

# Conduit Vascular Evaluation is Associated with Reduction in Anastomotic Leak After Esophagectomy

Chase Campbell · Mark K. Reames · Myra Robinson ·  
James Symanowski · Jonathan C. Salo

Received: 2 December 2014 / Accepted: 2 March 2015 / Published online: 20 March 2015  
© 2015 The Society for Surgery of the Alimentary Tract

## Abstract

**Background** Anastomotic leak following esophagectomy is associated with significant morbidity and mortality. A major factor determining anastomotic success is an adequate blood supply to the conduit. The aim of this study was to determine the impact of intraoperative evaluation of the conduit's vascular supply on anastomotic failure after esophagectomy.

**Methods** We retrospectively analyzed data from 90 consecutive patients undergoing esophagectomy with gastric conduit reconstruction. A change in surgical practice occurred after 60 cases were completed, when we introduced the use of intraoperative indocyanine green fluorescence angiography and Doppler examination to evaluate blood supply and assist in construction of the conduit. The leak rates before and after implementation of conduit vascular evaluation were compared.

**Results** After the introduction of intraoperative vascular evaluation of the gastric conduit, we noted a dramatic decrease in the rate of anastomotic leak from 20 % in the first 60 patients to 0 % in the succeeding 30 patients.

**Conclusions** Intraoperative vascular evaluation with indocyanine green fluorescence imaging and Doppler examination of the gastric conduit used to assist reconstruction after esophagectomy allows for enhanced construction of the conduit that maximizes blood supply to the anastomosis. This change in practice was associated with a significant reduction in anastomotic leak rate.

---

This paper was presented as an abstract at the 2013 Clinical Congress of the American College of Surgeons.

---

**Synopsis:** Intraoperative vascular evaluation of the gastric conduit during esophagectomy was performed using Doppler examination of the blood supply and intraoperative indocyanine green (ICG) fluorescence angiography. This approach was associated with a dramatic decrease in the incidence of anastomotic leak from 20% of cases to zero.

---

C. Campbell  
Department of Surgery, Carolinas Medical Center, Charlotte, NC,  
USA

M. K. Reames  
Sanger Heart and Vascular Institute, Charlotte, NC, USA

M. Robinson · J. Symanowski  
Department of Cancer Biostatistics, Carolinas Medical Center,  
Levine Cancer Institute, 1021 Morehead Medical Drive #6100,  
Charlotte, NC 28204, USA

J. C. Salo (✉)  
Division of Surgical Oncology, Department of Surgery, Carolinas  
Medical Center, Levine Cancer Institute, 1021 Morehead Medical  
Drive #6100, Charlotte, NC 28204, USA  
e-mail: jonathan.salo@carolinashealthcare.org

**Keywords** Esophagectomy · Blood supply · Indocyanine green · Fluorescence angiography · Anastomosis

## Introduction

Surgical resection remains a critical component of potentially curative treatment of cancer of the esophagus, despite advances in radiotherapy and chemotherapy. Successful healing of the esophageal anastomosis is an important factor in post-operative outcomes after esophagectomy, as anastomotic leak is associated with significant morbidity and mortality, and the subsequent healing of a leak can lead to an anastomotic stricture, which negatively impacts quality of life. A major factor in anastomotic healing is adequate blood supply to the esophagus and the esophageal replacement. Transposition of the stomach from abdomen to chest during esophagectomy requires division of the left gastric, left gastroepiploic, and short gastric vessels, which compromises blood supply to the anastomotic site.

Evaluation of the blood supply to the gastric conduit has traditionally been made on clinical grounds by inspection of

the gastric serosa. In an effort to reduce the risk of anastomotic leak, we employed the use of indocyanine green (ICG) fluorescence angiography and Doppler examination of the gastric conduit's vascular pattern to evaluate blood supply and assist in construction of the conduit. The aim of this study was to determine the impact of intraoperative evaluation of the conduit vascular pattern on anastomotic failure after esophagectomy. We hypothesized that addition of intraoperative evaluation of the conduit vascular pattern would lead to a lower rate of anastomotic failure.

## Methods

We have developed a single surgical team to focus on minimally invasive esophagectomy at Carolinas Medical Center consisting of a thoracic surgeon and gastrointestinal surgical oncologist. Approval for a retrospective study was obtained from the Institutional Review Board at Carolinas Medical Center (Charlotte, NC). From September 2007 to February 2013, 90 unselected patients underwent esophageal resection, reconstruction with a gastric conduit, and intrathoracic anastomosis. A majority of patients underwent some combination of a laparoscopic and thoracoscopic approach as described.<sup>1</sup> The abdominal phase of the procedure was performed laparoscopically with an epigastric hand port and three 5-mm ports. Dissection began by entering the lesser sac via the gastrocolic omentum, taking care to preserve the right gastroepiploic artery. The left gastric artery was dissected of nodal tissue and divided with a vascular stapler. The right gastric artery was preserved. The lower mediastinum was dissected with bipolar cautery to clear nodal tissue from the pleurae, aorta, and pericardium for removal with the specimen.

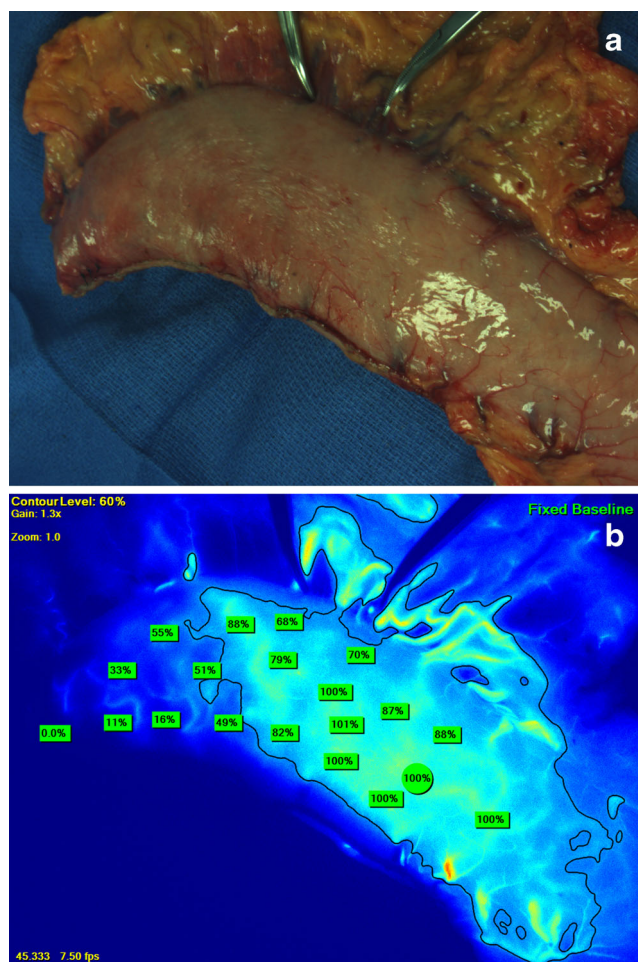
The gastric conduit was fashioned using an endoscopic GIA stapler to divide the lesser curvature of the stomach between the right and left gastric arteries. Gastric drainage was facilitated with pyloroplasty, pyloromyotomy, or botulinum toxin injection.

The thoracic phase was then initiated, with the patient positioned in the left lateral decubitus position. The pleura was incised and dissected to the level of the azygous vein, which was divided. After division of the esophagus, the gastric conduit was transposed into the right chest and an anastomosis created with a circular stapler using a flip-top stapler anvil affixed to a nasogastric tube (OrVil, Covidien, North Haven CT, USA). The anvil was then brought through a fenestration in the esophageal staple line. The superior end of the lesser-curve gastric staple line was then opened, and a 25- or 21-mm DST XL EEA stapler (Covidien, North Haven, CT, USA) was selected and inserted through the lesser curvature with its spike brought out through the greater curvature of the gastric conduit. The circular stapler components were mated and fired. After firing of the stapler, the opening in the lesser curvature was closed with a GIA stapler.

In January of 2012, after 60 patients had undergone resection, review of our data showed an anastomotic leak rate of 20 % and a change in surgical practice made in an attempt to reduce the rate of anastomotic leak. Beginning in January of 2012 with patient #61, intraoperative examination of the vascular supply of the conduit was performed using intraoperative Doppler and ICG fluorescence imaging. The gastroepiploic arcade was evaluated with Doppler and a marking suture placed in the most proximal area in which there was a strong biphasic arterial signal. This was designated as the preferred area for the anastomosis and was generally placed at the most cephalad arcade of the right gastroepiploic artery. A second suture was placed in the most cephalad area where there was any detectable pulse by Doppler examination, generally in the first or second of the left gastroepiploic arcades. ICG fluorescence angiography was performed using the SPY Elite System (LifeCell, Bridgewater, NJ, USA) using 5 mg of ICG injected intravenously. Images were taken at 60 s after injection. Relative fluorescence of the conduit was evaluated using a reference point midway between the greater and lesser curvature in the proximal (inferior) area of the conduit approximately 10 cm above the pylorus. An arbitrary cutoff of 75 % was selected and a running silk suture placed in the serosa at the border of the 75 % perfusion line. Representative images taken with conventional imaging (Fig. 1a) and with ICG fluorescence imaging (Fig. 1b) are shown.

After evaluation and marking, the conduit was then passed into the right chest. An attempt was made to position the anastomosis between the two marking sutures on the greater curvature and inferior to the silk suture marking the 75 % relative perfusion line. It was possible to position the anastomosis inferior to the 75 % relative perfusion line in all cases. The anastomosis was constructed in conventional fashion.

All patients underwent CT esophagram prior to oral intake. Anastomotic leak was defined as extravasation of contrast on postoperative CT esophagram or presence of empyema on chest CT or elevated drain amylase level with clinical evidence of leak. Trends in the rate of anastomotic leak over time were displayed using a CUMulative SUM (CUSUM) chart. CUSUM charts are used to plot normalized cumulative failure rates (cumulative scores) over time where the score at the first time point is zero. Each success results in an upward deflection of the plot and each failure results in a downward deflection of the plot.<sup>2</sup> CUSUM charts were constructed with SAS version 9.4 (SAS Systems, Cary, NC). Comparisons between groups were performed using R Statistics version 3.02 (R Foundation for Statistical Computing, Vienna, Austria). Categorical variables were compared using Fisher's exact test. Continuous variables



**Fig. 1** Intraoperative photographs of a gastric conduit prior to transposition into the right chest. Normal photograph (a) and color-coded perfusion map of relative indocyanine-green fluorescence (b). The lesser curvature staple line is to the *bottom of the image*, and the cephalad (distal) portion of the conduit is to the *left of the image*

were compared between groups with Wilcoxon rank sum test. Differences were considered significant at the  $\alpha=0.05$  significance level.

## Results

For all 90 patients, data were collected and compiled, as summarized in Table 1. Sixty patients underwent operation prior to the change in practice in January 2012 (group 1), and 30 patients underwent operation subsequently (group 2). The mean age was 62 years old (range 22 to 81), 82 % were males, 80 patients were White, and 10 were African-American. Indications for surgery included adenocarcinoma (75 patients), squamous cell carcinoma (8 patients), neuroendocrine tumors (2 patients), and benign disease (5 patients, which included 3 esophageal strictures and 2 leiomyomata of the esophagus). Neoadjuvant chemotherapy along with radiation therapy was administered in 54 patients, and 6 patients received

neoadjuvant chemotherapy alone. Adjuvant therapy was administered postoperatively in 18, 1 of whom received radiation only, 12 received chemotherapy, and 5 received radiation and chemotherapy. In the 85 patients undergoing surgery for malignancy, 81 R0 resections (95 %) and 4 R1 resections were obtained. Median lymph node harvest was 12 nodes.

In our series, for the abdominal portion, one case was converted from laparoscopy to laparotomy due to dense intestinal adhesions, and the remainder of cases were completed with laparoscopy. Similarly for the thoracic portion, 82 cases were performed thoracoscopically, 4 were converted from thoracoscopy to thoracotomy, and 4 were treated with initial thoracotomy (Table 2).

Patient, operative, and tumor characteristics between the two groups (before and after change in practice) were similar with the exception that more patients in Group 2 were treated with preoperative chemotherapy and radiation therapy compared with Group 1 (90 vs 50 %). This difference in treatment was due to a higher proportion of patients in Group 1 with early stage disease (cT1N0 and cT2N0). In addition, the treatment of the pylorus differed between the two groups, with more patients in Group 1 treated with pyloromyotomy (22 vs 0 %) and more patients in Group 2 treated with botulinum toxin (53 vs 13 %).

Median hospital stay was 11 days (range 8 to 86 days) and did not differ between the two groups. Thirty-day mortality was zero, and 90-day mortality was 2.2 %, which did not differ between the two groups (see Table 3).

In the first 60 patients (Group 1), the rate of anastomotic leak was 20 %, prompting a change in surgical technique. Patient #61 in the series was evaluated with Doppler examination and ICG fluorescence angiography; the subsequent 9 patients were evaluated with Doppler examination alone, and the final 20 patients in this series were evaluated with both modalities.

The overall leak rate in the series was 13.3 % (12 of the 90 patients). After the practice change, there were no leaks in the succeeding 30 cases. This difference is significant by Fisher's exact test ( $p=0.007$ ). The CUSUM chart is shown in Fig. 2. This chart shows a clear turning point in the CUSUM score at patient #61, coincident with the change in surgical practice. Prior to patient #61, there is a clear upward trend in CUSUM scores, due to an increase in the rate of anastomotic leak. After patient #61, there is a decline in CUSUM scores, due to improving performance (and no anastomotic leaks).

## Discussion

Healing of the esophagogastric anastomosis is essential for optimizing outcomes after esophagectomy. Anastomotic leak following esophagectomy is one of the most serious complications and occurs in up to 30 % of cases in some published

**Table 1** Patient characteristics ( $n=90$ )

|                             |                | Group 1<br><i>n</i> (%) | Group 2<br><i>n</i> (%) | Total<br><i>n</i> (%) | <i>p</i> value      |
|-----------------------------|----------------|-------------------------|-------------------------|-----------------------|---------------------|
| Age                         | Median         | 62                      | 64                      | 62                    | 0.161 <sup>a</sup>  |
|                             | Range          | 22–76                   | 44–81                   | 22–81                 |                     |
| Gender                      | Male           | 47 (78 %)               | 27 (90 %)               | 74 (82 %)             | 0.245 <sup>b</sup>  |
|                             | Female         | 13 (22 %)               | 3 (10 %)                | 16 (18 %)             |                     |
| Race                        | White          | 53 (88 %)               | 27 (90 %)               | 80 (89 %)             | >0.999 <sup>b</sup> |
|                             | Black          | 7 (12 %)                | 3 (10 %)                | 10 (11 %)             |                     |
| Histology                   | Adenocarcinoma | 48 (80 %)               | 27 (90 %)               | 75 (83 %)             | 0.510 <sup>b</sup>  |
|                             | Squamous Cell  | 7 (12 %)                | 1 (3.3 %)               | 8 (8.8 %)             |                     |
|                             | Neuroendocrine | 1 (1.7 %)               | 1 (3.3 %)               | 2 (2.2 %)             |                     |
|                             | Benign         | 4 (6.7 %)               | 1 (3.3 %)               | 5 (5.5 %)             |                     |
| Clinical T classification   | Tis            | 2 (3.5 %)               | 0 (0 %)                 | 2 (0.2 %)             | 0.150 <sup>b</sup>  |
|                             | T1a            | 7 (13 %)                | 0 (0 %)                 | 7 (8.2 %)             |                     |
|                             | T1b            | 7 (13 %)                | 2 (6.9 %)               | 9 (11 %)              |                     |
|                             | T2             | 7 (13 %)                | 3 (10 %)                | 10 (12 %)             |                     |
|                             | T3             | 33 (59 %)               | 24 (83 %)               | 57 (67 %)             |                     |
| Clinical N classification   | N0             | 34 (61 %)               | 14 (48 %)               | 48 (56 %)             | 0.427 <sup>b</sup>  |
|                             | N1             | 21 (38 %)               | 14 (48 %)               | 35 (41 %)             |                     |
|                             | N2             | 1 (1.8 %)               | 1 (3.5 %)               | 2 (2.4 %)             |                     |
| Clinical M classification   | M0             | 55 (98 %)               | 29 (100 %)              | 84 (99 %)             | >0.999 <sup>b</sup> |
|                             | M1             | 1 (1.8 %)               | 0 (0 %)                 | 1 (1.1 %)             |                     |
| Pathologic T classification | T0             | 11 (20 %)               | 5 (18 %)                | 16 (19 %)             | 0.462 <sup>b</sup>  |
|                             | Tis            | 1 (1.8 %)               | 0 (0 %)                 | 1 (1.1 %)             |                     |
|                             | T1a            | 9 (16 %)                | 4 (14 %)                | 13 (15 %)             |                     |
|                             | T1b            | 8 (14 %)                | 3 (10 %)                | 11 (13 %)             |                     |
|                             | T2             | 14 (25 %)               | 4 (14 %)                | 18 (21 %)             |                     |
|                             | T3             | 13 (23 %)               | 13 (45 %)               | 26 (31 %)             |                     |
|                             | N0             | 36 (65 %)               | 12 (42 %)               | 48 (57 %)             |                     |
| Pathologic N classification | N1             | 12 (21 %)               | 10 (34 %)               | 22 (26 %)             | 0.179 <sup>b</sup>  |
|                             | N2             | 7 (13 %)                | 6 (21 %)                | 13 (15 %)             |                     |
|                             | N3             | 1 (1.8 %)               | 1 (3.4 %)               | 2 (2.3 %)             |                     |
|                             | M0             | 55 (98 %)               | 28 (97 %)               | 83 (98 %)             |                     |
| Pathologic M classification | M1             | 1 (1.8 %)               | 1 (3.4 %)               | 2 (2.3 %)             | >0.999 <sup>b</sup> |
|                             | M1             | 1 (1.8 %)               | 1 (3.4 %)               | 2 (2.3 %)             |                     |
| Neoadjuvant therapy         | None           | 22 (40 %)               | 3 (10 %)                | 25 (30 %)             | 0.001 <sup>b</sup>  |
|                             | Chemotherapy   | 6 (11 %)                | 0 (0 %)                 | 6 (7.1 %)             |                     |
|                             | Chemo/XRT      | 28 (50 %)               | 26 (90 %)               | 54 (64 %)             |                     |
| Adjuvant therapy            | None           | 43 (77 %)               | 24 (83 %)               | 67 (79 %)             | 0.334 <sup>b</sup>  |
|                             | Radiation      | 1 (1.8 %)               | 0 (0 %)                 | 1 (1.1 %)             |                     |
|                             | Chemotherapy   | 10 (18 %)               | 2 (6.9 %)               | 12 (14 %)             |                     |
|                             | Chemo/XRT      | 2 (3.6 %)               | 3 (10 %)                | 5 (5.8 %)             |                     |
|                             | R0 resection   | 55 (98 %)               | 26 (90 %)               | 81 (95 %)             |                     |
| Lymph node harvest          | (median)       | 11.5                    | 12.0                    | 12.0                  | 0.375 <sup>a</sup>  |
| Follow-up (months)          | (median)       | 25.6                    | 12.3                    | 21.2                  |                     |

Total group is divided into the initial 60 resections (group 1) and the subsequent 30 patients after change in practice (group 2)

<sup>a</sup> Wilcoxon Rank sum test with continuity correction

<sup>b</sup> Fisher's exact test

**Table 2** Operative management

|                                       | Group 1 (n=60)<br>n (%) | Group 2 (n=30)<br>n (%) | Total (n=90)<br>n (%) | p value            |
|---------------------------------------|-------------------------|-------------------------|-----------------------|--------------------|
| Thoracic approach                     |                         |                         |                       | 0.999 <sup>b</sup> |
| Thoracoscopy                          | 54 (90 %)               | 28 (94 %)               | 82 (91 %)             |                    |
| Thoracoscopy converted to thoracotomy | 3 (5.0 %)               | 1 (3.3 %)               | 4 (4.4 %)             |                    |
| Thoracotomy                           | 3 (5.0 %)               | 1 (3.3 %)               | 4 (4.4 %)             |                    |
| Abdominal approach                    |                         |                         |                       | 0.699 <sup>b</sup> |
| Laparoscopy                           | 57 (95 %)               | 30 (100 %)              | 87 (97 %)             |                    |
| Laparoscopy converted to laparotomy   | 2 (3.3 %)               | 0 (0 %)                 | 2 (2.2 %)             |                    |
| Laparotomy                            | 1 (1.7 %)               | 0 (0 %)                 | 1 (1.1 %)             |                    |
| Gastric drainage                      |                         |                         |                       | 0.001 <sup>b</sup> |
| None                                  | 4 (6.7 %)               | 0 (0 %)                 | 4 (4.4 %)             |                    |
| Botulinim toxin                       | 8 (13 %)                | 16 (53 %)               | 24 (27 %)             |                    |
| Pyloromyotomy                         | 13 (22 %)               | 0 (0 %)                 | 13 (14 %)             |                    |
| Pyloroplasty                          | 34 (57 %)               | 14 (47 %)               | 61 (53 %)             |                    |
| Pneumatic dilation                    | 1 (1.7 %)               | 0 (0 %)                 | 1 (1.1 %)             |                    |
| OR time in minutes                    |                         |                         |                       | 0.006 <sup>a</sup> |
| Median                                | 548                     | 501                     | 534                   |                    |
| Hospital length of stay               |                         |                         |                       | 0.928 <sup>a</sup> |
| Median                                | 11 days                 | 12 days                 | 12 days               |                    |
| Range                                 | 6–86 days               | 8–57 days               | 6–86 days             |                    |

<sup>a</sup> Wilcoxon rank sum test with continuity correction

<sup>b</sup> Fisher's exact test

series.<sup>3</sup> Such leaks are associated with significant morbidity and mortality.<sup>4</sup> Perioperative anastomotic leaks have been shown to adversely affect long-term survival after gastroesophageal surgery, including cancer-specific survival.<sup>5</sup>

Anastomotic failure is thought to be related to inadequate blood supply to the anastomosis.<sup>6</sup> The blood supply of the gastric tube appears to depend entirely on the right gastroepiploic artery with no appreciable contribution from the right gastric artery or from branches of the left gastroepiploic arteries.<sup>7</sup> The fact that a constructed gastric tube is supplied by this single artery makes it of paramount importance that the distal tube is well perfused. The dissection of the gastrocolic ligament and the transformation of the stomach into a gastric tube for esophageal replacement have been shown to reduce perfusion at the distal portion of the stomach.<sup>8,9</sup> Decreased conduit perfusion, as measured by laser Doppler spectroscopy or intramucosal gastric pH, has been shown to predict increased risk of anastomotic complications.<sup>6,10,11</sup>

Beyond measuring perfusion, augmentation of blood flow to the distal aspect of the conduit may represent a strategy for improving anastomotic healing. One such method is ischemic preconditioning by partial devascularization of the stomach through ligation of the left gastric artery or short gastric vessels prior to surgery in an effort to facilitate the formation of collateral vessels that would improve distal flow. Despite the

attractiveness of this strategy, several studies, including a randomized trial, have failed to demonstrate an impact of ischemic preconditioning on the rate of anastomotic leak.<sup>12–15</sup>

Without successful strategies for increasing the blood supply to the gastric conduit, analysis of the gastric conduit perfusion may be helpful in construction of the conduit and choice of anastomotic site. Traditionally, perfusion to the gastric conduit and anastomosis has been evaluated based on clinical inspection. Many methods have been employed to evaluate perfusion of the conduit. Focal measurements of tissue perfusion such as laser flowmetry and spectrophotometry<sup>6,8–11</sup> or intramucosal pH or mucosal CO<sub>2</sub><sup>10</sup> have been shown to predict anastomotic failure but do not provide a geographic image of perfusion within the conduit.

Fluorescent imaging using indocyanine green is readily available in the operative room, gives real-time feedback, and can display a geographic view of tissue perfusion. ICG fluorescence angiography has been employed during breast reconstruction to predict skin flap necrosis.<sup>16,17</sup> Preliminary published reports suggest the value of this technology in esophageal cancer surgery.<sup>18</sup> A surgical series of 11 patients who underwent esophagectomy using ICG fluorescent imaging suggests that the perfusion pattern did predict a leak in one patient in this series. Ten patients were judged to have good perfusion of their gastric conduit, and one, in retrospect, was

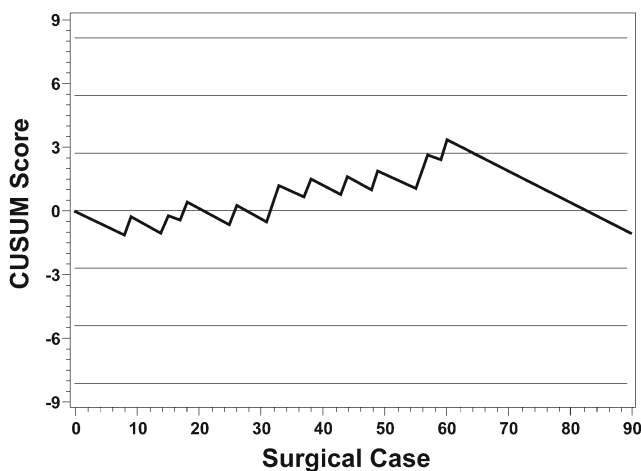
**Table 3** Perioperative complications

| Complications              | Group 1<br>(n=60)<br>n (%) | Group 2<br>(n=30)<br>n (%) | Total<br>(n=90)<br>n (%) | p value             |
|----------------------------|----------------------------|----------------------------|--------------------------|---------------------|
| <b>Respiratory</b>         |                            |                            |                          |                     |
| Pneumonia                  | 14 (23 %)                  | 10 (33 %)                  | 24 (27 %)                | 0.324 <sup>a</sup>  |
| Prolonged ventilation      | 9 (15 %)                   | 11 (37 %)                  | 20 (22 %)                | 0.030 <sup>a</sup>  |
| Tracheostomy               | 6 (10 %)                   | 6 (20 %)                   | 12 (13 %)                | 0.204 <sup>a</sup>  |
| ARDS                       | 8 (13 %)                   | 4 (13 %)                   | 12 (13 %)                | >0.999 <sup>a</sup> |
| <b>Cardiovascular</b>      |                            |                            |                          |                     |
| Atrial arrhythmia          | 11 (18 %)                  | 9 (30 %)                   | 20 (22 %)                | 0.282 <sup>a</sup>  |
| Myocardial infarction      | 0 (0 %)                    | 1 (3.3 %)                  | 1 (1.1 %)                | 0.333 <sup>a</sup>  |
| <b>Anastomotic failure</b> |                            |                            |                          |                     |
| Anastomotic leak           | 12 (20 %)                  | 0 (0 %)                    | 12 (13 %)                | 0.007 <sup>a</sup>  |
| Anastomotic stent          | 7 (12 %)                   | 0 (0 %)                    | 7 (7.7 %)                | 0.090 <sup>a</sup>  |
| Graft necrosis             | 0 (0 %)                    | 0 (0 %)                    | 0 (0 %)                  | –                   |
| Chylothorax                | 1 (1.8 %)                  | 0 (0 %)                    | 1 (1.1 %)                | >0.999 <sup>a</sup> |
| Pulmonary embolism         | 0 (0 %)                    | 2 (6.7 %)                  | (2.2 %)                  | 0.109 <sup>a</sup>  |
| <b>Reoperation</b>         |                            |                            |                          |                     |
| Esophagobronchial fistula  | 1 (1.7 %)                  | 0 (0 %)                    | 1 (1.1 %)                | >0.999 <sup>a</sup> |
| 30-day mortality           | 0 (0 %)                    | 0 (0 %)                    | 0 (0 %)                  | –                   |
| 60-day mortality           | 0 (0 %)                    | 1 (3.3 %)                  | 1 (1.1 %)                | 0.333 <sup>a</sup>  |
| 90-day mortality           | 0 (0 %)                    | 2 (6.7 %)                  | 2 (2.2 %)                | 0.109 <sup>a</sup>  |

<sup>a</sup> Fisher’s exact Test

judged to have poor perfusion of the conduit. One of two leaks in the series occurred in the patients whose conduit had poor perfusion at the cephalad end.<sup>19</sup>

We report our experience with the use of evaluation of the vascular supply of the gastric conduit using a combination of ICG fluorescence imaging and Doppler. We have analyzed outcomes with the cumulative sum (CUSUM) chart, which



**Fig. 2** CUSUM graph of anastomotic leak rate over time. A change in surgical practice occurred with case #61. Until case #61, the cumulative sum (CUSUM) of failure was increasing and began to decline at case #61, coincident with a change in practice

allows sequential evaluation of processes with binary outcomes. This test is ideally suited to detect small changes in outcomes over time, such as the effects of cumulated experience (“learning curve”) or the impact of a change in process. Originally used for industrial processes, the CUSUM test has recently been applied to surgical outcomes.<sup>20–22</sup> In our series, the CUSUM statistic demonstrated that immediately prior to the change in practice with patients #57 and #60, the rate of anastomotic failure had increased to 20 %. With the change in practice that begun with patient #61, the anastomotic leak rate declined for the remainder of the study period.

A limitation of our study is its retrospective nature. The reduction in anastomotic leak rate may have been influenced by other factors related to the experience of the surgical team, known as the learning curve. To look for this effect, we compared the first 30 patients with the second 30 patients within Group 1. The rate of anastomotic leak was slightly higher in the second 30 patients (chi-square  $p=0.333$ , data not shown), perhaps due to the tendency to operate on higher-risk patients as our team gained experience. We did not see a difference in operative time between the first 30 patients and second 30 patients within Group 1 (Wilcoxon  $p=0.6735$ , data not shown).

In comparing Group 1 with Group 2, we noted that operative time was significantly reduced in Group 2, despite the introduction of additional evaluation of the gastric conduit. This reduction in operative time in Group 2 may be reflective of the experience of the operative team, but our subjective experience is that over time, vascular evaluation of the conduit decreased operative time by imparting confidence in the adequacy of the conduit. In any case, the introduction of intraoperative vascular examination of the conduit was associated with a dramatic decrease in anastomotic failure.

**Conclusion**

Despite advances in nonoperative management of esophageal cancer, esophagectomy remains the mainstay of potentially curative treatment for adenocarcinoma of the esophagus. Anastomotic leak remains a significant source of morbidity and reduces cancer-specific survival. We report our early results after employing the use of ICG fluorescence imaging and Doppler evaluation of the gastric conduit used to evaluate blood supply during esophagectomy reconstruction. This evaluation has helped determine the optimal site for anastomosis based on perfusion to the distal conduit. Despite the limited numbers, we have experienced a statistically significant and clinically relevant decrease in leak rate after this change in practice. Evaluation of conduit perfusion allows for enhanced discretion in choosing the optimal site of anastomosis based on vascular pattern. Further investigation via a large-scale multicenter randomized controlled trial is needed

to establish the utility of this novel technology for widespread use and for standardization of techniques during esophagectomy or other gastrointestinal anastomosis.

**Acknowledgments** The expert assistance in preparation of the manuscript by Susie Hurley DNP is gratefully acknowledged.

**Conflict of Interest** No author has a relevant financial disclosure

## References

- Hanna EM, Norton HJ, Reames MK, Salo JC. Minimally invasive esophagectomy in the community hospital setting. *Surg Oncol Clin N Am*. 2011;20(3):521–530.
- Yap CH, Colson ME, Watters DA. Cumulative sum techniques for surgeons: a brief review. *ANZ J Surg*. 2007;77(7):583–586.
- Urschel JD. Esophagogastrostomy anastomotic leaks complicating esophagectomy: a review. *Am J Surg*. 1995;169(6):634–640.
- Alanezi K, Urschel JD. Mortality secondary to esophageal anastomotic leak. *Ann Thorac Cardiovasc Surg*. 2004;10(2):71–75.
- Lagarde SM, de Boer JD, ten Kate FJ, Busch OR, Obertop H, van Lanschot JJ. Postoperative complications after esophagectomy for adenocarcinoma of the esophagus are related to timing of death due to recurrence. *Ann Surg*. 2008;247(1):71–76.
- Pham TH, Pery KA, Enestvedt CK, et al. Decreased conduit perfusion measured by spectroscopy is associated with anastomotic complications. *Ann Thorac Surg*. 2011;91(2):380–385.
- Liebermann-Meffert DM, Meier R, Siewert JR. Vascular anatomy of the gastric tube used for esophageal reconstruction. *Ann Thorac Surg*. 1992;54(6):1110–1115.
- Schroder W, Stippel D, Beckurts KT, Lacher M, Gutschow C, Holscher AH. Intraoperative changes of mucosal pCO<sub>2</sub> during gastric tube formation. *Langenbecks Arch Surg*. 2001;386(5):324–327.
- Schilling MK, Redaelli C, Maurer C, Friess H, Buchler MW. Gastric microcirculatory changes during gastric tube formation: assessment with laser Doppler flowmetry. *J Surg Res*. 1996;62(1):125–129.
- Tarui T, Murata A, Watanabe Y, et al. Earlier prediction of anastomotic insufficiency after thoracic esophagectomy by intramucosal pH. *Crit Care Med*. 1999;27(9):1824–1831.
- Pierie JP, De Graaf PW, Poen H, Van der Tweel I, Obertop H. Impaired healing of cervical oesophagogastrostomies can be predicted by estimation of gastric serosal blood perfusion by laser Doppler flowmetry. *Eur J Surg*. 1994;160(11):599–603.
- Bludau M, Holscher AH, Vallbohmer D, Gutschow C, Schroder W. Ischemic conditioning of the gastric conduit prior to esophagectomy improves mucosal oxygen saturation. *Ann Thorac Surg*. 2010;90(4):1121–1126.
- Wajed SA, Veeramootoo D, Shore AC. Video. Surgical optimisation of the gastric conduit for minimally invasive oesophagectomy. *Surg Endosc*. 2012;26(1):271–276.
- Veeramootoo D, Shore AC, Wajed SA. Randomized controlled trial of laparoscopic gastric ischemic conditioning prior to minimally invasive esophagectomy, the LOGIC trial. *Surg Endosc*. 2012;26(7):1822–1829.
- Nguyen NT, Nguyen XM, Reavis KM, Elliott C, Masoomi H, Stamos MJ. Minimally invasive esophagectomy with and without gastric ischemic conditioning. *Surg Endosc*. 2012;26(6):1637–1641.
- Phillips BT, Lanier ST, Conkling N, et al. Intraoperative perfusion techniques can accurately predict mastectomy skin flap necrosis in breast reconstruction: results of a prospective trial. *Plast Reconstr Surg*. 2012;129(5):778e–788e.
- Komorowska-Timek E, Gurtner GC. Intraoperative perfusion mapping with laser-assisted indocyanine green imaging can predict and prevent complications in immediate breast reconstruction. *Plast Reconstr Surg*. 2010;125(4):1065–1073.
- Kubota K, Yoshida M, Kuroda J, Okada A, Ohta K, Kitajima M. Application of the HyperEye Medical System for esophageal cancer surgery: a preliminary report. *Surg Today*. 2013;43(2):215–220.
- Pacheco PE, Hill SM, Henriques SM, Paulsen JK, Anderson RC. The novel use of intraoperative laser-induced fluorescence of indocyanine green tissue angiography for evaluation of the gastric conduit in esophageal reconstructive surgery. *Am J Surg*. 2013;205(3):349–352.
- Bowles TA, Watters DA. Time to CUSUM: simplified reporting of outcomes in colorectal surgery. *ANZ J Surg*. 2007;77(7):587–591.
- Rogers CA, Reeves BC, Caputo M, Ganesh JS, Bonser RS, Angelini GD. Control chart methods for monitoring cardiac surgical performance and their interpretation. *J Thorac Cardiovasc Surg*. 2004;128(6):811–819.
- Platell C, Barwood N, Dorfmann G, Makin G. The incidence of anastomotic leaks in patients undergoing colorectal surgery. *Colorectal Dis*. 2007;9(1):71–79.