

The Features of Stomach Vascularisation Pattern and Their Impact on Oesophageal Reconstruction with a Gastric Pull-up

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Abbreviations:

ICG: Indocyanine green;

HSI: Hyperspectral imaging;

StO2: Tissue oxygen saturation;

CT: Computed tomography;

MRI: Magnetic Resonance Imaging.

Rezumat

Caracteristicile pattern-ului de vascularizație al stomacului și impactul în tehnicile reconstructive ale esofagului cu rezervor gastric

Indiferent de tehnica reconstructivă, conceptele de fundamente în reconstrucția viscerală au ca bază principală suportul vascular necesar pentru grefonul de substituție. Factorul vascular reprezintă elementul esențial pentru orice tehnică reconstructivă deoarece el condiționează întinderea materialului visceral și, alături de alți factori, securitatea suturilor. În cazul stomacului, debitul vascular consistent și variațiile anatomice minime în ceea ce privește anatomia vasculară reprezintă un prim argument teoretic. Al doilea argument se bazează pe caracteristicile rețelei vasculare intraparietale care permit suplerea perfuziei viscerele în condițiile întreruperii fluxului sangvin prin unul sau mai mulți pediculi. Hipoperfuzia în grefon rămâne totuși o posibilă cauză pentru eșec, cea mai invocată complicație prin consecință fiind cea a unui risc fistular anastomotic ridicat. O serie de tehnici moderne - date arteriografice cu reconstrucția vasculară preoperatorie sau studii de evaluare intra-operatorie de tip fluometrică prin metoda de scanare laser Doppler, măsurarea nivelului oximetriei în grefon, examinarea „Laser Speckel” (în pete) sau a utilizării Indocyanine green (ICG) - sunt metode pentru identificarea precoce a calității perfuziei/microperfuziei în grefonul gastric în vederea diminuării acestui risc. Dubiul perfuziei în grefon gastric obligă la tehnici de augmentare vasculară. În lipsa acestora, rezultatul este incert și dificil de corectat.

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Cuvinte cheie: reconstrucție esofagiană, model de vascularizare gastrică, grefă gastrică

Abstract

Regardless of the reconstruction surgery used, the fundamental concepts of visceral reconstruction are based on the vascular support needed for the substituting graft. The vascular factor is the main element of any reconstruction technique, as an underlying condition for the visceral material stretch and, along with other factor, for the suture safety. In the case of the stomach, a consistent vascular flow and the minimal vascular anatomy variations are the first theoretical argument. A second argument is based on the intraparietal vascular network features allowing for supplementing visceral perfusion as the blood flow is stopped in one or more pediculi. Graft hypoperfusion is, however, a potential cause of failure, and the most frequently invoked complication is, therefore, a high risk of anastomosis fistulae. A series of modern techniques - arteriography data for the pre-operative vascular reconstruction or Doppler laser fluorometry intraoperative assessments, graft oximetry, laser speckle (spot) scan or the use of indocyanine green staining (ICG) - represent methods of early determination of the gastric graft perfusion/micropfusion quality used in reducing such risks. The doubts regarding the gastric perfusion mandate the use of vascular augmentation techniques. If such techniques are not used, the final outcome is uncertain and difficult to correct.

Key words: esophageal reconstruction, gastric vascularisation pattern, gastric graft

Introduction

Regardless of the reconstruction surgery used, the fundamental concepts of visceral reconstruction are based on the vascular support needed for the substituting graft. The individual vascular particularities may lead to the surgeon being inclined or obligated to use a certain visceral option for one procedure or another: stomach, small intestine, or colon. This work aims at presenting the scientific arguments for the vascular component in the oesophageal reconstruction using stomach grafts and a synthesis of the existing literature data, from the point of view of the Sf. Maria Clinical Hospital of UMF Carol Davila of Bucharest.

Data Collection Methods and Search Strategy

The article is based on the analysis of data deemed relevant for the theme in the studies published by „St. Mary” General and Oesophageal Surgery Clinic, ”St. Mary”

Clinical Hospital as well as on articles identified in Embase (Excerpta Medica Database), PubMed Central (PMC), Cochrane Library, MEDLINE, EBSCO. We also searched for and used clinical trials and data from research studies updates. The search words were oesophageal cancer, oesophageal carcinoma, esophagectomy, resection, surgery and operation, oesophageal reconstruction, gastric conduit, vascular graft evaluation. The article focused on the data assessing the stomach and gastric graft vascularisation in the oesophageal substitution dispositive. Only such studies were deemed eligible, thus being considered in compiling this article.

Substantiation and Theoretical Argument

The stomach reconstruction principles and subsequent surgical techniques (*Figs. 1, 2*), regardless of the method, was based on the stomach vascular support particularities. Although a series of research works had already clarified the gastric vascularisation



Figure 1. Intraoperative view of the gastric pull-up preparation for elevation and oesophageal substitution using the Nakayama technique



Figure 2. Final intraoperative view of the tubulised gastric graft, along with the resection of the lesser curvature - Akiyama technique

structure, Barlow's in-depth studies manage a precise determination of the intraparietal arterial and venous distribution (1-3), and his observations were subsequently confirmed by other specialised studies (4-6).

The gastric perfusion is supported, mainly, by four vascular sources: the right and left gastric arteries, the left gastroepiploic artery along with the short gastric arteries and the right gastroepiploic artery. The consistent flow and the minimal vascular anatomy variations of this distribution are the first theoretical argument. Secondly, the intraparietal vascular network features allowing for supplementing visceral perfusion as the blood flow is stopped in one or more pediculi. How is this possible?

The complex layout of the submucous vessels and the existence of two main parietal and gastric arterial and venous systems provide the effectiveness. More concretely, the vascular morphology comprises:

- a) The main submucous plexus, consisting of large arteries, irrigated by the gastric and gastroepiploic arteries. These arteries have oblique branches for distribution, ensuring the irrigation of the mucous membrane (Disse's arterioles). There's also a corresponding venous plexus;
- b) The secondary submucous plexus, consisting of arterioles and venules of various sizes, from a 100- μ to capillary-sized diameters. Its components have different origins and behaviours. Some of the arterioles come in as direct termi-

nation from the main submucous plexus and from their proximity, and the veins have dilatations interconnected with the adjacent vessels. Other vessels are arterial and venous vessels with variable dimensions, too, stemming from the main submucous plexus, distributed in successive arches throughout the submucous membrane. This plexus also has the features of an intricate network not penetrating the muscularis mucosae but maintaining communication with the muscular mucosa vessels.

Both vascular plexuses contain a series of arterial-venous anastomoses (glomus), as described by Busscher, 40-60 μ in diameter, but never smaller than 30 μ . Their still controversial role seems to be the bypass of blood flow outside the food cycles.

The next step led to corroborating the anatomy and histology data with the first-hand surgical data. The occlusion of one or more pediculi confirmed the maintaining of a sufficient gastric perfusion, even when irrigated from a single vascular source, as the result of the vascular interconnectivity and of the intraparietal network. The only exception is the right gastric pediculus, without an apparent satisfactory vascular potency, and with a more than negligible role (7,8).

Therefore, modulated by the actual inflow possibilities and by the anatomic route, the only vascular sources that can provide perfusion, in the single variant, are the two gastroepiploic pediculi. Considering this,

numerous arteriography determinations were imagined, and, along with the actual surgical technique possibilities, the three main methods of stomach reconstruction were imagined: (i) entire stomach (Nakayama – vascular sourcing from the right gastroepiploic artery $\pm$ the right gastric artery), (ii) standard isoperistaltic gastric tube by resecting the lesser curvature (Akiyama – vascular sourcing from the right gastroepiploic artery), (iii) anisoperistaltic tube (Gavriliu I & II – vascular sourcing from the left gastroepiploic artery).

Under these conditions, the problem that might cause insufficient vascular flow or, at a minimum, a low flow rate, is mainly related to the type of the greater stomach curvature, i.e., the vascular anastomosis mode (Koskas classification) (9):

- Type I – direct anastomosis of the two gastroepiploic vascular sources;
- Type II – no anastomosis between the two vessels;
- Type III – gracile, symbolic, vascular anastomosis possibly between two minor collateral branches;
- Type IV – direct vessel anastomosis, but over 4 cm away from the greater stomach curvature (sometimes even by the epiploic arches). Even our observations confirm that the distance between the vascular arch of the greater curvature and the visceral margin is pretty constant, but there might be variations and they should be considered for preventing accidental lesions or even sectioning. There is a good reason for the recommendation (10) to mobilise the stomach from right to left before gastrolisis, thus maintaining the possibility to pediculate the left gastroepiploic artery for gastropasty.

Statistically, there are indications of at least interesting variations according to this classification: type I – 54%, type II – 28%, type III – 12%, type IV – 6%. We noticed that the situation deemed unfavourable (type II and even III) occurs in over one third of the population mass. Data from similar studies (7, 11-13) indicate potentially intriguing varia-

Table 1. Vascular anastomosis model variations of the greater stomach curvature arterial ring

Studies	Type I	Type II	Type III	Type IV
Koskas	54%	28%	12%	6%
Lieberman-Meffert		30%		
Diop		40%		
Levasseur	51%	34%	10%	5%
Avlisatos		22%		
Voyumi	60%	22%	13%	4%

tions that are, most probably, a consequence of individual subjectivity – *Table 1*.

The shortcoming of this type of classification is the strictly macroscopic assessment made solely intraoperatively. Under these circumstances, arteriography research was initiated (12,14-16) to determine whether the situations are convenient or unfavourable as early as during the preoperative assessment. The more precise and easy-to-interpret outcomes provided substantially different values upon comparing the numbers: macroscopy - type I – 51%, type II – 34%, type III% - 10%, type IV – 5% versus arteriography - type I – 64%, type II – 15%, type III – 15%, type IV – 5%. Even if this is not a notable difference, it's suspected that it's due to a deficient macroscopic assessment, resulting, in most cases, from a high adiposity of the gastrocolic ligament. In conclusion, the intraoperative assessment of the potentially insufficient anastomosis types (types II and III) of the greater curvature is often overestimated, as the latest data indicate an average value of 27.5%. This vascular anatomic pattern was defined as “mediocre gastroepiploic anastomoses”, and it was determined that most post-operative complications, be they fistulas or stenoses, or even functional complications occurred precisely in such patients (17,18).

Imaging Studies of the Vascular Support

However, even under unfavourable vascular conditions, although the percentage of post-operative complications is slightly higher, the values stay at reasonable level. In such situations, the vascular support can be assisted by other mechanisms: the vessels' size and the

intraparietal connectivity of the two gastroepiploic pediculi, respectively. The angiography data (19) about these two parameters in patients classified in the “mediocre” range (types II and III) were pretty conclusive.

Therefore, a communication via the intraparietal plexuses of the two gastroepiploic vascular sources in all the examined cases is confirmed; however, the flow rate isn't uniform and, as a result, it cannot always a sufficient perfusion level. The most severely affected area is the farthest from the vascular pediculus, i.e., the fornix area, the same area that is the last to capture the angiography radio tracker. Within the same assessment population, the percentage of fornix arterial exclusion was significantly lower than in the population with lower arterial and venous sizes whenever the vascular size was important. Additionally, it was determined that the stomach tubulisation significantly decreases the vascular inflow to the graft, especially in the graft cervical end, in comparison with a full stomach mobilisation (14, 20-22).

This phenomenon seems secondary to the surgical involvement of the intervacular communication between the right and left gastroepiploic arteries' areas. The results lead to giving preference and recommending using the entire stomach, thus ensuring the best quality of vascular support.

The arteriography data were enhanced by

using fluorimetry assessment studies, with the hyperspectral imaging (HSI) assessments being the most valuable. This imaging technique allows for determining the oxygen saturation of tissues (StO₂), in the gastric graft or the tubulised graft, in this case, confirming the best perfusion whenever the entire stomach is preserved (*Figs. 3, 4*). Another accessible option is the intraoperative Doppler laser scan. Doppler support allowed for gastric vascular mapping depending on the blood flow speed changes upon clamping the gastric pediculi during stomach mobilisation (23-26).

The obtained data are conclusive, highlighting a significant drop in gastric perfusion in all subjects investigated post stomach mobilisation, with a global average of 41%. There are major differences between the analysed areas, as follows: antrum - 25% average drop, fundus - 55% average drop (!). The cellular ischemic distress is confirmed by the tonometry gastric intramucosal and jejune pH measurements, with a drop in the pH level. Before the gastric mobilisation, the average intramucosal pH (pHi) was of 7.37 in the stomach and of 7.46 in the jejunum, and of 7.18 and 7.37, respectively, post preparation. In the case of stomach tubulisation there are more significant graft perfusion level changes, in inverse proportion with the distance: the farthest from the cervical end, the bigger the perfusion drop. In percentages, the average

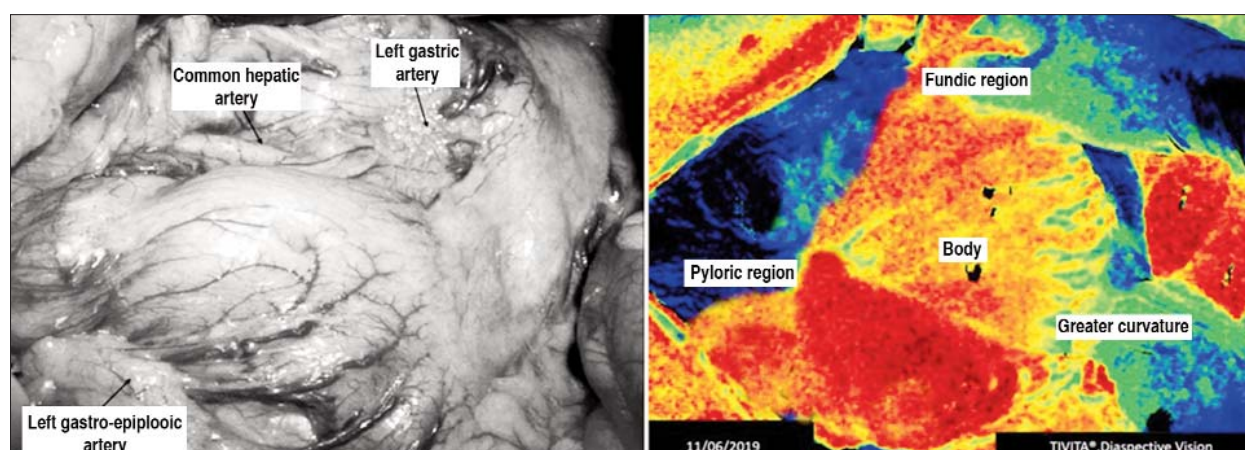


Figure 3. Hyperspectral imaging (HSI). Convenient oxygen saturation (StO₂) found in the gastric graft, after mobilisation and ligature of the left gastric and left gastroepiploic pediculi

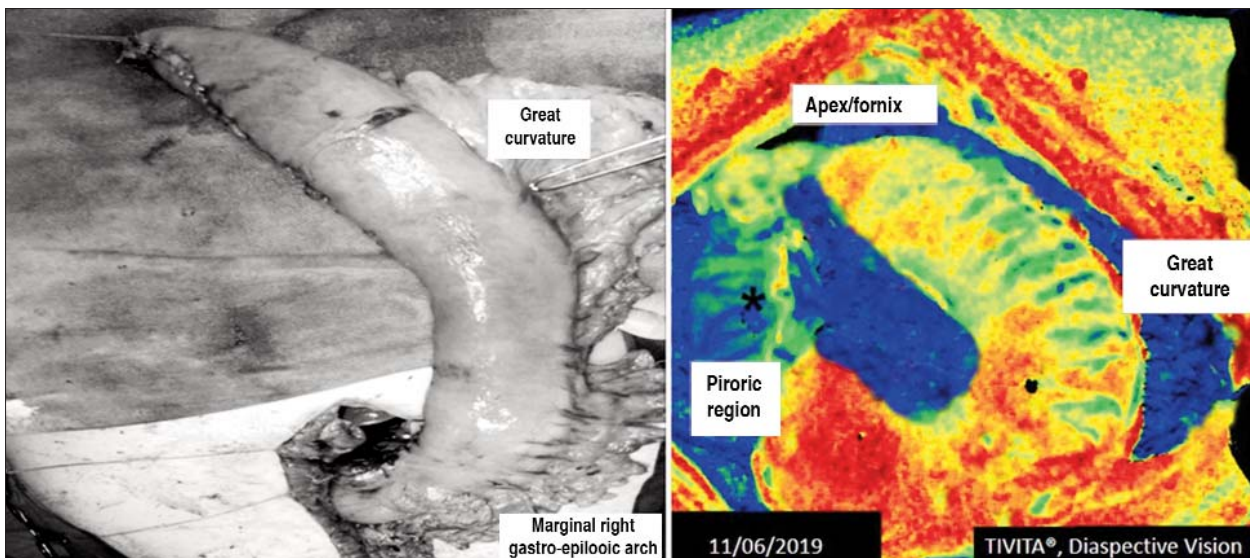


Figure 4. Hyperspectral imaging (HSI). Low oxygen saturation (StO₂) found in the tubulised gastric graft, especially in the apex and fornix

perfusion determination at the cervical end drops by 72%, by 44% at approximately 5 cm distally from it and by only 28% at 10 cm from the gastric “gastric” implantation. Whereas all these studies were performed in the pre-elevation steps, Koskas and Gayet (9) initiated cadaver research with all three gastric graft procedures, by injecting coloured plastic in the vascular tree. The results confirm poor injection or even no injection (!) in the extreme cranial area of the graft arterial network in 9 of 14 cases. The average length of this area considered devascularised is of $1.3 \text{ cm} \pm 1.3 \text{ cm}$.

There are authors (27-29) who suggest that the aetiology factor for the high percentage of anastomosis fistulae is a suboptimal vascular flow, especially in the distal graft end (cervically elevated) (Figs. 5, 6). It was determined, in corroboration with the fistula-related complications data, that there is a proportional relation between the number of patients with the highest vascular flow rate deficiency and the number of patients that developed a cervical oesphagogastric fistula. In other words, the lower the vascular flow is, the higher is the risk of anastomosis fistulae. Other researchers (30) indicated, in opposition to the aforementioned studies, that it is not the fistula-formation risk that is increasing in proportion with the

decrease of vascular flow, but the risk of post-operative stricture as a result of faulty cicatrisation. A qualitative assessment of the vascular flow was required besides its quantitative assessment. The method used was pulse oximetry, facilitating the identification of the ischemic visceral areas. The technique



Figure 5. Arteriography scan of the right gastroepiploic irrigating pediculus. Sufficient height in the graft and sufficient perfusion flow rate

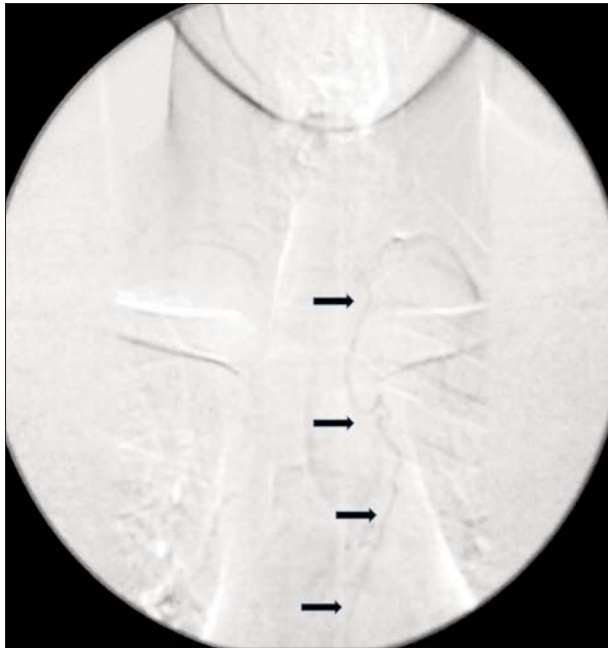


Figure 6. Arteriography scan of the right gastroepiploic irrigating pediculus. Low vascular flow, with hypoperfusion, but with sufficient height in the graft

used experimentally in gastric tubulisations performed on canine subjects indicated severe ischemia of the stomach fundus. It is of interest to note that in humans, i.e., after a significant drop in oxygen pressure post graft construction, its level did not drop anymore even after the cervical elevation.

The supplied data encouraged the surgical teams to use both methods intraoperatively for the vascular assessment of the end prepared for anastomosis, predicting the fistula formation risk. In an attempt to mitigate the effects of acute ischemia during stomach tubulisation, studies were modelled for early, preoperative “adaptation” of the gastric pull-up to ischemia. A significant improvement of the complications rate and, especially, a good quality of anastomosis cicatrization were noticed (31,32) Although there is the possibility of performing a laparoscopic vascular clamping (33-35) approximately 2-3 weeks ahead of surgery preserving the greater curvature arch, the intraoperative radiology method is easier, using selective source embolization of the left gastric artery, the right gastric artery and the right gastroepiploic artery. The

measurements performed on these patients indicated a drop in the vascular flow of approximately 25% (in the 23 to 28 range), compared with 65-69% in patients subject to standard surgery. As for the oximetry level in the study patient population, it remained at an adequate level, without significant drops (under 90 mm ppa O₂). The surgeon’s adaptability to the existing possibilities might render necessary, especially in longiline patients or patients with obvious devascularisations of the new tube’s extremity, an increase in vascular flow using revascularisation techniques. In such cases, the precaution of maintaining a reasonable length of the short gastric vessels’ ends might prove extremely useful. The micro-anastomosis revascularisation of this vascular path will ensure a substantial increase of the blood flow rate (36-38).

By performing a venous anastomosis alone, the blood flow will improve by one third, while by also performing an arterial anastomosis, the vascular flow rate will improve by almost 100 %. The results are clear: lower rates of anastomosis-related complications.

Some extremely modern studies (39) are based on state-of-the-art technology acquisitions that promise, in time, to contribute to very effective assessments for determining vascular conditions. The first such study deals with computer-assisted vascular reconstruction by using the CT and MRI technologies which, besides providing a 3D anatomy determination, allow for morphology and fluids’ dynamics structural assessments. The results of this study create the conditions for specific quantitative hydromechanical assessments, such as the blood-related stress and strain of the vascular wall under different anatomy particularities, with such data being impossible to acquire in vivo using other techniques. A second example is the laser speckle (spot) investigation, a procedure that allows for tissular perfusion determination (40,41). The method is based on the capture of light reflected from tissue structure upon exposure to a certain laser wavelength, with the image acquired presenting as a dark and light speckle (spot) pattern. Any intra-tissue

movement (blood flow) will change that pattern, allowing for perfusion assessment.

Studies comparing this technique with the Doppler laser technique indicate a better resolution for laser speckle imaging, but the wide scale availability of this method is still insufficient at this moment.

A modern method (42-44), although used for a significant period of time for liver function assessments, is using indocyanine green (ICG) to determine perfusion/micro-perfusion in the gastric graft. A bolus injection of 2.5 mg ICG followed by an infrared scan allows for real time determination of the perfusion quality in various areas of the graft, i.e., the areas with a sufficient vascular flow rate vs. those with perfusion deficiency.

Its benefits are, obviously, predictive in nature, therefore mandating amending the surgery by using a procedure that allows for vascular flow augmentation, such as microvascular, carotid or jugular, arterial or venous anastomosis techniques between the graft arch and the cervical pediculi (super-charge or superdrainage) or other convenient sources (45-47).

Other non-surgical (48-51), intermediate, methods were discussed for providing efficient perfusion, using various drugs, such as Prostaglandin E1. There's no sole method used. Others, such as applying the graft and wrapping it in a nitroglycerine-soaked drapes would lead to vasodilatation and lowering the venous congestion; VEGF intake therapies would allow for faster healing and developing new vascularisation sparing us from the risk of ischemia.

Intra- and postoperative conditions and solutions

Teaming with the anaesthesiologist (18) during surgery is also mandatory, so the later can consistently maintain the cardiovascular indicators within the normal range (especially blood pressure, pulse, peripherals' oximetry and Hb), as those are important factors in mitigating the impact of ischemia. Predictive preoperative schemes are described; once

identified, they can be used for risk minimisation (52).

However, despite the numerous precautions and technical artifices used, stomach mobilisation is not spared from the most redoubtable vascular complication, i.e., irreversible ischemia followed by graft necrosis. Such incidents present as two different types, with different solutions and prognoses: (i) focal necrosis and (ii) extensive necrosis (sometimes of the entire substitute), respectively. The etiologic cause, regardless of the extent of the lesion, is arterial or venous insufficiency. The main difference between the two mechanisms, from the occurrence and identification moment's point of view, is that, while arterial ischemia becomes evident most often before the end of the surgery, the venous insufficiency presents a much slower, more insidious development, over several days, with an initial congestion phase, later followed by infraction.

The incidence of the gastric graft necrosis is not to be neglected, as the statistical data (53-55) rarely indicate, even in experienced medical facilities who have performed a large number of reconstructive techniques, lower than 2-digit values (in the vast majority of cases, 5-10%).

An exception is Orringer et al. (56), reporting the lowest graft necrosis rate of 2% (!) over 2000 proprietary stomach reconstruction cases (!), regardless of the indication.

Besides the direct etiologic causes (pedicular vascular ligature) exceptional situations (56,57) were reported, such as azygos vein arch graft strangulation, a sufficient reason for authors to recommend a routine ligature in all cases of transmediastinal elevation.

Therefore, early, intraoperative identification will allow for immediately amending the potential causes: checking the position of the vascular pediculus and of the graft, of the elevation duct sizes, of the graft elongation degree, potential repositioning of the graft in the abdomen monitored for potential recoloration, providing cardiovascular (maintaining blood pressure and pulse) and vasodilating support (58-60). Failure will lead to abandoning reconstruction and a potential later attempt.

Within the immediate postoperative evolution, the alarm for potential necrosis is triggered by the occurrence of inexplicable tachycardia, fever, difficult to manage sepsis, worsened general health, a foetid fluid with a foul smell in the drain tube. The fastest it is identified, the more limited the complication rates are. Some surgeons (61) recommend maintaining a "window" by the cervical end of the incision for regular macroscopic viewing and assessment of the oesophageal substitute.

The surgical resolution of the focal necrosis, while not as redoubtable, complications-wise, might be just as difficult. As previously presented, the area with the highest risk of ischemia is the stomach fundus. Therefore, the alarm for ischemic necrosis might be triggered by the presence of an early anastomosis fistula. If the macroscopic assessment of the graft does not allow for determining the necrotic area, betadine serum lavage and proper draining might be salutary while waiting for cicatrisation. Finding a necrotic area mandates a resection followed, possibly, by a recut with an oesophageal-gastric anastomosis within the same surgery session. If the local and general conditions are unfavourable, the anastomosis shall be delayed for a later moment, with the oesophageal stump extroverted to skin level and the elevated stomach affixed to the SCM muscle to prevent its potential retraction.

An extensive graft necrosis will prove to be just as difficult for the surgeon as it is for the patient. In this case, the elevation path is important. The intrathoracic passage, regardless of the method used, exposes the patient to the highest extent to severe complications and even death. This is the reason why the earliest possible determination of a necrotic evolution is important. Unfortunately, in this case, the only solution is to extract the graft, provide an oesophagostomy, jejunum and parenteral food support, extensive and support antibiotic therapy.

An atypical, intermediate variation of ischemia is the full non-necrotic parietal ischemia, with mucosal ischemia only, accompanied, sometimes, by the non-occurrence of

ischemic lesions, and the occurrence of functional lesions only. In this case, extremely difficult to treat forms of atrophic graft evolutions were described, accompanied by obvious hypermotility and transit discomfort during deglutition.

In conclusion, an ischemic accident is not at all a rare complication, needing to be prevented by all means, by identifying the complication as early as possible and with solutions depending strictly on the lesions' particularities.

Conclusions

The anatomic and vascular particularities of the gastric pull-up are, therefore, the fundament of its visceral availability for oesophageal substitution, in both variants, tubulisation or full stomach. Besides its relatively univocal vascular configuration, ensuring a sufficient flow rate, the stomach also benefits from a series of intraparietal microvascular features providing for a high-quality graft. Providing sufficient graft perfusion is mandatory, as it prevents the risk of postoperative complications such as anastomosis fistulae, anastomosis stenoses or even graft necrosis. Intraoperatively, besides the macroscopic assessment and the bleeding of anastomosis cut performed by the surgeon, the vascular support is relatively easy to validate/invalidate using various techniques. The doubts regarding the gastric perfusion mandate the use of vascular augmentation techniques. If such techniques are not used, the final outcome is uncertain and difficult to correct.

Conflict of Interest

The authors declare that they have no conflict of interest.

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