Review

# Esophageal Reconstruction Using a Pedicled Jejunum with Microvascular Augmentation

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The pedicled colon segment is widely accepted as a substitute to the gastric tube in esophageal reconstruction of cases where the stomach is not available. The usefulness of reconstruction with a pedicled jejunum has also been reported in recent years. In order to make a long jejunal graft, at least the second and third jejunal vessels have to be severed. However, this leads to a decrease of circulation in the pedicled jejunum. This poor circulation was primarily responsible for the high rates of gangrene and mortality (22.2% and 46.5%, respectively) in the beginnings of jejunal reconstruction. Advances in microsurgery have now enabled surgeons to overcome these disadvantages, as a result, both the rates of gangrene and mortality have decreased to almost zero since the addition of microvascular anastomosis with the jejunal vessels and the internal thoracic vessels. At present, the reconstruction using a pedicled jejunum is a safe operation that provides such advantages as a low incidence of intrinsic disease, more active transport of food, and a lower rate of regurgitation by peristalsis, compared with the reconstruction using the pedicled colon. The disadvantage of the procedure is the relatively high rate of anastomotic leakage (11.1% to 19.2%). Improvements in the surgical procedures to overcome this disadvantage are, therefore, needed before it can be recommended without any reservations.

Key words: esophageal reconstruction, jejunum, microvascular anastomosis, complication

#### Introduction

The first choice for esophageal reconstruction after esophagectomy is a gastric pull-up procedure. However, the stomach cannot be always used as a graft. In patients with a history of partial or total gastrectomy, or who require a gastrectomy due to synchronous double cancer of the stomach or tumor invasion or metastasis into the gastric wall, reconstruction using an organ other than the

Department of Surgery, School of Medicine, Kinki University, Osaka-Sayama, Osaka, Japan stomach is necessary. The reconstruction after esophagectomy, which is totally different from that after abdominal surgery (whose digestive continuity is reconstructed in an orthotopic manner with direct anastomosis or interposition by mobilization of the digestive tract), requires moving tissue from other digestive tract locations to the neck to replace the esophagus. In order to make a long graft, it is necessary to sever the mesenteric vessels; however, this leads to reduced blood flow in the graft. The critical points for esophageal reconstruction are the creation of a graft with an adequate length and sufficient blood supply. With regard to these points, reconstruction using the colon is favorable as a substitute for the gastric tube. However, the use of the colon poses numerous disadvantages, such as high rates of gangrene and mortality, and an increased incidence of postoperative pulmonary complications and intrinsic diseases.<sup>1)</sup> Therefore, esophageal reconstruction using the jejunum

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has been reevaluated, because it is relatively free of intrinsic disease<sup>2, 3)</sup> and has the advantage of providing active transport of food by peristalsis.<sup>2–7)</sup> We herein review the progress, outcomes and the functional evaluation of the surgical procedure of jejunal reconstruction, and examined the utility and safety of the method as an alternative to the gastric tube by comparing with the use of jejunal and colonic grafts.

# **Progress of Pedicled Jejunal Reconstruction**

The first successful use of the jejunum for esophageal reconstruction in a human patient was reported by Roux in 1907.8) In 1944, Yudin reported the surgical outcome of 74 patients who were reconstructed with Roux's pedicled jejunal method in a review of 80 cases of esophageal reconstructions.<sup>9)</sup> He stated that only 16 patients could be directly anastomosed with the jejunal flap and the cervical esophagus, while the remaining 58 patients required the addition of a cutaneous tube between the esophageal and intestinal stomas to complete the digestive continuity. He advocated the difficulty performing total esophageal replacement with jejunum due to the variability in small bowel vascular anatomy. This was also the theme of the review of Ochsner and Owens in 1934,10) who demonstrated that the rate of flap loss and mortality in Roux's pedicled jejunal technique were 22.2% and 46.6%, respectively, and pointed out that this procedure had a considerably high risk. Inadequate blood supply of the jejunal flap was considered to be the principal reason. Longmire modified Roux's jejunal technique in 1946,<sup>11)</sup> and incorporated microvascular anastomosis between the mesenteric vessels of the jejunal flap and the internal thoracic vessels, thereby successfully augmenting the circulation of the flap. Additionally, in 1956, Androsov reported the benefit of this vascular augmentation by the addition of microvascular anastomosis in esophageal reconstruction with the jejunum.<sup>12)</sup> However, the technical complexity of the microsurgery precluded its widespread acceptance, despite the fact that Androsov introduced the technique of mechanical vessel suturing. At last, with the recent technical advances in microsurgery, the use of a pedicled jejunal flap for esophageal reconstruction has become more widely accepted.

# Surgical Anatomy of the Arterial Supply to the Jejunum

The variation of blood supply to the small intestine

was reported in detail by anatomic studies based on 400 dissections by Michels et al.<sup>13</sup> According to their report, the first 60 cm of the jejunum used as a graft has 3 jejunal arteries on average (range; 1 to 5 jejunal arteries), showing 3 to 5 in 84% of cases, 1 to 2 in 16%, and only 1 in 8% of cases. These mesenteric vessels connect with each other, forming a vascular loop through the collateral vessels.

# **Current Procedures Used for Surgery**

# Our methods of creating a pedicled jejunum

The jejunal mesenteric vessels are first inspected and evaluated by transillumination of the mesentery. To preserve the first jejunal vessel, we create the jejunal flap, by severing the second and third jejunal vessels, and then use the fourth jejunal vessel as a vascular pedicle. Before cutting off the vessels, adequate circulation of the mobilized jejunal flap should be confirmed by pulsation of collateral arteries and the vasa recta, and the peristalsis and color of the jejunum by the atraumatic clamp test. Next, the mesentery is dissected up to the collateral arcades, straightening the sinusoid turns in the small bowel caused by a naturally foreshortened mesentery. This procedure is indispensable for improvement of the pull-up level and prevention of redundancy of the graft, enabling the long reconstruction up around the sternal notch by using the pedicled jejunal flap (Fig. 1). Furthermore, for a total esophageal replacement that requires a longer jejunal flap for the reconstruction up to the pharynx, some groups have previously described to be effective for dividing the mesentery of the jejunum to the serosal border between the second and third collateral branches. Thus, it allows the conduit to completely unfurl, creating an increase in the flap length.<sup>3, 6, 7)</sup> However, the proximal part of the jejunal flap severs the vascular continuity of the mesenteric arcade close to the free jejunum, therefore, revascularization by the addition of microvascular anastomosis with the secondary jejunal vessel(s) is essential. The success of the procedure significantly influences the outcome of the surgery. When total or near-total esophageal replacement is required, the colon is preferred over the stomach as the organ for grafting. This is because the pedicled colon can provide adequate length without vascular augmentation by microvascular anastomosis<sup>14–17</sup>; however, the development of conduit redundancy over time impairs food transit, and colonic necrosis carries a significant mortality risk.1, 18) Therefore, there is still controversy regarding whether



Fig. 1 Tentative presternal positioning of the jejunal flap. The right side of the figure indicates the cranialis of the patient.

	Year	No. of pts	Reconstruction route			Super-	Mortality	Gangrene	Leakage	Stenosis
Reference			Sub- cutaneous	Retro- sternal	Posterior mediastinum	charge	(%)	(%)	(%)	(%)
Ochsner <sup>10)</sup>	1934	36	36	0	0	_	46.6	22.2	n.a.	n.a.
Yudin <sup>9)</sup>	1944	74	74	0	0	_	4.1	4.2	n.a.	n.a.
Longmire <sup>11)</sup>	1946	1	1	0	0	+	0	0	n.a.	n.a.
Androsov <sup>12)</sup>	1956	11	11	0	0	+	0	9.1	n.a.	n.a.
Hirabayashi <sup>4)</sup>	1993	14	14	0	0	+	0	0	14.3	n.a.
Nishihira <sup>5)</sup>	1995	54	1	23	30	-	0	n.a.	n.a.	n.a.
Heitmiller <sup>6)</sup>	2000	1	0	1	0	+	0	0	0	0
Chana <sup>19)</sup>	2002	11	11	0	0	+	0	0	36.4	18.8
Maier <sup>2)</sup>	2002	35	0	35	0	-	7.7	2.9	11.4	48.6
Hosoya <sup>20)</sup>	2004	78	78	0	0	+	0	0	10.3	10.0
Ascioti <sup>3)</sup>	2005	26	0	13	13	+	0	7.7	19.2	4.8
Ueda <sup>21)</sup>	2007	27	27	0	0	+	0	0	11.1	n.a.
Doki <sup>22)</sup>	2008	25	25	0	0	+	0	0	24.0	n.a.

pts. patients; n.a., not assessed

the jejunum or the colon should be employed as a substitute organ for the stomach in total esophageal reconstruction.

#### **Pull-up route**

Subcutaneous reconstruction was favorable in many reports, as shown in **Table 1**.<sup>2–6, 9–12, 19–22)</sup> This was primarily because Longmire reported the microvascular anastomosis with the internal thoracic vessels in the reconstruction thorough this subcutaneous route.<sup>11</sup> Although this subcutaneous reconstruction has a disadvantage in that it is the longest route, many surgeons have suggested that it also provides advantages in that it allows

the jejunal flap to be pulled-up safely and without torsion,<sup>7)</sup> and also allows for safe and simple placement of the decompression tube.<sup>7)</sup> On the other hand, the posterior mediastinal route has the advantage of being the shortest distance, but it has disadvantages in that it cannot be accessed by two-stage reconstruction after esophagectomy,<sup>6, 7)</sup> and it is difficult to insert the decompression tube because the procedure is done blind, thereby increasing the risk of postoperative delayed midconduit perforation,<sup>7)</sup> which was reported by Ascioti et al. to be observed in 7.7% of patients reconstructed thorough the posterior mediastinum.<sup>3)</sup> Additionally, the posterior location makes the passage of the jejunum without torsion

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more difficult.<sup>7)</sup> In contrast, Swisher et al. stated that the retrosternal route is very accessible due to its anterior location, and it can be used even in two-stage reconstruction, and assures the safety of the pull-up of the jejunal flap and insertion of the decompression tube,<sup>7)</sup> while Heitmiller et al. insisted that a median sternotomy is required for a safe pull-up without torsion. In any case, the major disadvantage of this route is the necessity to enlarge the thoracic inlet with the left side partial resection of the manubrium, clavicle, and first rib, however, this allows access to the internal thoracic vessels, which can be advantageous.<sup>3, 7)</sup> Consequently, considering the safety of reconstruction and the convenience of the microvascular anastomosis, it may be preferable to bring the pedicled jejunal flap thorough the subcutaneous or retrosternal route at the present time.

#### Microvascular anastomosis

The application of microvascular anastomosis to general surgery was first reported by Carrel in 1906<sup>23)</sup> after a successful transplantation of an autologous small bowel into the necks of dogs with microvascular anastomosis of donor vessels and the common carotid artery and internal jugular vein. In 1946, Longmire first reported a successful vascular augmentation (supercharge and superdrainarge) by the addition of the microvascular anastomosis between the jejunal mesenteric vessels and the internal thoracic vessels in the esophageal reconstruction with the pedicled jejunum.<sup>11)</sup> As shown in **Table 1**, no flap necrosis was observed in patients since 1990, when the addition of microvascular anastomosis and microsurgery were positively employed, excluding 2 cases reported by Ascioti (7.7%) which had received the long-segment jejunal flap extended by division of continuity of the collateral arcade.<sup>3)</sup> Even after evaluation of all of the available data in Table 1, flap loss was observed in only 2 of 193 cases (1.0%) with microvascular anastomosis,<sup>3, 4, 6, 11, 12, 19–22)</sup> showing extremely low incidence, compared with 12 of 145 cases (8.3%) without microvascular anastomosis.<sup>2, 5, 9, 10)</sup> Moreover, there was no mortality in patients with microvascular anastomosis,<sup>3, 4, 6, 11, 12, 19–22)</sup> whereas the mortality rate was reported to be from 4.1% to 46.6% in patients without microvascular anastomosis.<sup>2, 5, 9, 10)</sup> Chana et al. described that, based on their experience, a jejunal segment as long as 30 cm can survive on a single pedicle, however, for segments between 30 cm and 50 cm in length, which are required in jejunal pull-through, supercharging should be carried out to a second set of vessels.<sup>19)</sup> Maier et al., who did not perform the additional

microvascular anastomosis, reported that the addition of a free jejunal interposition was needed for the completion of reconstruction in one case due to the intraoperative venous congestion of the upper third of the jejunal loop, and four patients developed a reduced perfusion at the highest point of the jejunum, resulting in anastomotic dehiscence.<sup>2)</sup> Considering these results, the microvascular anastomosis should be added for vascular augmentation of the flap in all cases of esophageal reconstruction with the pedicled jejunum.

Microvascular anastomosis was performed mainly between the proximal jejunal mesenteric vessels and the internal thoracic vessels in most cases (**Fig. 2**).<sup>3, 4, 6, 11, 12, 20–22)</sup> As alternative recipient vessels, the branches of the external carotid artery and the internal jugular vein<sup>7)</sup> or the transverse cervical artery and the concomitant vein or a branch of the external jugular vein grafts<sup>19)</sup> were also often used. If these vessels are not available, the thoracoacromial or thoracodorsal vessels may be employed, however, these will require vein grafts.<sup>19)</sup>

The advantages of using the internal thoracic vessels are their availability, single-pedicle arteriovenous blood supply, ease of harvesting, and the mobility of the vascular pedicle. Longmire anastomosed with the left internal thoracic vessels in his first report.<sup>11)</sup> however, Schwabegger et al. reported on the basis of dissection of 86 cadavers,<sup>24)</sup> that the mean diameter of the internal thoracic vein was 2.34 mm in the studied females and 2.28 mm in males at the cranial edge of the fourth rib on the right side, and decreased to 1.68 mm in females and 1.58 mm in males on the left side, thus, the right was larger than the left. Taking these facts into consideration, the anastomosis with the right internal thoracic vessels may be preferable whenever the procedure is possible. However, the left internal thoracic vessels are the first choice in the retrosternal reconstruction, because the left side partial resection of the manubrium, first rib, and clavicle required for enlargement of the thoracic inlet enables easy access to the left internal thoracic vessels.<sup>3, 7)</sup> It may be important to evaluate the diameter of both sides of the internal thoracic veins on contrast-enhanced computed tomography before surgery, and to select the reconstruction route considering which side of the internal thoracic vessels should be employed for microvascular anastomosis.

Regarding the actual effect of the supercharge technique in jejunal reconstruction, Ueda et al.<sup>22)</sup> described that the venous partial pressure of oxygen taken from the vein of the proximal pedicle of the jejunal graft, which



Fig. 2 Microvascular anastomosis of the second jejunal vessels and the left internal thoracic vessels. The right side of the figure indicates the cranialis of the patient.

reflects on the blood perfusion within the local tissue, showed marked increases (mean, 177.8%) after the addition of the arterial and venous anastomosis, indicating the usefulness of the additional microvascular anastomosis for vascular augmentation of the jejunal flap. In contrast, the adequate improvement of the venous partial pressure of oxygen could not be obtained after only venous anastomosis (mean, 115.7%), thus suggesting that the anastomosis of both the artery and vein is recommended whenever possible.<sup>22</sup>

# **Reconstruction of the Digestive Tract**

An esophago-jejunal or pharyngo-jejunal anastomosis is performed in the neck with circular stapler in an endto-side fashion in Japan,<sup>4, 20-22)</sup> and hand sewing in an end-to-end fashion in Western countries,<sup>2, 3, 19)</sup> according to the literature. The rate of anastomotic leakage was 13.2% (19/144) using the circular stapler method and 19.4% (14/72) using the manual suturing method, showing no significant difference between the two anastomotic methods (p = 0.229). The difference in the frequency of anastomotic stricture according to the anastomotic methods is of great concern; however, a comparison could not be conducted for the present study due to lack of data about postoperative anastomotic stricture. Reconstruction is completed by the interposition of the pedicled jejunal flap between the esophagus and the stomach, or by the Roux-en Y method if a previous gastrectomy were performed. Swisher et al. stated that the jejunogastric anastomosis should be performed high on the posterior wall of the stomach to avoid the occurrence of a saddlebag deformity and poor gastric emptying.

### **Surgical Outcome**

In the beginning, as reported by Ochsner and Owens,<sup>10)</sup> the esophageal reconstruction using a pedicled jejunum showed a gangrene rate of 22.2% and a mortality rate of 46.6%, and it was considered to be a surgical procedure with extremely high risk. With the recent progress in microsurgery and the recent applications of additional microvascular anastomosis, there were no postoperative deaths or minimal flap loss during the last 20 years,<sup>3, 4, 6, 19–22)</sup> as shown in Table 1 and described in the paragraph 'Microvascular anastomosis.' Furthermore, Maier et al.<sup>2)</sup> reported that anastomotic stricture was observed in 4.8% to 18.8% of patients with microvascular anastomosis,<sup>3, 19-22)</sup> compared with 48.6% of cases without microvascular anastomosis.<sup>2)</sup> They described that there was neither jejunoesophageal reflux nor belching; therefore, the additional microvascular anastomosis appeared to successfully reduce the risk of anastomotic stricture. However, the rate of esophago-jejunal anastomotic leakage was demonstrated to be 11.1% to 19.2%, which was still high in spite of the addition of the microvascular anastomosis,<sup>3, 19–22)</sup> suggesting that physical influences other than the blood supply, such as tension, pressure and bending of the anastomosis site, affect this leakage. No redundancy of the jejunal flap has been reported except one case that underwent reoperation.<sup>3)</sup>

# **Functional Evaluation of the Graft**

The advantages of using the jejunum for esophageal replacement are the active transport of food by peristalsis and the prevention of regurgitation commonly seen in gastric pull-up procedures. Although there have been a few reports about the motor activity of the pedicled jejunal flap, Moreno-Osset et al.<sup>25)</sup> and Nishihira et al.<sup>5)</sup> revealed in manometric studies that the swallow stimulus induced progressive waves from the oral side to the anal side, thus suggesting the participation of peristalsis in food transit in the pedicled jejunal flap. Furthermore, Nishihira et al.<sup>5)</sup> reported that the jejunal flap retained its peristaltic properties for several years after surgery. Esophageal substitutes do not have peristalsis, and food is transported with gravity in the segment reconstructed with gastric tube and colonic grafts.<sup>26, 27)</sup> However, this lack of peristalsis causes food congestion and regurgitation, sometimes leading to esophagitis and aspiration

	Pedicled jejunum	Pedicled colon		
Surgical procedure				
Length	limited	adequate		
No. of anastomoses	2 or 3	3 or 4		
Microvascular anastomosis	necessary	case by case		
Difference of diameter				
to the esophagus	equal	greater		
		(except ileocecal reconstruction)		
Graft volume	small	large		
No. of enterobacteria	few	many		
Complications				
Mortality rate	extremely low	high		
Graft necrosis rate	low	high		
Anastomotic leakage rate	alm	lost equal		
Redundancy	rare or mild	high		
Function				
Regurgitation	a few	moderate		
		(except ileocecal reconstruction)		
Food transit	peristalsis	gravity		
Reservoir function	poor	good		
Incidence of intrinsic disease	rare	high		

Table 2 Comparison of esophageal reconstruction with the jejunum and colon

No., number

pneumonia. On the other hand, the reconstruction with the pedicled jejunum was reported to lead to a low incidence of esophagitis and no development of aspiration pneumonia from one year after the procedure onward,<sup>5)</sup> indicating that the pedicled jejunal reconstruction has an advantage in its functional aspects in comparison to either gastric or colonic reconstruction.

# Which is the Best Esophageal Substitute for the Gastric Tube, the Jejunum or the Colon?

We examined the optimal substitute for the gastric tube (Table 2). The reconstruction of a long distance is not recommended for the pedicled jejunal flap, because severing the continuity of mesenteric arcade is required in order to make a long jejunal flap and straighten it. Nevertheless, the reconstruction with the pedicled jejunum has many advantages compared with pedicled colonic reconstruction,<sup>1)</sup> such as the lower rate of flap loss and mortality, fewer anastomosis sites and enterobacteria, a decreased difference from the esophageal diameter, better function of food transit<sup>2-7)</sup> and a lower incidence of regurgitation,<sup>5)</sup> and no significant risk of intrinsic disease such as unexplained massive gastrointestinal hemorrhage or colon carcinoma.<sup>2, 3)</sup> On the other hand, some advantages of reconstruction with the pedicled colon are the ability to create a long graft, good reservoir function, and prevention of regurgitation by Bauhin's valve in the ileocecal graft.<sup>1)</sup> However, some additional disadvantages of using the colon are the need for a large space at the thoracic inlet<sup>2)</sup> and a high rate of reoperation due to graft redundancy.<sup>1)</sup> Considering the circumstances mentioned above, the reconstruction with a pedicled jejunum, although it requires the addition of microvascular anastomosis, has more advantages and is preferable in both aspects of safety and function compared to the reconstruction with a pedicled colon, and we recommend its use whenever possible.

### Conclusion

We herein reviewed esophageal reconstruction using the pedicled jejunum after esophagectomy. Incorporation of microvascular anastomosis by the progress and spread of microsurgery has brought about a rapid improvement of surgical reliability in reconstruction with the pedicled jejunum, which has been reevaluated as an alternative reconstruction procedure in cases where the stomach cannot be used. This procedure has numerous advantages in terms of its low perioperative risk, good motor activity of the flap, very low incidence of intrinsic disease and so on, compared with the colonic reconstruction. However, it also has some disadvantages, such as the relatively high rate of anastomotic leakage. Hereafter, efforts should be focused on decreasing the incidence of anastomotic leakage, and surgical techniques should be improved that are aimed at the establishment of safer surgical procedures for wider use.

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