3 8.7±0.3 8.8±0.3</td>
</tr>
<tr>
<td>Significance level</td>
<td>&gt;0.1 &gt;0.02 &gt;0.1</td>
<td>&gt;0.2 &gt;0.2 &gt;0.2</td>
</tr>
</tbody>
</table>

p=0, respectively). In the study group, correlation between contraction frequency and contraction duration was poor (coefficients of correlation 0.03 p>0.8 and –0.02 p>0.9) while correlation between relaxation duration of the whole prepyloric part and its distal fragment was moderate (coefficient of correlation 0.34 p>0.06). There were significant differences between the analyzed groups with respect to the above mentioned correlation coefficients (p<0.002; p<0.002; p>0.08).

**DISCUSSION**

The patients’ quality of life following esophagectomy and subsequent replacement by a narrowed stomach is largely dependent on the surgical technique and normal functioning of the substitute (26, 27). It must be emphasized that truncal vagotomy is an integral part of this procedure, which along with the change of gastric capacity and shape, results in disturbed motility of the upper gastrointestinal tract. The major problems related to functional disturbances of the esophageal substitute are establishing a pattern of motility and differentiating between passive and active emptying.

Emptying by the substitute depends on several physiological phenomena. Under normal circumstances, the food is stored in the proximal gastric portion, which functions as a reservoir. This occurs by a reflex relaxation induced by inhibitory vagal nerves and mediated by nitric oxide (NO), as well as vasoactive intestinal peptide (VIP). This allows for storage of large food volumes in the stomach without a significant increase in intragastric pressure (5-10 cm H2O). When the proximal part of the stomach gradually becomes expanded, inhibitory reflexes become weaker and tonic contractions appear due to induction by cholinergic stimulatory vagal nerves. Increased tension in the gastric wall and increased intragastric pressure result in an increased pressure gradient between the stomach and the duodenum, ultima-
tely leading to fluid emptying. The pyloric part is responsible for fragmenting solid foods to pass through the pylorus only when their diameter is approximately 0.1 mm and when they are suspended in the fluid medium. Peristaltic contractions of the distal part are regulated by pacemaker potentials and are only mildly regulated by neurohormones. Cholinergic nerves increase the frequency of action potentials, which results in stronger gastric contractions. The proximal part is believed to be responsible for the passage of fluid foods while the distal part is for solid foods. In conclusion, gastric passage is regulated by gastric-duodenal pressure gradient, pyloric function, gravity, thoracic and abdominal pressure, and compliance of the gastric wall depending on relaxation of its proximal part.

Truncal vagotomy always accompanies esophagectomy. It disturbs the function of both the proximal and distal parts of the stomach, resulting in abnormal relaxation and abolishment of tonic contraction in these segments (17, 28, 29). Disturbed peristalsis is also typical for the distal part. Furthermore, pyloric hyperreactivity is observed after esophagectomy. These factors may be responsible for delayed substitute emptying. This apparently dominant motor pattern was observed by Walsh et al. (20). However, the effects of the vagal nerve are not limited to its direct effect on the stomach because truncal vagotomy also results in the abolishment of duodenal-gastric inhibitory reflex (28), which involves inhibition of gastric emptying by vagal nerves. This reflex involves hormonal and autonomic components. Esophagectomy does not significantly affect the first component, which is supported by data obtained by Logeman et al. who demonstrated that experimental glucagon administration resulted in gastric relaxation while such reaction was absent following food ingestion (30). This may be responsible for facilitated gastric emptying, resulting in normal or faster food passage through the substitute, an observation made by Casson et al. (31). Narrowing of the gastric lumen and transformation into a narrow organ with reduced capacity and loss of relaxation in the proximal part are probably responsible for decreased compliance of the substitute wall with food stimulus (32). Wall compliance, which depends on elasticity and wall tension, is a pressure increase that we could record in an organ following a parti-

ular volume increase (33). Thus slight amount of food in the substitute could result in rapid pressure increase, rapid contraction, higher amplitude and as a consequence, faster emptying. The theory of post-vagotomy hyperreactivity of the pyloric part must also be mentioned here (20).

In our study group, the substitute emptying rate was determined by radiotracer retention and was higher in the respective time points compared to controls, a result consistent with the study by Morton et al. (22). Active food passage through the substitute was also demonstrated in the study group: the contraction frequency of the substitute was approximately 3x/min, which was not different than the motility pattern in the control group. Walsh et al. (20) and Lee et al. (25) also obtained similar results. According to many authors, a substitute created from a narrowed stomach empties passively and demonstrates no active contractions; as a consequence, body position is believed to play a dominant role in this phenomenon (17, 34, 35). Changes in the motility pattern in the substitute, as compared to pre-operative results, were evidence of interference with the physiological motility patterns of this organ and their regulation. However, we should also remember about the discrepancies observed in the healthy population. This made us consider other factors that underlie the contradictory observations by various authors. An example of this hypothesis included differences in the contraction amplitude of the distal pyloric part, an observation we made in both the study group and the control group. Time after surgery was another factor independent of surgical activity that may be responsible for the variability of result. Substitute function is believed to improve over time.

In conclusion, proper surgical technique of creating a substitute from a narrowed stomach allowed maintenance of physiological motor function of the organ that was essentially similar to the motility pattern in healthy subjects. Differences in results obtained by various authors may be caused by factors mentioned in the discussion.

CONCLUSIONS

Creation of a gastric substitute after its narrowing and denervation (truncal vagotomy) did not abolish gastric contractility. Contraction
frequency, amplitude, and contraction and relaxation duration of the prepyloric portion of the translocated substitute were not significantly different than the motility pattern of the upper gastrointestinal tract in healthy volunteers. However, we must emphasize that contraction and relaxation activity of the distal fragment of the prepyloric portion significantly differed from activity in the whole prepyloric portion.

REFERENCES

COMMENTARY

After esophageal resection due to cancer, the continuity of the digestive tract is reconstructed using the stomach or large bowel. Selected surgical centers use the jejunum or transverse colon, as well as 10-15 cm of the ileum subjected to anastomosis. The functioning of the newly developed digestive pathway depends on the intestinal segment or portion of the stomach used. Radiological examinations with contrast medium assess the act of swallowing. The authors of the study used the novel method of dynamic scintigraphy to evaluate the functioning of the esophageal substitute. They described the contracting and decontracting activity of the organ. The authors highlighted the importance of the operative technique in the preparation of the esophageal substitute. The study lacks indications concerning the details of the operative technique, which significantly influences the functioning of the novel digestive pathway.

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