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Esophageal Reconstruction with Small Intestine

1. Vascular anatomy of the small intestine

The small intestine as a whole, i.e. the jejunum and the ileum, is supplied with arterial blood by intestinal arteries (aa. jejunales and aa. ilei), which are branches of the superior mesenteric artery (a. mesenterica superior) and run together in the intestinal mesentery. Individual intestinal arteries, from 10 to 15 in number, referred to as main trunks, anastomose with each other by means of so-called vascular arcades. The outflow of venous blood belongs to the confluence of the portal vein and takes place in homonymous veins.

Numerous anatomical studies on vascular structure of the jejunum have demonstrated that only 30% of population reveals so-called adequate vascular system for esophageal reconstructions, which enables reconstructive surgery with a pedicled segment of the jejunum. Further 30% of population has definitely disadvantageous vascular anatomy in the aspect of reconstructive surgery, while the remaining individuals present with so-called intermediate arrangements, which only in few cases permit mobilization of a pedicled esophageal graft from this intestinal segment. Thus the use of the jejunum to create an esophageal graft is strictly conditioned by the possibility of mobilization of a long enough and well vascularized intestinal segment reaching up to the neck. The above mentioned individually differentiated vasculature of the mesojejunum is thus the key point allowing or excluding use of the jejunum for esophageal reconstruction.

Figure 1 Angiogram of an adequate arterial system of the mesojejunum (well developed main vascular trunks connected by long and well developed arcades)
From the point of view of reconstructive surgery, the above-mentioned vasculature systems of the mesojejunum may be presented in the following way.

An adequate vasculature contains well developed, long vascular trunks, which anastomose between themselves by means of equally well developed and long arcades (Fig. 1).

An inadequate vascular system is such, in which the main vascular trunks either do not form anastomosing arcades, or between some of the trunks there are poorly developed arcades alternating with trunks with bushy architecture. Such systems may be observed in anatomical preparations of the small intestine, or intraoperatively (Fig. 2, 3).

**Figure 2** Angiogram of an inadequate arterial system of the mesojejunum (main vascular trunks do not form anastomosing arcades)

**Figure 3** Intraoperative picture of an inadequate vasculature of the mesojejunum (main vascular trunks branch and do not form anastomosing arcades)
An intermediate system is a mixture of adequate and inadequate systems. With this type of vasculature, it is rarely possible to mobilize a long enough and well supplied segment of the jejunum on a vascular pedicle, even when the surgeon is equipped with highest quality skills. In such cases it is better to abandon this part of intestine and consider colon graft by means of one of the methods described in the chapter on esophageal reconstruction with colon.

2. Esophageal reconstructions using the jejunum

As presented in the previous chapter, reconstructive surgery using the jejunum consists of a number of consecutive stages: abdominal, cervical and thoracic.

The abdominal cavity is approached from upper midline incision reaching from the xiphoid process of the sternum to the umbilicus. Next first loops of the jejunum are exposed, starting from the duodenojejunal flexure, and the type of vasculature can be determined at this point. In order to enable visualization of the vasculature, the jejunum should be lifted upwards and its mesentery should be illuminated with a lateral source of light, so-called transillumination (Fig. 3). If vascular system appears adequate, the next step is to evaluate the efficacy of vascular anastomoses by means of a biological trial. Vascular forceps are clamped on the main vascular trunks which are to be cut below their bifurcation, starting from the 2nd intestinal artery in order to create conditions in which the selected and separated intestinal segment is supplied exclusively from this artery and vein which create the future vascular pedicle of the graft. Usually it is the 3rd or the 4th intestinal artery. If the vascular anastomoses in the selected intestinal segment are efficient, the intestine maintains natural colour and peristalsis. Disrupted blood supply is manifested by intense peristalsis and cyanosis or marble-like appearance of the intestine and lack of visible pulse in the distal straight vessels of the investigated intestinal segment. A precise evaluation of the adequacy of vasculature in the separated intestinal segment may be achieved by intraoperative ultrasound Doppler scanning.

Figure 4 Intraoperative picture of onset of mobilization of a pedicled graft from the jejunum
A positive biological trial means that the graft mobilization may be started. For this reason the vascular trunks, i.e. the second or the second and third intestinal artery and vein should be ligated and transected following prior clamping with forceps in the proximity to the site of their branching from the mesenteric vessels (Fig. 4, 5). It is important, as length of the vascular pedicle is crucial to obtain a long enough and well vascularized graft reaching up to the neck.

Radial, Y-shaped incision of the mesenteric layer of the peritoneum with a 2-cm safety margin from the border vessels, i.e. arches anastomosing the transected trunks of the mobilized intestine allows to obtain a straight graft and at the same time it elongates its vascular pedicle. The next step involves full mobilization of the graft. The jejunum is transected 20 cm from the duodenojejunal flexure and in the caudal portion beyond the vascular trunk which forms...
the graft pedicle (Fig. 6). In order to obtain sufficient mobility of the created graft, a few-centimeter segment of the intestine is excised following parietal ligation and cutting of the terminal straight vessels in the caudal portion. This procedure is referred to as reduction in the distal portion of the graft (Fig. 7). The cephalic stump of the graft should be closed tight with a manual suture or stapled, and its caudal segment is closed with a temporary suture until it becomes anastomosed with the stomach. Thus created graft is covered with a surgical towel soaked in warm saline. Next continuity of the gastrointestinal tract within the abdominal cavity should be restored by anastomosing the jejunal stumps remaining after mobilization of the graft. During this procedure, the created graft should be observed periodically for blood supply.

Figure 7 Diagram and intraoperative picture of full mobilization of the graft with prepared reduction of the intestine in caudal segment

The next activity at this stage of the surgery is to place the created graft in the epigastrium. There are several variants. The first of them, and most advantageous, is to move the graft beyond the colon and the stomach. This is the shortest route towards the neck and involves passing the mobilized graft together with its vascular pedicle through a slit in the transverse mesocolon and the lesser omentum from the mesogastrium to the epigastrium. Thanks to prior reduction of the intestine in the caudal portion, the graft is more mobile and the pedicle, which remains beyond the stomach, is well protected. However this variant cannot be applied in all the patients. This especially concerns individuals after extensive surgeries in the
epigastrium. Then one of two possible variants of pull-through of the graft should be chosen. The first of them consists in passing the graft behind the colon and in front of the stomach. In comparison to the previous method, this modality is less advantageous and requires mobilization of a significantly longer intestinal segment. The main reason for this is the fact that the graft pedicle surrounds the greater curvature of the stomach and thus hampers mobility of the graft, what should be remembered at the beginning of graft mobilization. The last variant is the least advantageous. In this variant the graft is pulled in front of both, the colon and the stomach. It requires mobilization of even longer segment of the jejunum in comparison to the previous methods. Additionally, another drawback is that the vascular pedicle, which surrounds the transverse colon and the stomach, is exposed to pressure, what may disrupt blood circulation in the graft.

As can be understood from the surgical details presented above, every decision made at individual stages of the operation must be carefully balanced, as it affects the outcome of the reconstructive surgery.

After termination of the abdominal stage of mobilization and translocation of the graft to the epigastrium, the next activity is to construct a retrosternal canal and pull the graft through the canal to the neck. A detailed description of this stage of operation was presented in the previous chapter.

After placing the graft in the retrosternal canal, the next step is to anastomose its caudal portion with anterior wall of the prepyloric stomach. During this procedure a special attention should be paid to the blood supply to the portion of the graft which is exposed onto the neck. Normally supplied graft in the portion exposed onto the neck maintains peristalsis, reveals pulsation in the terminal intestinal vessels close to the intestinal wall, and the intestinal wall is shiny and pink. In cases any disturbances in blood supply to the portion exposed on the neck are noticed, the graft should be evacuated from the canal and the cause of obstructed blood flow should be immediately determined and removed.

In this place it is worth reminding that creation of the retrosternal canal, and especially translocation of the graft through the canal are associated with a risk of intestinal torsion around the vascular pedicle, suspension of the pedicle on the diaphragm at the site of the opening of the canal from the abdominal side, and in ultimate case, disruption of the graft's vascular pedicle. Disruption of the vascular pedicle is a severe complication, which is most commonly irreversible, and it thwarts the whole reconstructive surgery. In this case a trial to anastomose ruptured vessels may be undertaken, however a positive outcome is doubtful. In case of intestinal torsion around the pedicle, the twisting should be resolved, the intestine should be covered with a surgical towel soaked in warm saline, and after restoration of normal blood supply, the graft should be again pulled through the retrosternal canal. If the blood supply was disrupted through pressure of the diaphragm at the level of the inferior opening of the retrosternal canal, the diaphragm should be incised sagittally in the canal axis. In this way the canal opening is widened and the pressure on the graft pedicle - relieved.
When the graft is anastomosed with the stomach, and blood supply to the cervical portion of the graft remains normal, the final stage of the reconstructive surgery, i.e. esophageal-intestinal anastomosis on the neck may start. Cervical anastomosis is the last, but at the same time extremely important stage of the reconstructive surgery, as it exerts a significant effect on the future function of the substitutive esophagus. Erroneously performed cervical anastomosis may be the reason of disturbances on swallowing, and in ultimate cases, of occlusion of the substitutive esophagus. The most advantageous is the end-side to side anastomosis of the cervical esophagus with the lateral intestinal wall. It is broad enough and it has a beneficial effect on the future function of the substitutive esophagus. In order to prevent the cephalic portion of the graft from forming an inclining downwards diverticulum, 1-2 sutures should be placed to suspend the stump of the cervical part of the graft on the sternocleidomastoid muscle (Fig. 8).

**Figure 8** Diagram and radiogram (lateral projection) of cervical end-side to side anastomosis (the sutures run diagonally from behind and up towards the front and below)

After this stage, suturing the abdominal and cervical layers terminates the reconstructive surgery.

Recapitulating the above described esophageal reconstruction with the jejunum, it should be stressed that it has several advantages. The substitutive esophagus resumes excellent function, what is associated with the properties of the jejunum. Peristalsis is vivid, what favours quick and efficient passage of the content through the substitutive esophagus and prevents reflux. Moreover, translocation of the graft through the retrosternal canal and anastomosis with the cervical esophagus is easier in comparison to the colon. Finally, the intestinal defect in the abdominal cavity is minimal.
Follow up examinations immediately after the surgery as well as remote observations confirm an excellent function of thus performed esophageal reconstruction (Fig. 9).

3. Esophageal reconstructions using the ileum

Discussing reconstructive surgery with the use of the small intestine, it should be stressed that not only the jejunum may be used for esophageal reconstruction. The knowledge of modalities presented below may be useful in cases in which, due to anatomical conditions, reconstructive surgery using another portion of the intestine may appear unfeasible. Thus it seems reasonable to recollect anatomical details of vascularization in the ileocaecal angle.

The ileocaecal vessels, which run in the mesenteric root of the small intestine downwards and to the right, are responsible for blood supply to the terminal portion of the ileum, the caecum, and the vermiform appendix. Through the iliac branches they join with terminal arteries and veins of the intestine departing from the superior mesenteric vessels, and through the colon branch with arteries and veins of the right colon (Fig. 10).

Adequate vascular system within the terminal portion of the ileum and the right colon may be used to mobilize an isoperistaltic graft by means of three modalities:

1. from the ileum on ileocolic vascular pedicle;
2. from the ileum and caecum on ileocolic vascular pedicle;
3. from the terminal portion of the ileum, the caecum, and part of the ascending colon on right or middle colic vascular pedicle.
Choice of one of the above modalities is closely associated and conditioned by an adequate and fully efficacious vasculature, which is able to provide the best possible blood supply to the future graft.

3.1. Esophageal reconstruction with the use of the ileum alone

The ileum is extremely rarely used in esophageal reconstructions due to a short mesoileum and running in several rows, short arcades anastomosing intestinal vessels. Thus adequate evaluation of the vascular efficacy in this portion of the intestine is very difficult even for an experienced surgeon. Another reason is associated with the fact that a graft made from the ileum in general has a tortuous course, i.e. there is a significant excess of the ileum in relation to the mesentery, what exerts a negative effect on the function of the substitutive esophagus, despite peristalsis characteristic for the small intestine. Thus it should be emphasized decidedly that this type of reconstructive surgery should be considered only in cases in which, due to anatomical conditions, reconstruction with another segment of the intestine is impossible. However awareness of this surgical modality is a chance for patients to regain the possibility of oral alimentation.
The surgical technique is as follows. The abdominal cavity is approached from the upper midline incision passing by the umbilicus on the right side and going several centimeters below. Next the caecum, the ascending colon together with the ileocolic vessels, and the terminal portion of the ileum together with its mesentery and terminal branches of the superior mesenteric vessels should be prepared and separated from the posterior abdominal wall. Thus mobilized portion of the intestine enables a detailed evaluation of the vasculature in the mobilized intestinal segment. In case circulation is found adequate, i.e. ileocolic vessels are long, well developed and form wide and firm arcades anastomosing with the right colic vessels and, through the iliac branch, with vessels in the terminal portion of the ileum, a biological trial should be undertaken. The trunks of the terminal portion of the ileum which is to be transected, as well as the colic branch of the ileocolic vessels are clamped with vascular forceps just at its departure from the main ileocolic trunk. The selected terminal segment of the ileum is thus supplied only from the ileocolic vessels.
A positive result of the biological trial allows continuation of the operation. However it should be remembered that length of the vascular pedicle is crucial for obtaining a long enough graft. As the mesoileum is short, and the main vascular trunks form several rows of arcades, mobilization of the ileum is much more difficult in comparison to the jejunum; moreover, it requires mobilization of a relatively long intestinal segment, which would reach the neck without tension. Mobilization of the graft starts from ligation and transection of the vessels which were previously clamped, with a special attention paid not to damage the continuity of the parietally placed arcades between ileocolic vessels and vessels of the terminal portion of the ileum. The graft is fully mobilized when the ileum is transected in the caecal portion and in the proximal segment at a level which is considered sufficient to obtain a required length of the graft (Fig. 11). Thus the graft, created totally from the ileum, has an ileocolic vascular pedicle and, after being pulled through the retrosternal canal, will be in isoperistaltic position. When the graft mobilization is completed, the vermiform appendix is resected. Further stages of the surgery, as described previously, involve formation of a retrosternal canal in which the graft is placed, reconstruction of the gastrointestinal continuity in the abdomen, i.e. anastomosing the ileum remaining after mobilization of the graft with the caecum and anastomosing the graft with the stomach and the cervical esophagus. The presented surgical modality was proposed by Bernat in 1988, and the patients operated on with this technique regained the possibility of nutrition through the mouth. (Fig. 12).

3.2. Esophageal reconstruction using the ileum and the caecum

The below presented technique for esophageal reconstruction is an original modality developed and proposed by Jezioro in 1958. It is based on an adequate vascular system for esophageal reconstruction in the region of the ileocolic angle. The main advantage of this surgical technique involves the use of a shorter segment of the ileum in comparison to the modality described above. Moreover, the caecum together with Bauhin’s valve are included in the graft and create its caudal portion, at the same time performing the function of an antireflux mechanism.

![Diagram of mobilization of the graft from the ileum and the caecum on ileocolic vascular pedicle](image-url)
The surgical technique is similar to the above-described modality of esophageal reconstruction with the ileum, the main difference lying in this that the colic branch of the iloecolic vessels should be ligated and transected just at the level of ramification of the right colic trunk in order to provide blood supply to the caecum. Thus an isoperistaltic graft is created on an iloecolic vascular pedicle. Mobilization of the ileum is similar to that described for the esophageal reconstruction with the ileum alone. But in this surgical modality the segment of the ileum is slightly shorter, and the caecum, as mentioned above, is included into the graft and creates its caudal portion (Fig. 13, 14). The vermiform appendix is resected after mobilization of the graft.

The mobilized intestinal segment is passed behind the colon and the stomach to the retrosternal canal. The ileum, forming the upper portion of the graft, is exposed to the neck and anastomosed with the cervical esophagus, and the caecum is anastomosed with the anterior wall of the prepyloric stomach. The intestinal passage in the abdominal cavity is reconstructed by anastomosis between the part of the ileum remaining after mobilization of the graft and the ascending colon. Anastomosis of the ileum exposed on the neck with the cervical esophagus completes the operation.

The presented technique of reconstructive surgery has a number of advantages. The cephalic portion of the graft is formed from the small intestine with a vivid peristalsis. On the other hand, the caecum together with the iloecolic valve, as mentioned before, plays the function of an antireflux barrier.

The drawbacks include relative tortuosity of the graft, what elongates the passage through the esophageal substitute.

Clinical follow up at a remote time indicated that the function of so created esophagus may be considered good (Fig. 15).
3.3. Esophageal reconstruction using the ileum, the caecum and part of the ascending colon

The last of the surgical modalities with the use of the ileum involves mobilization of a graft consisting of the ileum in its cephalic portion and from the caecum and part of the ascending colon in the caudal portion. The described below technique differs from the two techniques presented previously in this that the distal portion of the graft is made from the caecum and a short segment of the ascending colon, while the pedicle includes the right or middle colic vessels.
Figure 16 Diagram of mobilization of graft from the ileum, the caecum and part of the ascending colon on middle colic vascular pedicle

This variant of reconstructive surgery is possible in patients with effective vasculature systems between vessels in the terminal portion of the ileum and the right colon. Then an isoperistaltic graft may be created on a pedicle of right or middle colic vessels. However it should be remembered that a graft on right colic vascular pedicle has a shorter pedicle than a graft pedicled on middle colic vessels.

Figure 17 Intraoperative picture of mobilization of terminal portion of the ileum and the right colon

The surgical technique differs slightly from the two previously described surgical modalities. After laparotomy, the terminal portion of the ileum and the right colon must be mobilized. If the adequacy of vasculature in the terminal ileum and the right colon is ascertained macroscopically, and a biological trial of the graft pedicle on the right colic vessels is also posi-
tive, the ileocolic vessels and the trunks of the vessels in the terminal ileum are ligated and transected with anastomosing arcades left intact. The ascending colon is transected beyond ramification of the right colic vessels, and the ileum – at a distance of 20 cm from the caecum. In cases in which a longer graft is necessary, also the right colic vessels should be ligated and transected, and the graft should be pedicled on middle colic vessels. In this variant the mobilized segment of the ileum is shorter than in the two previously described esophageal reconstructions with the use of the ileum, or the ileum and the caecum, and it is straight (Fig. 16, 17, 18). The vermiform appendix is resected in a routine manner following full mobilization of the graft.

The remaining surgical procedures are the same as presented in previous chapters. The mobilized graft is pulled behind the colon and the stomach to the retrosternal canal. The remaining stump of the ileum is connected to the residual right colon. The caudal portion of the graft, i.e. the ascending colon is anastomosed to the anterior wall of the prepyloric stomach, while the cephalic portion, which has been created from the terminal segment of the ileum - to the cervical esophagus.

The above presented modality of esophageal reconstruction has many advantages. The cephalic portion of the esophageal substitute is created from the small intestine with a vivid peristalsis, and Bauhin’s valve, which is located in the middle of the graft, may be considered an antireflux barrier. Moreover, the abdominal defect remaining after mobilization of the graft is relatively slight.

The function of thus created esophageal substitute is effective, what finds confirmation on remote follow up (Fig. 19).
Recapitulating the above-presented modalities of esophageal reconstructions with the use of the small intestine, it should be underlined that they extend our knowledge on the possibilities of using the small intestine for esophageal reconstruction.

Figure 19 Radiogram of substitutive esophagus from the ileum, the caecum and part of the ascending colon (A-P projection)

4. References


