SURGICAL APPROACHES & ANATOMICAL EVALUATIONS *"MODERN PERSPECTIVES"*

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PREFACE

This book is the result of a comprehensive work that integrates the current state of surgical knowledge, anatomical perspectives and contemporary developments in a coherent manner. Surgical practice is a dynamic field within the medical sciences that requires constant renewal and progress. Accordingly, the compilation of up-to-date information on surgical anatomy and surgical procedures is an essential task for all medical professionals working in this field.

This work not only presents the basic principles, but also addresses advanced concepts and practical applications to help the reader understand potential challenges in surgical procedures. In this way, it helps surgeons and other healthcare professionals to strengthen their clinical skills through a solid theoretical foundation.

Each chapter offers a wide range of content developed through the careful synthesis of knowledge and expertise from respected academics and experienced healthcare professionals. Chapter authors explain surgical procedures and associated anatomical structures in detail, giving readers easy access to the essential information they need during surgery. At the same time, they provide strategic advice on how to deal with unexpected circumstances that may arise.

This comprehensive work is an essential reference for surgeons, medical students and all professionals working in the field of surgery. Covering a broad spectrum from basic surgical principles to complex and advanced procedures, the book reinforces the theoretical background and supports practical, day-to-day surgical activities.

Our sincere thanks go to all the authors who contributed to the preparation of this volume. Each chapter represents a careful integration of original content, academic expertise and practical experience. The aim of this collaboration is to create a permanent reference work for anyone seeking knowledge in the field of surgery.

Finally, it is important to emphasize that the transfer of surgical knowledge requires constant development and updating. We are convinced that this book will be a valuable guide for the education and training of all relevant healthcare professionals. We hope that it will make a lasting, significant contribution to the evolving body of surgical knowledge.

Assoc. Prof. Dr. Turkan DUBUS

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CHAPTER 1

SURGICAL ANATOMY OF THE PANCREAS

Op. Dr. Mahmud MAHMUDOV

INTRODUCTION

The pancreas, which functions as both an endocrine and an exocrine gland, is a retroperitoneal organ that lies behind the stomach and along the posterior abdominal wall, extending horizontally between the duodenum and the spleen. Anatomically, the pancreas is located at the level of the first and second lumbar vertebrae (L1–L2). It has a prismatic structure and measures 12–15 cm in length, 2–3 cm in width and 4–5 cm in height. The pancreas weighs about 70 grams in males and 66 grams in females.

Since the early days of surgical practice, the pancreas has been considered one of the most complex organs to operate on, mainly because of the pancreatic head, where numerous important anatomical structures intersect. A comprehensive understanding of the surgical anatomy of the pancreas has always been an essential prerequisite for a successful surgical procedure (Kahai et al., 2023).

EMBRYOLOGY

The pancreas, which is embryologically derived from the endoderm, develops from the primitive duodenum at the junction of the foregut and midgut by fusion of ventral and dorsal pancreatic buds.

These ventral and dorsal parts (buds) contribute to different regions of the pancreas when they fuse. The ventral bud forms the lower part of the pancreatic head and the spinous process, while the dorsal bud forms the upper part of the head, the body and the tail of the pancreas.

Later, the excretory duct of the dorsal bud unites with the excretory duct of the ventral bud to form the main pancreatic duct (Wirsung duct). The bile duct, which consists of the ventral part, joins the distal end of the main pancreatic duct at the level of the duodenum and flows into the duodenum as a common duct.

If the duct structures of the dorsal and ventral segments do not fuse completely during the embryonic period, an embryological anomaly called pancreas divisum occurs. At this time, the ventral duct, which drains most of the pancreatic parenchyma, opens into the large papilla of the duodenum, while the dorsal duct, which drains about 20 % of the pancreatic parenchyma, opens into the small papilla. Pancreatic divisum is observed in about 2% of the population. Although it does not usually cause significant clinical symptoms, a small proportion of those affected may present with recurrent episodes of pancreatitis or chronic abdominal pain (Gilroy et al., 2021)

GENERAL ANATOMY

The pancreas is usually divided into five parts: the pancreatic head, the uncinate process, the neck, the body and the tail.

Pancreatic head and uncinate process

The head of the pancreas is located in front of the inferior vena cava and the left renal vein and is enclosed by the "C"-shaped curve of the duodenum. The uncinate process is an extension of the lower part of the pancreatic head, which grows medially and surrounds the portal vein from behind. The abdominal aorta is located behind the uncinate process.

The indentation between the uncinate process and the pancreatic body, through which the superior mesenteric artery and the superior mesenteric vein pass, is known as the pancreatic incisura (Figure 1).

In individuals with typical anatomy, the distal part of the common bile duct runs through the upper half of the pancreatic head. The pancreatic duct and the common bile duct merge to form the common bile duct.

Therefore, cancers in the pancreatic head can lead to obstruction of the common bile duct.

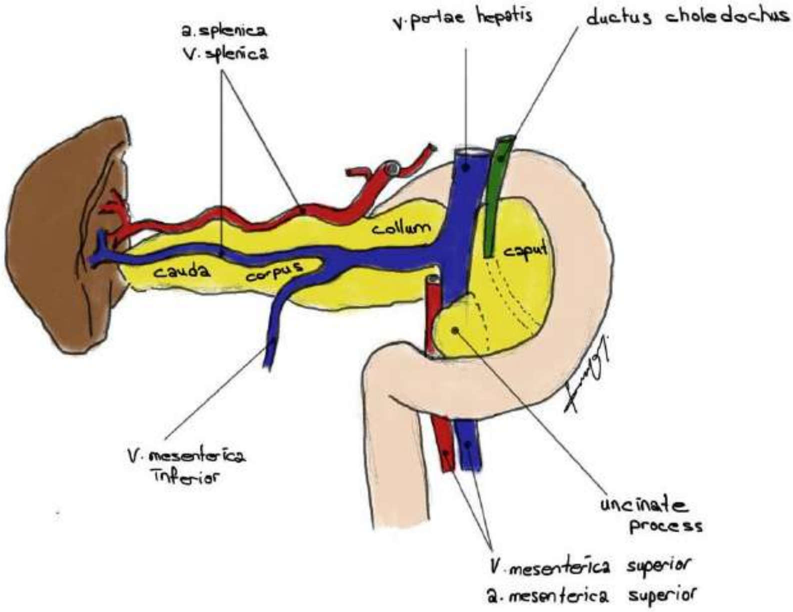

Figure 1. Anatomical structures of the pancreas. The relationship between arterial, venous and biliary structures (Gilroy, 2021).

Pancreatic neck

The pancreatic neck is the smallest part of the pancreas and measures about 1.5-2 cm. The anterior surface, which is covered by the peritoneum, lies next to the pyloric part of the stomach, while the posterior surface is located near the portal vein and the superior mesenteric artery.

Another surgical significance of the pancreatic neck arises during Whipple's operation (pancreaticoduodenectomy), in which it is crucial to determine whether the tumor has invaded the portal vein.

A blunt dissection is performed between the pancreatic neck and the portal vein and the pancreatic neck is mobilized. The transection line is then established and the dissection is continued to the left of this line, separating the main dissection from the surrounding tissues up to the spleen.

Pancreatic body

The pancreatic body has the shape of a triangular prism with an anterior, posterior and inferior surface and an anterior, superior and inferior margin. The pancreatic body is located in front of the bursa and is free of peritoneum on its posterior surface.

Pancreatic tail

The splenic artery and vein run along the posterior surface of the pancreatic tail, which extends towards the spleen and is the narrowest part of the pancreas (Kahai, 2023).

ARTERIAL BLOOD SUPPLY

The celiac artery, which arises from the aorta at the level of vertebrae T12–L1, runs for about 1-1.5 cm before branching into the following branches:

- Common hepatic artery (hepatic artery)
- Left gastric artery
- Splenic artery (Figure 2).

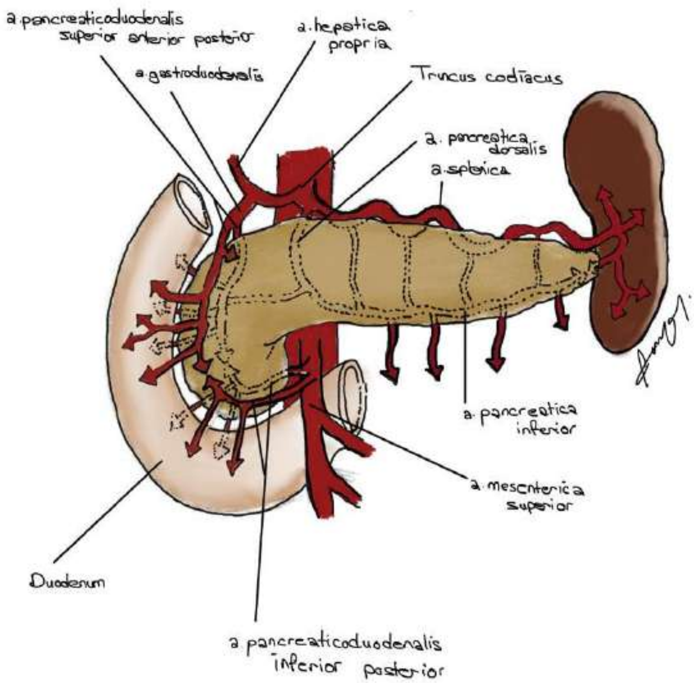

Figure 2. Arterial circulation of the pancreas (Gilroy, 2021).

Common hepatic artery (Arteria hepatica)

The common hepatic artery runs along the upper edge of the head of the pancreas on the right, while the splenic artery leads to the spleen on the left. The common hepatic artery then continues towards the liver and gives off its gastroduodenal branch, one of its two main branches.

The gastroduodenal artery branches into two main branches behind the first part of the duodenum:

- Right gastroepiploic artery
- Upper pancreaticoduodenal artery

Before it joins these branches, the gastroduodenal artery gives off further branches, including the supraduodenal artery and the retroduodenal artery.

The right gastroepiploic artery runs along the greater curvature of the stomach and contributes to the blood supply to the greater curvature of the stomach. The superior pancreaticoduodenal artery (SPDA) supplies the head of the pancreas and the duodenum with blood. It originates from the gastroduodenal artery (GDA) and is divided into two main branches: the superior pancreaticoduodenal artery anteriorly and the superior pancreaticoduodenal artery posteriorly.

The superior pancreaticoduodenal artery gives off 8-10 branches on the anterior surface of the pancreatic head, with the main branch forming an anastomosis with the inferior pancreaticoduodenal artery.

The anterior inferior pancreaticoduodenal artery branches off from the superior mesenteric artery at the lower edge of the pancreatic neck. It can also form a common vessel with the posterior inferior pancreaticoduodenal artery.

Splenic artery:

The splenic artery, one of the three branches of the celiac trunk that arises from the aorta, runs along the body and tail of the pancreas. Its first branch is usually the dorsal pancreatic artery, which branches off to the left into the inferior (transverse) pancreatic artery and usually opens into one of the arterial arches that supply the pancreas.

Vascular anomalies:

The vascular structure of the pancreas, particularly the atypical and non-standard anatomical variations of the arterial vessels, is of critical importance in complex procedures such as pancreaticoduodenectomy.

For example, in 9-15% of cases, the right hepatic artery arises from the superior mesenteric artery (SMA) and not from the actual hepatic artery. This variant, known as the right replacement hepatic artery, carries a higher risk of tumor infestation of the pancreatic head and the uncinate process. The same vessel can also branch off from the right gastric artery in 2% of cases or from the gastroduodenal artery in 6% of cases.

The vascular anomalies occurring during surgery are not limited to the right hepatic artery. The most common anomaly of the common hepatic artery is its origin from the SMA and not from the celiac trunk.

VENOUS DRAINAGE

Venous drainage of the pancreas is supported by four main venous streams which correspond to the arterial supply:

- Suprapancreatic and retropancreatic portal vein
- Infrapancreatic superior mesenteric vein
- Superior mesenteric vein (superior mesenteric vein)
- Venous channel of the spleen

Venous drainage of the pancreatic head: As with the arteries, venous drainage of the pancreatic head and duodenum takes place via four main veins: the anterior superior pancreaticoduodenal vein (ASPD), the posterior superior pancreaticoduodenal vein (PSPD), the anterior inferior pancreaticoduodenal vein (AIPD) and the posterior inferior pancreaticoduodenal vein (PIPD). The ASPD vein drains into the right gastroepiploic vein, which then drains into the colic vein before flowing into the superior mesenteric vein (SMV). The PSPD vein drains from the upper, posterior part of the pancreas into the portal vein. The AIPD and PIPD veins normally drain into the superior mesenteric vein (SMV).

Venous drainage of the neck, body and tail of the pancreas: Venous drainage in these regions is mainly via two main veins: the splenic vein and the transverse pancreatic vein. Some veins that originate from the pancreas in these regions drain directly into the splenic vein, while others drain into the left gastroepiploic vein.

Portal vein:

The portal vein is formed by the union of the superior mesenteric vein and the splenic vein behind the neck of the pancreas. It runs posterior to the pancreas and anterior to the inferior vena cava. The common bile duct lies to the right of the portal vein, while the common hepatic artery lies to the left (Yorganci, 2022).

LYMPH DRAINAGE

The lymphatic drainage of the pancreas is directed from the center outwards (centrifugal). The lymphatic fluid from the pancreatic head drains into several groups of lymph nodes, including the ancreaticoduodenal lymph nodes, the lymph nodes of the hepatoduodenal ligament and the pre- and postpyloric lymph nodes. The entire lymph flow of the pancreas takes the form of a rich perilobular anastomotic network. Due to this extensive lymphatic and vascular system and the retroperitoneal location of the pancreatic cancer, it spreads rapidly.

The lymphatic drainage of the body and tail of the pancreas is directed to the middle colic, hepatic and splenic arteries.

The final lymphatic drainage of the pancreas is directed to the celiac, superior mesenteric, aortic and aortic vena cava lymph nodes.

This extensive lymphatic plexus is generally divided into five main lymph node groups:

- Superior
- Inferior
- Anterior
- Posterior
- Splenic nodes (Figure 3)

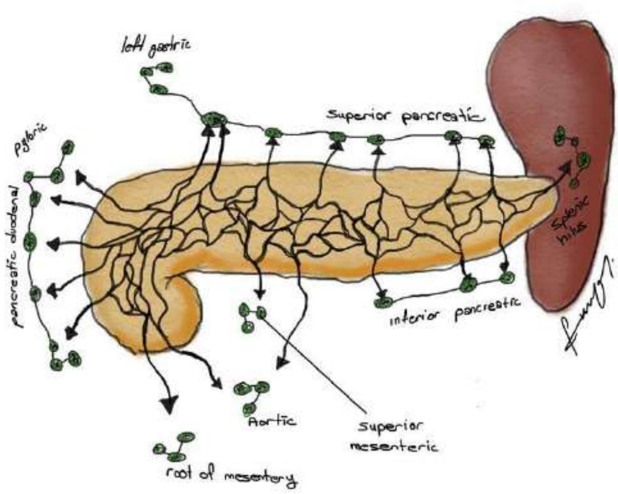

Figure 3. Lymphatic drainage of pancreas (Gilroy,2021).

Upper nodesThe lymphatic trunks from the upper anterior and posterior half of the pancreas end in these nodes. Most of these nodes are located in the suprapancreatic region, with some draining into the lymph nodes of the gastropancreatic fold and hepatic chain.

Inferior nodesThe lower half of the pancreatic head and body drains into the inferior lymph nodes. Most of this group are infrapancreatic lymph nodes, named for their location. Occasionally, one of these trunks may drain directly into the lumbar trunk.

Anterior nodesTwo lymphatic trunks originating from the anterior surface of the upper and lower part of the pancreatic head extend to the pyloric and pancreatic duodenal nodes.

Posterior nodes As the name suggests, these lymph nodes are located in the upper and lower posterior part of the pancreatic head. From here, the lymphatic flow flows into the posterior pancreaticoduodenal lymph nodes, which are crucial for receiving the primary lymph flow from the ampulla of Vater, the common bile duct and the para-aortic lymph nodes.

Splenic nodes Lymphatic trunks originating from the pancreatic tail drain into the splenic hilum, the splenophrenic ligament and the upper and lower lymph nodes of the pancreatic tail (Denk, 2023).

Lymphatic vessels of the pancreas

The lymphatic vessels of the pancreas continue to be an important area of research. In order to perform lymphatic drainage during surgery without increasing morbidity, it is crucial to know the location and variations of the lymphatic trunks and lymph nodes that need to be included in the dissection.

To define the boundaries of the dissection and determine the transection site during surgery, particularly in pancreatic cancer, it is important to understand that the lymphatic drainage of the head and body of the pancreas is different than that of the tail.

Numerous studies have been conducted to clarify the complex lymphatic system of the pancreas. Donatini and Hidden injected dye into various segments of the pancreas and tracked the lymph flow. Their study showed that the body and tail of the pancreas drained towards the spleen and lower pancreatic region. The dye released from the pancreatic head followed one of three pathways:

1. The anterior and posterior lymphatics drain toward the superior mesenteric region;

2. The dye from the anterosuperior segment of the head drains mainly into the gastroduodenal region;

3. The posterosuperior segment of the head drains to the nodes along the common bile duct and the hepatic artery.

Donatini and Hidden also found that the right intercoeliacomesenteric node is the main drainage site for lymph from the pancreatic head. They found no direct connection between the lymph nodes of the pancreatic curvatures and those of the stomach.

The lymphatic drainage is from the pancreas to the duodenum. Although some studies suggest that extensive lymph node resection in advanced adenocarcinoma of the pancreatic head does not significantly affect survival, patients who have more lymph nodes removed during radical surgery live longer than patients with less extensive resections. In another study, histopathologic evaluation of metastatic lymph nodes in pancreatic head cancer specimens showed that dissection including para-aortic lymph nodes contributed significantly to survival (Mukaiya et al., 1998).

Ductal structure

The ductus Wirsung, the main duct of the pancreas, begins at the tail and opens into the duodenum via the ampulla Vater. This duct normally runs along the midline near the posterior pancreatic parenchyma, curves downward in the head and empties into the common bile duct before draining into the duodenum. Around 20 side branches open into this main duct, which maintains a pressure of 15-30 mmHg, which is higher than that of the common bile duct (7-17 mmHg). This pressure gradient prevents the bile from flowing back into the common bile duct. In addition, the sphincter of Oddi, located in the ampulla of Vater, plays an important role in preventing reflux.

Another critical structure is the ductus Santorini, which opens into the duodenum at the lesser papilla, which is located approximately 2 cm proximal to the common bile duct. The position of the small papilla is determined by the gastroduodenal artery located directly in front of it. Especially during gastrectomy, a dissection involving the gastroduodenal artery can lead to injury to the small papilla (Yamane, et al., 2023)

Nerve network

The nerve network of the pancreas is just as branched as the vascular and lymphatic system. Understanding the origins of the sympathetic and parasympathetic nerve fibers in the pancreas is essential, particularly for diagnosing the source of pain in tumor invasion. However, the exact source of pain in pancreatic diseases associated with invasion, inflammation or increased ductal pressure remains unclear. For this reason, blockade of the celiac plexus is currently the only effective method of pain relief.

The sympathetic fibers of the pancreas originate from the thoracic splanchnic nerves T6-T10 and the celiac plexus, while the parasympathetic fibers originate from the posterior vagal truncus (Yasin, 2010).

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CHAPTER 2

CLINICAL SIGNIFICANCE OF THE TRACHEA: STRUCTURE, FUNCTION, AND DISEASES

Dr. M. Ali UNAL

Dr. Senol MERTOGLU

Assoc. Prof. Dr. Turkan DUBUS

1. INTRODUCTION

The trachea plays an important role in the passage of air, as it is the main route by which inhaled air enters the lungs (Ball et al., 2023). This tubular structure, which extends from the larynx to the main bronchi, serves as the main conduit for the flow of respiratory air. The anatomical structure, histology and physiology of the trachea are of paramount importance not only for the maintenance of airway health, but also for various medical procedures such as tracheotomy and endotracheal intubation.

This section provides a comprehensive overview of the general features of the trachea, its anatomical structure, histologic layers, vascular and neural innervation, functional significance, and clinical relevance. The aim is to provide a detailed, academic view suitable for healthcare professionals and clinicians.

2. GENERAL CHARACTERİSTICS OF THE TRACHEA

The trachea is the part of the respiratory system that begins immediately after the larynx and branches into the two main bronchi (Downey & Samra, 2023). In an average adult, the trachea is about 10-12 cm long and has a diameter of 2-2.5 cm. This structure serves as an important conduit for the safe transportation of inhaled air to the lungs.

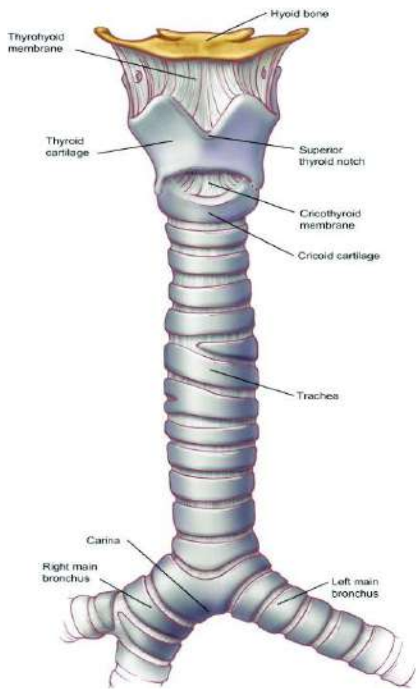


Figure 1. Anterior view of the trachea (Furlow, P., & Mathisen., 2018).

Anatomically, the trachea extends from the lower part of the neck to the upper part of the chest cavity. It lies centrally in the mediastinum, in front of the esophagus and behind the thyroid gland, the large vessels and other vital neck structures. This location is important for its role in breathing and for its accessibility during medical procedures such as tracheotomy or endotracheal intubation.

The trachea begins at the level of the lower cervical vertebra (C6), directly under the cricoid cartilage of the larynx, and runs downwards. It branches at the level of the T4-T5 vertebrae (carina) into the right and left main bronchi (Amador et al., 2023)..

On the surface, the trachea is surrounded by several important structures that provide protection and structural support:

- Anterior: the trachea is bordered by the thyroid gland, sternum and thymus gland (Figure 1).
- Posterior: The esophagus is located directly behind the trachea and forms a close anatomical connection.
- Lateral: The carotid arteries and the vagus nerves are located on both sides of the trachea.

These surrounding structures play a crucial role in determining the anatomical location of the trachea in a well-protected and safe region of the neck and chest. This strategic location is crucial for the stability of the airway and the protection of the trachea from external mechanical forces. The proximity to vital vascular and nerve structures also emphasizes the clinical importance of precise anatomical knowledge, especially during procedures such as tracheotomy and thyroidectomy, where accidental injury to these structures can lead to serious complications.

3. ANATOMICAL STRUCTURE OF THE TRACHEA

The trachea essentially consists of four main structural components: the fibrous-cartilaginous framework, the mucosal layer, the submucosa and the muscle and elastic tissue (Figure 2).

- **Fibrocartilaginous scaffold:**

This scaffold forms the supporting skeleton of the trachea and is characterized by hyaline cartilaginous rings and membranous tissue in the posterior region. The hyaline cartilage rings provide structural rigidity and prevent the airway from collapsing during breathing, while the posterior membranous part provides flexibility and interaction with the esophagus.

- **Mucosal layer:**

The innermost lining of the trachea, the mucosal layer, is covered with pseudostratified, columnar ciliated epithelium. This layer plays a crucial role in the mucociliary clearance mechanism, which facilitates the removal of inhaled particles, microorganisms and debris from the airways. The coordinated action of the cilia pushes the mucus upwards towards the throat, where it can be swallowed or coughed up.

- **Submucosal layer:**

The submucosal layer is located under the mucosa and consists of elastic fibers, blood vessels, nerves and mucous glands. The submucosa maintains the moisture of the mucosa and increases the flexibility of the tracheal wall. The secretions of the mucous glands contribute to the formation of a protective mucus layer that supports mucociliary clearance.

- **Muscles and elastic tissue**:

The tracheal muscle (a smooth muscle) and elastic fibers are located at the back of the trachea, where they form the membranous wall. This muscular and elastic structure allows changes in the tracheal diameter so that the trachea can contract or expand according to physiological requirements. This arrangement also facilitates the expansion of the esophagus during swallowing.

Together, these four essential components of the trachea enable it to maintain airway patency, resist ambient pressure and balance the movement of the esophagus during swallowing. Their functional integration enables efficient ventilation, protection against pathogens and support during clinical procedures such as intubation and tracheostomy.

3.1. External structure: tracheal rings

The trachea is composed of horseshoe-shaped hyaline cartilage rings that provide both flexibility and structural integrity. Each ring is "C"-

shaped, with the open portion located in the posterior region where it is covered by a membranous wall. This anatomical arrangement allows the esophagus to expand and enable the passage of food during swallowing.

The tracheal rings are important in maintaining the structural integrity of the trachea and ensuring that the airway remains permeable (open). Normally, the human trachea contains 16 to 20 hyaline cartilage rings, each forming a horseshoe-shaped structure. This configuration improves the flexibility and elasticity of the trachea and prevents the airways from collapsing when pressure changes, such as when breathing or coughing.

The posterior part of each tracheal ring is connected by the trachealis muscle, a smooth muscle that plays an important role in the flexibility of the tracheal wall. This muscle facilitates the expansion of the esophagus during swallowing and thus enables the passage of food. In addition, the trachealis muscle can contract to narrow the lumen of the trachea, which can increase the force of airflow when coughing and thus facilitate the removal of mucus or foreign bodies.

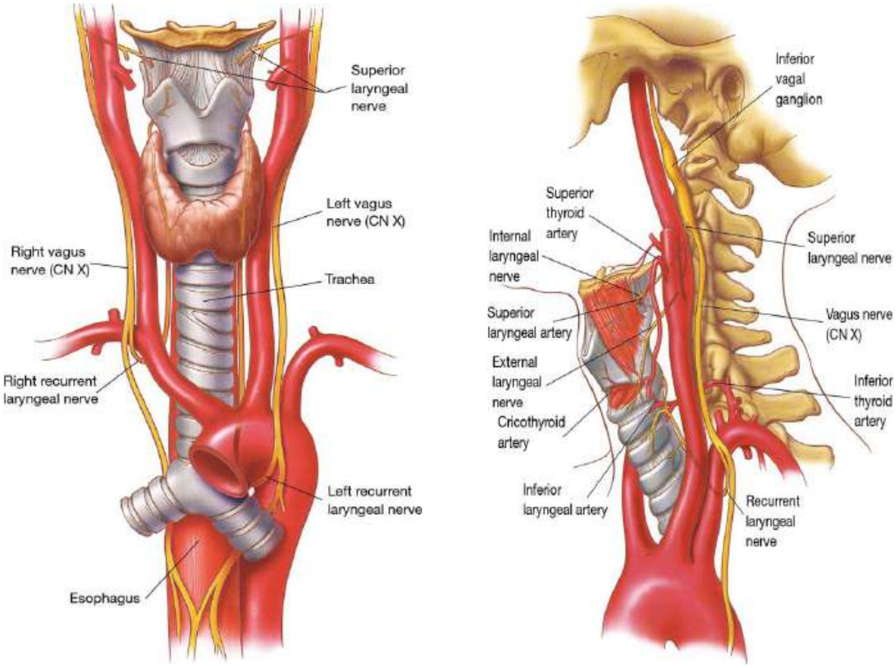


Figure 2. Anterior and lateral views of the trachea and its anatomical relationships (Drevet et al., 2016)

4. HISTOLOGICAL STRUCTURE OF THE TRACHEA

The trachea consists of four different layers:

4.1. Mucosa (innermost layer)

The inner surface of the trachea is lined with pseudostratified, columnar ciliated epithelium (De Rose et al., 2018). This epithelial structure plays a crucial role in the defense mechanisms of the respiratory system. It facilitates the function of the mucociliary clearance system, which helps to remove dust, microbes and other foreign particles from the airways.

The mucosal layer contains goblet cells, which are responsible for mucus production. The mucus secreted by these cells traps inhaled particles and pathogens so that they can be expelled or swallowed. This mechanism ensures that the air entering the lungs is cleaner and free of irritants. The mucociliary clearance system is a fundamental part of the body's immune defense against respiratory infections and protects against inhaled pathogens and pollutants in the air.

4.2. Submucosa (second layer)

The submucosa is an important structural layer of the trachea that contains elastic fibers, blood vessels, nerves and mucous glands. This layer increases the flexibility and elasticity of the trachea so that it can expand and contract during breathing.

The mucous glands (glandulae tracheales), which are located in the submucosa, secrete mucus that keeps the mucosal surface moist. This moisture supports the healthy function of the epithelial cells and improves the effectiveness of the mucociliary clearance system. the submucosal layer also contains blood vessels that supply nutrients to the tracheal tissue and nerve fibers that mediate sensory and autonomic control of tracheal functions. This layer plays a crucial role in maintaining the functional integrity of the trachea and ensuring its resilience to external environmental factors.

4.3. Fibrocartilaginous layer (middle layer)

The fibrocartilaginous layer is a fundamental component responsible for maintaining the structural integrity of the trachea and ensuring that the airways remain open. It consists of tracheal cartilage rings and a posterior membranous structure.

The tracheal cartilage rings are made of hyaline cartilage and are shaped like a horseshoe or the letter "C" (Rehman et al., 2023). These rings ensure that the trachea remains open by supporting the structure and counteracting collapse due to changes in internal or external pressure. The rigidity and flexibility of these cartilage rings prevent the trachea from narrowing during inhalation and exhalation or due to mechanical pressure from outside.

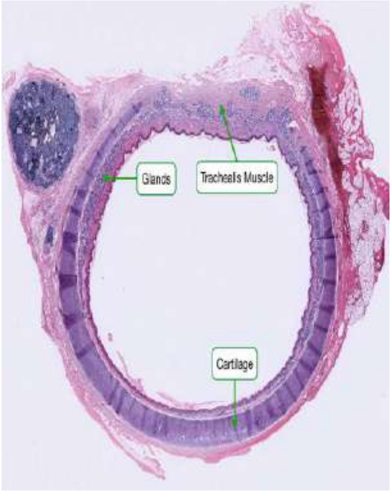
At the back of the trachea, where the cartilage is missing, there is a membrane-like wall. This membrane consists of elastic fibers and smooth muscle (tracheal muscle). The tracheal muscle is flexible and allows the esophagus to expand into the tracheal space when swallowing food or liquids. the tracheal muscle can also contract to reduce the diameter of the tracheal lumen, which increases the speed of airflow when coughing and facilitates the expulsion of mucus or foreign bodies.

This layer is critical to the trachea's ability to maintain airway patency while adapting to pressure changes and interactions with the esophagus.

4.4. Adventitia (outer layer)

The adventitia is the outermost layer of the trachea and consists of loose connective tissue. This layer acts as a connecting structure and anchors the trachea to the surrounding anatomical structures. It maintains the position of the trachea in the neck and chest and allows easy movement when breathing, swallowing and moving the head and neck.

The adventitia surrounds and supports important structures such as blood vessels, nerves and lymphatic vessels that run along the trachea. This layer provides a flexible yet stable connection between the trachea and adjacent tissues, including the thyroid gland, esophagus and major vessels such as the carotid artery and jugular veins. Its task is to maintain the anatomical stability of the trachea and protect it from displacement or pressure caused by movements of the neck or chest (Figure 3.a., b.).



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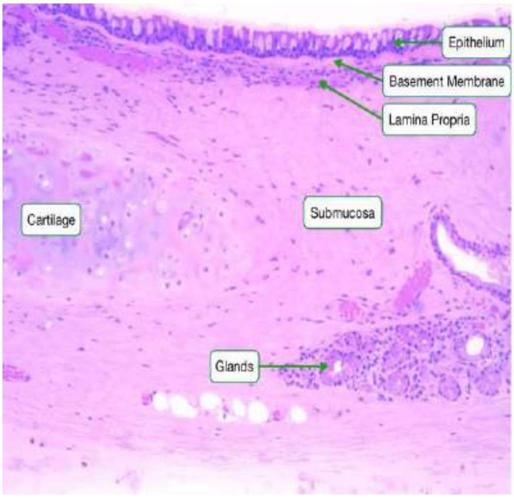

(b)

Figure 3. (a). The trachea links the larynx to the primary bronchi and is supported by cartilaginous rings. **(b).** The tracheal wall is composed of ciliated pseudostratified epithelium, cartilage, and glands.

(Yale Team-Based Learning. (n.d.). ***Histology of the respiratory system lab*****. Retrieved from**

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5. BLOOD CIRCULATION AND LYMPHATIC SYSTEM

The vascular structure of the trachea ensures good blood circulation and facilitates the immune response through the lymphatic system (De Rose et al., 2018).

5.1. Arterial supply

The arterial supply to the trachea is provided by branches of the thyroid arteries and the upper branches of the bronchial arteries. One of the most important arteries responsible for the blood supply to the trachea is the inferior thyroid artery (A. thyroidea inferior). This artery supports the blood supply to the upper part of the trachea and ensures the supply of oxygen and nutrients to the tissue in this area.

In addition, the upper branches of the bronchial arteries supply the lower sections of the trachea. These arteries supply the tissues in the lower sections of the trachea with oxygen-rich blood, maintain metabolic activity and support cell function. This dual arterial system ensures continuous and adequate blood flow along the entire length of the trachea and plays a crucial role in maintaining the structural integrity and functional viability of the tracheal tissue.

5.2. Venous drainage

Venous drainage of the trachea occurs via the brachiocephalic vein, the internal jugular vein and the thyroid veins. This system enables the efficient return of deoxygenated blood from the tracheal tissue to the central circulation.

The venous blood collected from the trachea flows into the brachiocephalic vein, which serves as the main venous line for the return flow of deoxygenated blood into the superior vena cava. The internal jugular vein and the thyroid veins also play an important role in this drainage process. These veins collect metabolic waste products and carbon dioxide from the tracheal tissue and ensure proper removal and drainage from the respiratory system. This efficient venous drainage is essential for maintaining metabolic balance and oxygenation of the trachea and surrounding tissues.

5.3. Lymphatic drainage

Lymphatic drainage of the trachea is provided by the paratracheal and pretracheal lymph nodes. These lymph nodes collect the lymphatic fluid from the trachea and play an important role in the immune defense of the respiratory system.

- Paratracheal lymph nodes are located on the sides of the trachea.
- The pre-tracheal lymph nodes are located in front of the trachea.

These lymph nodes serve as filtration sites where lymph fluid is processed to remove pathogens, foreign particles and cellular waste. The immune cells in these lymph nodes, such as macrophages and lymphocytes, identify and eliminate harmful microorganisms. This drainage system is crucial for protecting the trachea from respiratory infections and serves as an essential part of the body's defense system.

By filtering and processing the lymphatic fluid, the paratracheal and pretracheal lymph nodes provide additional protection against respiratory pathogens and ensure that the air entering the lungs is free of harmful particles. This mechanism also plays a role in the immune response to infections and in the metastasis of respiratory cancers, as abnormal cells can be trapped and processed in these lymph nodes.

6. NEURAL INNERVATION

The neural control of the trachea is regulated by the autonomic nervous system, which comprises both parasympathetic and sympathetic innervation.

- **Parasympathetic innervation:**

The parasympathetic innervation of the trachea is carried out by the vagus nerve (cranial nerve X) (Mieczkowski et al., 2023). The vagus nerve stimulates the contraction of the tracheal muscles, which leads to a narrowing of the airways. It also increases mucus secretion from goblet cells and submucosal glands. This increased mucus production supports the mucociliary clearance mechanism, which facilitates the trapping and removal of foreign bodies, pathogens and debris from the airways.

- **Sympathetic innervation:**

Sympathetic innervation is mediated by the truncus sympathicus. Activation of the sympathetic nervous system causes the smooth tracheal muscles to relax, which leads to a widening of the airways. This dilation increases the diameter of the trachea so that a larger volume of air can flow through, which is particularly important during physical exertion or stress, when the oxygen requirement is higher.

The balance between parasympathetic and sympathetic innervation allows the trachea to maintain an appropriate airway tone that ensures efficient air conduction and adaptation to environmental changes or physiological demands such as coughing, swallowing and movement.

7. FUNCTIONS OF THE TRACHEA

The trachea performs several vital functions in the respiratory system by providing effective airflow, protection and participation in immune defense. The most important functions are as follows:

- **Air supply:**

The trachea serves as the primary airway for the transfer of inhaled air from the larynx to the main bronchi, allowing a continuous flow of air to and from the lungs.

- **Mucociliary clearance:**

The trachea is lined with pseudostratified ciliated columnar epithelium and mucus-producing goblet cells. This system supports the mucociliary clearance mechanism, in which the coordinated action of the cilia moves mucus together with trapped dust, pathogens and foreign particles upwards towards the pharynx to be swallowed or expelled. This process plays a crucial role in the defense of the airways.

- **Role in voice production:**

While the trachea does not directly produce sound, it facilitates the passage of air through the larynx, where the vibration of the vocal cords produces sound, contributing to phonation.

- **Protection:**

The C-shaped hyaline cartilage rings provide rigidity and prevent the trachea from collapsing in the event of negative pressure during inspiration. These rings protect the trachea from external trauma and ensure a continuous flow of air.

These functions emphasize the essential role of the trachea in respiration, airway protection and immune defense, as well as its indirect contribution to voice production.

8. CLINICAL MEANING

The trachea is involved in several clinically significant conditions that may require medical or surgical intervention. These conditions include trauma, stenosis, obstruction, congenital anomalies and tumors.

8.1. Trauma to the trachea

Trauma to the trachea is a serious condition typically caused by penetrating or blunt trauma such as stab wounds, gunshot wounds, or automobile accidents. Trauma to the trachea can disrupt the structural integrity of the trachea and impair airflow.

Clinical signs of tracheal trauma include:

- Subcutaneous emphysema (air trapped under the skin)
- Hemoptysis (coughing up blood)
- Swelling of the throat and difficulty breathing

The treatment approach depends on the severity and extent of the injury. Mild cases can be treated with surgery, while severe injuries may require a tracheotomy to secure the airway. A tracheotomy is a surgical procedure in that an airway is created directly through the windpipe to restore airflow. Early recognition and rapid intervention are crucial to prevent airway obstruction and ensure the patient's survival.

8.2. Tracheal stenosis

Tracheal stenosis is a narrowing of the tracheal lumen that can be partial or complete and causes significant airway obstruction (Wang & Tian, 2022). The most common causes of tracheal stenosis include:

- Prolonged endotracheal intubation
- Infections
- Granulomatous diseases (e.g. tuberculosis, sarcoidosis) (Figure 4).

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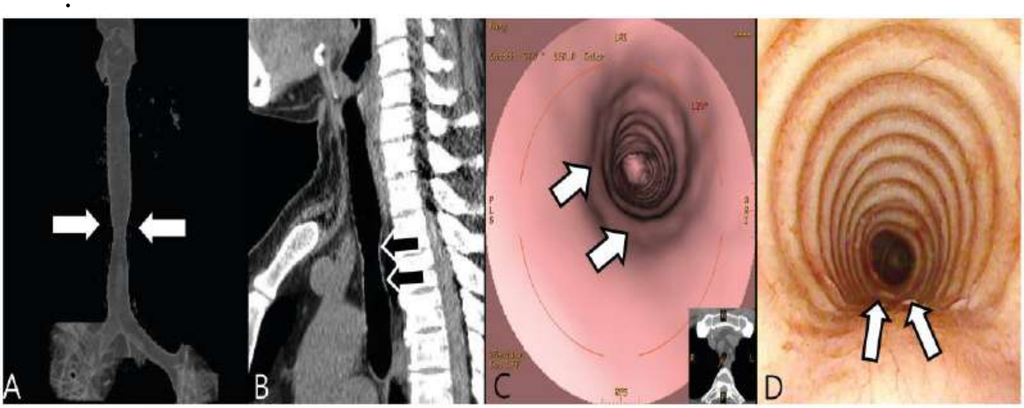

Figure 4. Virtual chest CT and bronchoscopic images

(A) 3D volume rendering shows tracheal stenosis.
(B) Sagittal CT reveals cartilaginous undulation in the posterior tracheal wall.
(C) Virtual CT-bronchoscopy displays complete tracheal rings at the stenotic site (arrows).
(D) Conventional bronchoscopy confirms the presence of complete tracheal rings (Song et al., 2020).

The clinical signs include:

- Dyspnoea (shortness of breath)
- Stridor (high-pitched, wheezing sound)

Treatment options include:

- Balloon dilation: a balloon catheter is inserted and inflated to widen the narrowed section of the trachea.
- Surgical resection: In severe cases, the affected segment is surgically removed and the healthy ends of the trachea are sutured back together.

Early detection and treatment is crucial to prevent airway obstruction and respiratory distress(Wang & Fan, 2023). .

8.3. Tracheotomy and tracheostomy

A tracheostomy is a surgical procedure in which an opening is made in the windpipe to create an alternative airway. If this opening is maintained in the long term with a tracheostomy tube, it is referred to as a tracheostomy.

Indications for a tracheotomy/tracheostomy:

- Obstruction of the airway (e.g. trauma, stenosis)
- Long-term mechanical ventilation
- Severe breathing difficulties

Although a tracheostomy can improve oxygen supply and ventilation, it also carries the risk of complications such as:

- Infection
- Tracheoesophageal fistula (abnormal connection between the trachea and esophagus)
- Stenosis (narrowing of the tracheal lumen)

Proper care, monitoring and cleaning of the tracheostomy tube is essential to avoid complications and ensure long-term respiratory support.

8.4. Tracheal tumors

Tracheal tumors are rare but clinically significant .(Handa et al., 2016) The two most common types of tracheal tumors are:

- Squamous cell carcinoma (originating from epithelial cells)
- Adenoid cystic carcinoma (originating from glandular structures)

The clinical signs include

- Chronic cough (often mistaken for a respiratory infection)
- Stridor (wheezing sound when breathing)
- Hemoptysis (coughing up blood)

Treatment options:

- Surgical resection (removal of the tumor)
- Radiotherapy
- Chemotherapy

Early detection and treatment is crucial for improving the prognosis and survival rate of patients with tracheal tumors (Mukkamalla et al., 2023).

8.5 Foreign bodies in the trachea

A foreign body in the trachea is an object that accidentally enters the airway and blocks it partially or completely. This is most common in children and elderly patients. Common objects include food particles (e.g. nuts, seeds) and small toy parts.

Clinical signs:

- Sudden breathing difficulties
- Coughing and choking
- Stridor and cyanosis (bluish discoloration of the skin)

Emergency management includes:

- Heimlich maneuver (to expel the foreign body)
- Bronchoscopy (to visualize and remove the foreign body)

Rapid action is essential to prevent complete airway obstruction and ensure the patient's survival.

8.6 Congenital anomalies

Congenital anomalies of the trachea are due to abnormal development of the trachea during embryogenesis. The two most common anomalies are:

- Tracheoesophageal fistula (abnormal connection between the trachea and the esophagus) (Salik et al., 2023).
- Tracheal atresia (absence or complete blockage of part of the trachea)

These anomalies cause severe respiratory distress in newborns and require urgent surgical correction. Early diagnosis and early intervention are essential to improve the chances of survival (Song et al., 2020).

9. CONCLUSION

The trachea plays a crucial role in air conduction, airway protection and mucociliary clearance. Its anatomy and clinical relevance are fundamental to the understanding and treatment of airway diseases such as trauma, stenosis, foreign body aspiration and tumors. Familiarity with tracheal pathologies and emergency management techniques is essential for medical staff to maintain airway patency and ensure patient survival.

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CHAPTER 3

SURGICAL TREATMENT OF TRACHEOESOPHAGEAL FISTULAS

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INTRODUCTION

A tracheoesophageal fistula (TEF) is a pathological connection between the respiratory and digestive systems. It can be either congenital or acquired. Congenital TEFs are due to abnormalities in the development of the esophagus, while acquired TEFs are rare conditions that have either benign or malignant causes. Compared to malignant TEFs, benign TEFs are less common, with 75% being due to trauma related to prolonged mechanical ventilation with an endotracheal cuff. The most common cause of malignant TEFs is malignant disease of the esophagus. TEFs can affect the lungs or the mediastinum.

Most malignant TEFs develop spontaneously due to tumor invasion. However, they can also develop due to complications related to radiotherapy, surgery, chemotherapy, laser treatments, instrumentation or tissue necrosis from previously implanted stents. Other tumors that can cause TEFs include, albeit to a lesser extent, malignancies of the mediastinal lymph nodes, thyroid cancer and laryngeal cancer.

The primary goal in treating patients with acquired TEF is to first differentiate between benign and malignant causes. Many of these patients are treated palliatively with stents in the trachea or esophagus due to advanced malignant disease. Other treatment options include chemotherapy, radiotherapy, surgery and other methods of fistula closure.

For benign TEFs, treatment is usually supportive and surgical. The surgical approach varies depending on the size and location of the fistula. The general strategy includes repair or resection of the tracheal defect and primary repair of the esophageal defect (Kim et al., 2021).

HISTORY

Prior to the 1960s, TEF was observed following trauma or granulomatous disease. The first case of TEF caused by an endotracheal tube balloon was reported by Flege in 1967 (Flege, 1967). In 1972 and 1973, Thomas published a series of studies with 46 cases of TEF after intubation and reported that most cases were related to the cuff of the tracheostomy tube (Thomas, 1972, 1973). However, surgical treatment attempts by both Flege and Thomas were unsuccessful.

The first significant step in the surgical treatment of TEF was taken by Grillo, who developed a more effective technique. Grillo identified the pathologic segment of the trachea associated with the fistula and closed the esophageal defect through a single cervical exploration with double-layered sutures. He also resected the tracheal segment involved in the fistula (Grillo et al., 1976).

ETIOLOGY

Acquired benign TEF can occur for various reasons, e.g. as a complication after tracheal or esophageal stenting, mechanical ventilation, tracheal or esophageal surgery, granulomatous mediastinal disease, trauma or iatrogenic factors such as ingestion of corrosive substances. Excessive inflation of the cuff of endotracheal tubes or tracheostomy tubes can lead to necrosis of the posterior wall of the trachea. Other risk factors favoring the development of TEF are the presence of a nasogastric tube, excessive movement of the endotracheal tube, the use of steroids, diabetes mellitus and immunodeficiency (Koch et al., 2022).

In esophageal surgery, aggressive lymph node dissection, postoperative anastomotic leakage or airway ischemia can also lead to the formation of TEFs. When TEFs are associated with malignant disease, they may result from direct tumor invasion or from complications related to chemotherapy and radiotherapy.

Radiotherapy increases the risk of esophageal perforation as it causes esophagitis, vasculitis, ischemia and ulceration in the esophagus (Table 1) (Salik et al., 2024).

Table 1: Etiologic causes of acquired TEF.

Malignant Causes	Iatrogenic Cause	Other Causes
• Esophageal cancer	• Tracheal tubes and intubation	• Blunt or penetrating trauma
• Tracheal cancer	• Esophageal stents	• Granulomatous infections
• Laryngeal cancer	• Tracheal and esophageal endoscopy	• Previous surgery on the esophagus or trachea
• Thyroid cancer	• Transesophageal echocardiography	• Ingestion of corrosive substances
• Lung cancer	• Percutaneous tracheostomy	• Toxic inhalation injuries
• Hodgkin's lymphoma		• Ingestion of alkaline batteries
• Non-Hodgkin's lymphoma		• HIV infection

Excessive flexion of the neck, kinking of the endotracheal tube, rigid suctioning and inflation of the cuff of the endotracheal tube at high pressure can lead to necrosis of the trachea, which may result in delayed development of TEF. If the cuff pressure of the endotracheal tube exceeds the perfusion pressure of the mucosa, this can lead to ischemia, necrosis and damage to the tracheal wall. In addition, the use of thick and rigid nasogastric tubes can exacerbate this condition as they injure the posterior tracheal wall and anterior esophageal wall and further accelerate the development of TEF.

In the intensive care unite (ICU), regular monitoring of cuff pressure is crucial to avoid complications. Maintaining cuff pressure below 20 mmHg and stabilizing cuff volume between 6–8 ml may help to reduce the risk of such injuries and prevent the development of TEF (Sandosham, 2018).

Advances in the quality of endotracheal tubes, tracheostomy tubes and nasogastric tubes, as well as improvements in mechanical ventilation, have reduced the incidence of benign TEFs from 70% to 47% (Spaander et al., 2021) .

DIAGNOSIS

Common clinical symptoms of TEF include severe coughing after fluid ingestion, a feeling of choking, recurrent lung infections and dysphagia (difficulty swallowing). In intubated patients being monitored in the ICU, TEF should be suspected if there is an increase in tracheal secretions, aspiration of gastric contents through the endotracheal tube, air leakage or abdominal distension.

In such cases, food particles, saliva or gastric acid entering the airway can cause pneumonia and, in some cases, sepsis (Puma et al., 2017).

Figure 1. Chest computed tomography (CT) scan of a patient diagnosed with a TEF, taken after a tracheostomy.

On a chest radiograph, esophageal dilatation at the distal end of the TEF and the presence of pulmonary infiltrates may indicate aspiration pneumonia. Oral contrast-enhanced and 3D reconstructed chest CT can provide detailed information about the fistula and any associated malignant tumors. Contrast agents have a diagnostic accuracy of approximately 70% in identifying TEFs and provide information on the location and size of the fistula (Figure 1).

Figure 2. Endoscopic view of the proximal esophagus showing the presence of a fistula during esophagoscopy.

Endoscopic methods such as bronchoscopy and esophagoscopy are also very effective for preoperative assessment and surgical planning. If the mucosa appears red and edematous on esophagoscopy, small fistulas may be missed. Methylene blue can be introduced into the esophagus for better detection, and the trachea can be examined by bronchoscopy. Bronchoscopy allows a thorough examination of the entire trachea and bronchial branches, and lavage samples can be taken for culture analysis (Figure 2) (Zeng et al., 2024).

In ICU patients, TEF is usually diagnosed while the patient is still on mechanical ventilation. Bronchoscopy can be used as an adjunct to tracheostomy to avoid potential complications.

TEF LOCALIZATION

In patients with a tracheostomy, the fistula usually occurs a few centimeters distal to the tracheostomy site, at the point where the inflated cuff of the cannula comes into contact with the trachea. Approximately 70% of malignant TEFs occur in the middle part of the esophagus, while 17% are found in the proximal esophagus. TEFs that develop in the distal esophagus tend to have a longer survival prognosis (Koo et al, 2024).

FIRST STEPS IN THE TREATMENT OF TEF

Once the diagnosis of TEF is confirmed, the primary goal is to stabilize the patient, stop oral intake and control aspiration to prevent the development of pulmonary sepsis.

For patients receiving mechanical ventilation, an adjustable tracheostomy tube or endotracheal tube should be positioned so that the cuff is distal to the fistula site. This procedure should be performed under the guidance of fiberoptic bronchoscopy to ensure accuracy.

To minimize gastroesophageal reflux, the head end of the bed should be elevated and aspiration should be performed through the nasogastric tube to draw air from the stomach. A gastrostomy or jejunostomy should be placed as soon as possible to ensure nutrition and reduce reflux. The nasogastric tube should be removed immediately to prevent further enlargement of the fistula. In addition, regular antibiotic therapy, intermittent bronchoscopic examinations and lavage should be performed to prevent the development of aspiration pneumonia (Kainth et al., 2021).

1. BENIGN TEFs

Spontaneous healing of benign TEFs is extremely rare and surgical treatment is considered the only definitive solution. Surgical intervention should be performed after a careful clinical and endoscopic examination. Patients with benign TEFs often experience complications such as infection, recurrent pneumonia, malnutrition, renal failure, neurological symptoms, the need for mechanical ventilation and tracheal stenosis. As a result, surgical approaches and planning may vary depending on the patient’s condition.

In many cases, tracheal or esophageal stents are used to temporarily close the fistula, prevent the passage of air and fluid and allow oral intake. However, esophageal stents can lead to complications such as bleeding, stent migration, rupture, narrowing or even the formation of a new fistula due to trauma when the stent is removed. It is therefore usually recommended to remove the stents after 6-8 weeks. Some experts argue that instead of stent implantation, early surgery should be performed as soon as the patient is stable. Studies suggest that surgery leads to better outcomes in patients with benign TEFs who are not dependent on mechanical ventilation (Poincloux et al., 2016).

Surgical treatment

Surgical treatment is a highly effective method of treating benign TEFs, although it is associated with a higher risk of morbidity and mortality compared to surgery for malignant TEFs. The complication rate is between 32% and 56%. The most common problems include tracheal dehiscence, esophageal leakage, anastomotic complications (e.g. recurrence), hoarseness, wound infections and pneumonia.

Despite these risks, advances in surgical techniques have significantly improved outcomes. The mortality rate associated with TEF surgery has fallen from around 10% to 2.8% in recent years. After the operation, around 83% of patients can be fed orally again and 71% can breathe without a tracheostomy tube.

Although it is not always possible to completely prevent benign TEF, surgical treatment offers an effective way of correcting the condition and improving the patient's quality of life (Alkrekshi & Bukamur, 2020).

2. MALIGNANT TEFs

Malignant TEFs usually develop as a pathological complication after the treatment of inoperable malignant tumors at an advanced stage. The main aim of treatment is to restore normal swallowing and breathing function. If left untreated, patients with malignant TEFs have a life expectancy of only 1 to 6 weeks. Non-surgical treatment options include stenting, radiotherapy and chemotherapy, but it is unclear whether these approaches have a significant impact on survival. Due to the high recurrence rate of malignant TEFs, primary repair is not usually performed. Instead, the main surgical procedures are esophageal bypass and esophageal exclusion (Amore et al., 2024; Feng et al., 2021).

In patients requiring major surgery, esophageal bypass may be performed to prevent airway contamination and allow oral intake. In these cases, the affected segment of the esophagus is isolated by blocking it at both the proximal and distal ends. To maintain gastrointestinal function, a substernal gastric, colonic or jejunal bypass is connected to the proximal part of the blocked esophageal segment. Esophageal exclusion is considered a radical surgical procedure. In cervical esophageal resection, the distal end of the esophagus is closed and the proximal end is brought to the skin surface as a stoma. As oral nutrition is no longer possible, a gastrostomy must be created to ensure nutrition.

Due to advances in palliative medicine, these aggressive surgical procedures are rarely performed today. Fistulotomy is considered an extremely aggressive approach as it requires resection of both the esophagus and the airway (Feng et al., 2021; Fernandes et al.,2023).

a. Treatment approaches

There is no standardized treatment protocol for TEF. However, certain steps are generally followed in all patients. Stabilization of the patient, prevention of pulmonary aspiration and isolation of the fistula from the airway should be the first priorities. Once these immediate measures have been taken, the appropriate treatment is selected based on the patient's general condition, medical history and the characteristics of the fistula. Surgery is considered the gold standard in the treatment of TEF. In most cases, surgery is performed as soon as the patient is off mechanical ventilation. However, in patients who are still dependent on mechanical ventilation, a one-stage surgical repair is recommended.

In cases where surgery is not indicated, other treatment alternatives such as stent placement, endoprosthesis, fibrin glue application or hyperbaric oxygen therapy may be attempted. Although spontaneous closure of the fistula is rare, a few cases have been reported in the literature (Qureshi et al., 2018).

b. Schedule for surgical treatment

No precise time frame for TEF surgery is given in the literature. However, the most important requirement is that the patient should be weaned off mechanical ventilation prior to surgery. This is because patients who need to be reconnected to mechanical ventilation after surgical repair are at risk of anastomotic pressure, which can lead to recurrence of the fistula, suture dehiscence, tracheocutaneous fistula, mediastinal abscess or other life-threatening complications.

To maintain positive ventilation without jeopardizing surgical repair, the tracheostomy tube should be positioned distal to the fistula and set to low pressure and high volume. These measures increase the likelihood of successful weaning of the patient from mechanical ventilation.

The optimal time for surgery is usually between the 4th and 5th day after weaning from mechanical ventilation. The optimum time for surgery is between the 4th and 5th day after weaning from mechanical ventilation. The optimal time for surgery is between the 4th and 5th day after weaning from mechanical ventilation. At this time, a one-stage surgical repair can be performed to ensure effective closure with healthy tissue around the fistula and to support the anastomosis (Young & Bigcas, 2024).

c. Direct closure of tracheal and esophageal defects

This surgical technique is only suitable for a very limited group of patients who fulfill certain criteria: The fistula must be small, there must be no infection, the patient's nutritional status must be adequate and, above all, there must be no additional pathology of the trachea. If these conditions are met, the TEF can be repaired primarily, even if this is rare.

For small fistulas located 3 cm above the carina, access via a skin incision along the anterior edge of the left sternocleidomastoid muscle is recommended. If the fistula is located on the carina, a right thoracotomy is required. Care must be taken not to injure the left recurrent laryngeal nerve. In some cases, a partial sternotomy may be necessary to reach the fistula site.

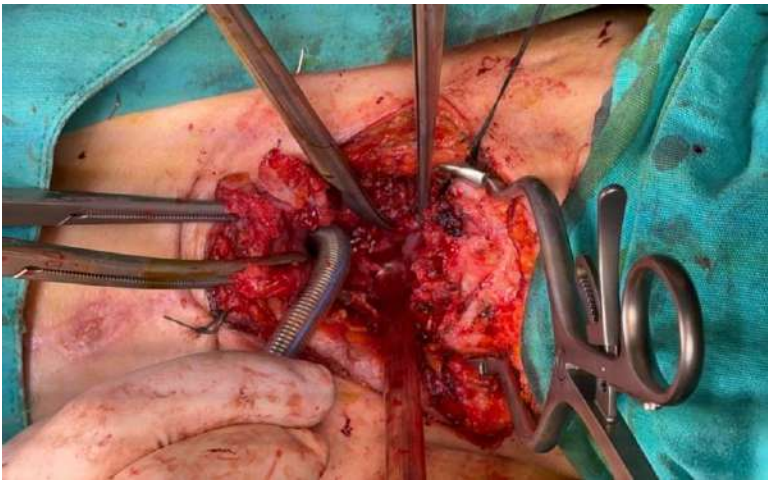

Figure 3. Intraoperative view of the surgical repair of a TEF.

4-0 polydioxanone (PDS) sutures (Ethicon, Inc., Somerville, NJ) are recommended to close the defect in the tracheal membrane. The esophageal defect is repaired in two layers — first the mucosal layer, then the muscular layer. To avoid contact between the esophageal and tracheal sutures, a muscle flap is often placed in between. The muscles of the sternohyoid or the ligamentum are usually used for this.

In the long term, complications such as tracheal stenosis or tracheomalacia can occur, sometimes requiring tracheal resection (Figure 3) (Cohen et al., 2024).

d. Resection and anastomosis of the trachea with primary repair of the esophagus

For this procedure, the patient is placed in the supine position with a pillow under the shoulders and the head in hyperextension. An oblique, anterior cervical incision is made in the neck. The skin, the subcutaneous tissue and the platysma muscle are lifted as a flap. The sternohyoid muscles are retracted and the thyroid gland is cut. The anterior surface of the trachea is exposed and the trachea is wrapped with sutures proximal and distal to the fistula to suspend it.

When manipulating the trachea, it is important to stay close to the outer wall of the trachea to avoid injury to the recurrent laryngeal nerves. The diseased part of the trachea is excised from the tortuous areas. To prevent the development of stenosis, it must be ensured that the distal tracheal segment is healthy. Ventilation is maintained via the distal trachea during the procedure.

Prior to the tracheal anastomosis, the esophageal defect is exposed and the fistula site is excised with a scalpel. The esophagus is repaired with 4-0 PDS sutures in two layers, first with the mucosa, then with the muscle layer. Some surgeons prefer a single layer repair, but the key is to completely remove the fistula.

For tracheal anastomosis, 4-0 PDS sutures are usually used, although 3-0 sutures are sometimes preferred. For subglottic TEFs, oblique incisions in the anterior-posterior plane are preferred to the usual transverse incisions to reduce the risk of injury to the recurrent laryngeal nerve (Cohen et al., 2024).

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CHAPTER 4

PANCREATIC ANATOMY AND VARIATIONS: CLINICAL AND SURGICAL INSIGHTS

Op. Dr. Dr.Yuksel Dogan

INTRODUCTION

This chapter is devoted to the study of the surgical anatomy of the pancreas, with emphasis on its anatomical variations. The earliest known description of the pancreas is found in Aristotle's Historia Animalium in which he describes the pancreas as lying in the upper abdominal region behind the stomach. The pancreas is an important organ that fulfills two main functions. Firstly, it synthesizes digestive enzymes and releases them into the intestine, thereby contributing to the gastrointestinal process. Secondly, it acts as an endocrine gland, releasing hormones directly into the bloodstream that are crucial for regulating the body's energy metabolism and energy storage (Tsuchiya et al., 2015).

Embryologically, the pancreas develops from two distinct pancreatic buds the dorsal and ventral buds which arise from the endodermal cells that cover the inner surface of the duodenum in the 4th to 7th week of development. The dorsal pancreatic bud matures faster and is located above the liver diverticulum, while the ventral pancreatic bud is located below it. The upper part of the pancreatic head as well as the body and tail of the pancreas develop from the dorsal bud. In contrast, the lower part of the pancreatic head and the uncinate process originate from the ventral bud (Snell, 2007; Standring, 2008).

1.1 Surgical anatomy

The pancreas is a glandular organ characterized by an enlarged head that is enclosed by the C-shaped curve of the duodenum. The bile duct is located in a groove on the posterosuperior side of the head and either runs towards the descending part of the duodenum or is embedded in its tissue. From the neck, the pancreatic body crosses the aorta and the second lumbar vertebra (L2). The anterior surface of the pancreatic body is enveloped by the peritoneum, while the posterior surface remains free of the peritoneum and is in contact with several vital structures such as the aorta, the superior mesenteric artery (SMA), the left adrenal gland, the left kidney and the associated renal vessels.

The pancreas is located in the retroperitoneal space and extends horizontally from the duodenum to the spleen. It has a yellowish, soft and nodular appearance. The weight of the organ varies according to age and sex and is usually around 5 grams in newborns, 85 grams in adult females and 100 grams in adult males. The pancreas measures about 14-18 cm in length, 2-9 cm in width and 2-3 cm in thickness.

Due to its central and deep location in the abdominal cavity, the pancreas is in close proximity to numerous organs, blood vessels and ligaments. Anteriorly, it lies next to the duodenum, stomach and spleen, posteriorly near the portal vein, the inferior vena cava and the diaphragmatic crus. In addition, the pancreas is closely connected to the jejunum, the transverse colon and the spleen on its anterior side. The splenic vein runs alongside the aorta, the right and left renal vessels, the left kidney, the upper mesenteric vessels, the thoracic duct and the celiac plexus. The pancreas is also connected superiorly to the bursa, anteriorly to the transverse mesocolon and inferiorly to the greater omentum.

The fasciae surrounding the pancreas vary in length. The united fascia of the pancreatic head is called Treitz's fascia, while the body and tail are enclosed by Told's fascia. Behind the pancreas, the splenic vein opens into Treitz's fascia. Fibrous bands connect the pancreas to the aorta and ensure its stability in the abdominal cavity. The right fibrous band runs behind the uncinate process, the right semiulnar ganglion and the superior mesenteric vein in the direction of the superior mesenteric artery and crosses the duodenum. The left fibrous band, on the other hand, is located between the semiulnar ganglion and the neck of the pancreas (Kimura, 2003).

1.1.1 Parts of pancreas

The pancreas is divided into five structurally similar regions: Head, uncinate process, neck, body and tail (Figure 1.).

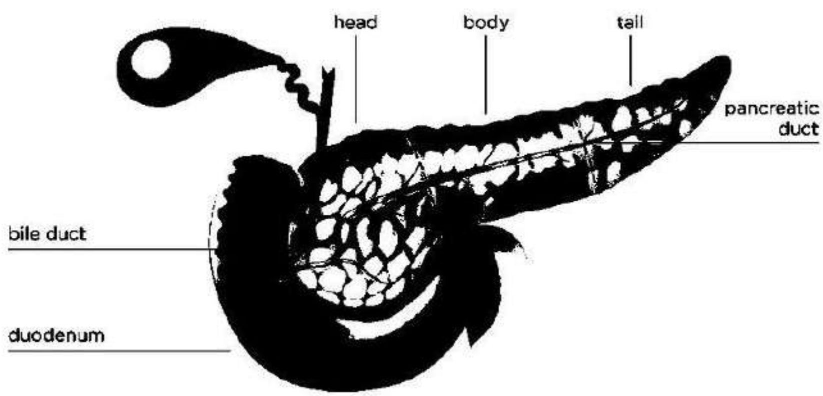

Figure 1: Parts of pancreas (Snell, 2007; Standring, 2008).

Pancreatic head

The head of the pancreas is located in the lumen of the duodenum, to the right of the second lumbar vertebra. Anteriorly, the head borders on the pylorus and the transverse colon; posteriorly, it lies next to the hilum and the inner edge of the right kidney as well as the inferior vena cava and the right renal veins. The posterior part of the pancreatic head is accessible through the Kocher maneuver. In addition, the distal segment of the common bile duct traverses part or all of the pancreatic parenchyma (Snell, 2007; Standring, 2008).

Parietal process (uncinate process)

The uncinate process is a small projection of the pancreas that protrudes downwards and to the left. It is located in front of the aorta and the inferior vena cava and behind the duodenum. Due to this anatomical position, it is close to the portal vein and the upper mesenteric vessels, which presents an additional challenge in pancreatic surgery.

Pancreatic neck (pancreatic collum)

The pancreatic neck is located between the pancreatic head (caput pancreatis) and the pancreatic body (corpus pancreatis) and is the shortest and slimmest part of the pancreas with a length of around 2 to 2.5 centimeters. The splenic hilum is located where the superior mesenteric artery branches off from the abdominal aorta, before the beginning of the hepatic portal vein. The border between the pancreatic neck and the pancreatic head is defined by a furrow formed anteriorly by the gastroduodenal artery and posteriorly by a deeper furrow that includes the junction of the superior mesenteric vein and the splenic vein with the portal vein. In the posterior part, the pancreatic neck is located in close proximity to the superior mesenteric artery, the superior mesenteric vein and the hepatic portal vein (Snell, 2007; Standring, 2008).

During the Whipple procedure, surgeons perform a blunt dissection to gain access to the space between the pancreatic neck and the portal vein and to check whether a tumor has invaded the portal vein axis. The pancreatic body, which is located at the level of the first and second lumbar vertebrae (L1 and L2), lies above and to the left of the midline and resembles a prism with three sides and three faces. The pancreas extends from the left side of the omental tuberosity and continues down the neck as the corpus pancreatis. Its anterior surface borders the posterior wall of the stomach, while the inferior surface borders the folds of the jejunum and ileum.

The posterior surface has a secondary retroperitoneal attachment that adheres to the posterior abdominal wall and associated structures (Snell, 2007; Standring, 2008).

Tail of the pancreas (cauda pancreatis)

The tail of the pancreas (cauda pancreatis) is the left-sided continuation of the pancreatic body and is completely enveloped by the peritoneum. The shape and length of the pancreas varies from person to person it can appear round and thick or flat and slender.

The tail may extend to the splenic hilum or end 3 to 4 centimeters to the right of the spleen without touching it. In cases where the tail does not reach the spleen, it remains connected via the pancreaticolienal ligament, through which the splenic vessels access the pancreas (Kimura, 2003).

1.1.2 Pancreas arteries and veins

The pancreas is supplied with arterial blood via branches of the hepatic artery, the superior mesenteric artery and the splenic artery.

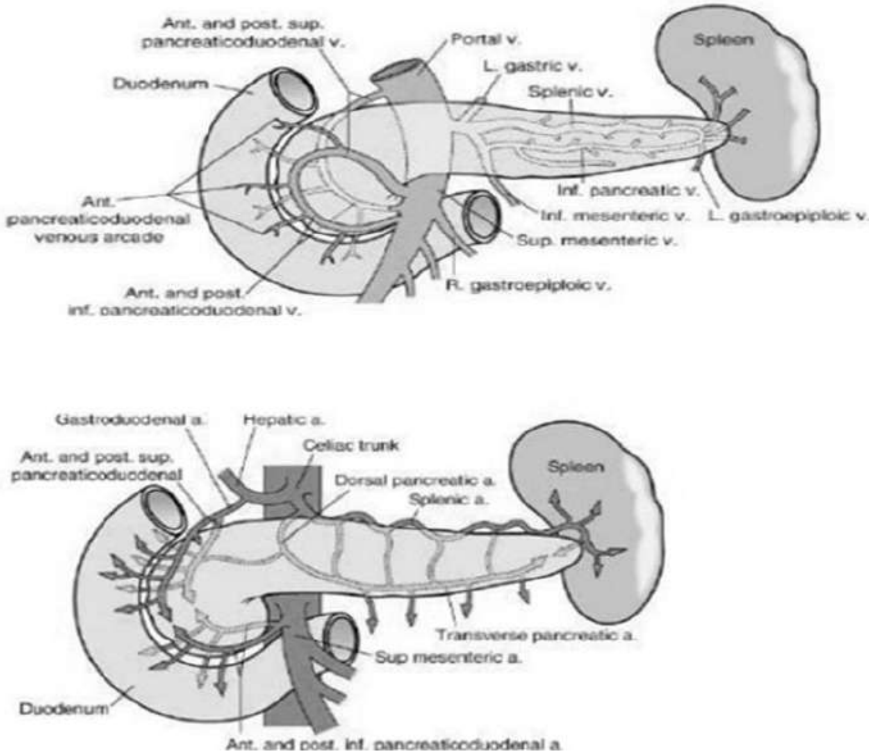

Figure 2: Pancreas arteries and veins (Lewis et al., 2018).

The body and tail of the pancreas are supplied with blood by the pancreatic branches of the splenic artery. The head is supplied by the superior pancreaticoduodenal artery anteriorly and posteriorly, which arise from the gastroduodenal artery, and by the inferior pancreaticoduodenal artery anteriorly and posteriorly, which branch off from the superior mesenteric artery (SMA) (Dams, et al., 2022).

The pancreas is supplied with blood via branches of both the celiac trunk and the SMA. Above the pancreatic head, the posterior superior pancreaticoduodenal artery (PSDA) and the anterior superior pancreaticoduodenal artery (ASPA) from the gastroduodenal artery together with the inferior pancreaticoduodenal artery (IPDA), which originates from either the proximal jejunal artery or the SMA, form a vascular network. The IPDA connects with the anterior and posterior branches of the superior pancreaticoduodenal artery and forms a separate branch to the uncinate process. The dorsal pancreatic artery (DPA), which arises from the splenic artery, the common hepatic artery or the celiac trunk, contributes to this anastomosis, while branches of the DPA and splenic artery supply the body and tail of the pancreas (see Figure 2.).

1.1.3 Lymphatic drainage of the pancreas

The venous drainage of the pancreas follows the arterial pathways, with blood flowing into the portal vein system and eventually reaching the liver. This drainage occurs via four main routes: the suprapancreatic and retropancreatic veins, the infrapancreatic superior mesenteric vein, the superior mesenteric vein and the splenic vein an area of great surgical importance.

Below the head of the pancreas, the proximal jejunal vein and the gastrocolic trunk flow into the superior mesenteric vein (SMV). The proximal jejunal vein and the gastrocolic vein drain the head and uncinate process of the pancreas, with the jejunal vein receiving the inferior pancreaticoduodenal vein before flowing into the SMV. The gastrocolic trunk, which is formed by the right gastroepiploic, middle and right colic veins, also drains into the SMV. The posterior superior pancreaticoduodenal vein drains into the main portal vein, while the anterior superior pancreaticoduodenal vein drains into the gastrocolic trunk before draining into the SMV. Venous drainage from the body and tail is more variable, with small vessels draining into the splenic vein .

The pancreas has an extensive and multidirectional lymphatic drainage system that mirrors the venous drainage. The superior lymph nodes, located at the upper edge of the pancreas, drain the anterior and upper part of the gland, while the inferior nodes, located at the lower edge of the head and body, are responsible for draining the anterior and posterior lower part. The anterior nodes mainly drain the anterior surface of the pancreatic head. Lymph nodes are also located below the pylorus, in the groove between the pancreas and duodenum and at the mesenteric root of the transverse colon. The posterior nodes drain the posterior part of the pancreatic head. Other nodes are located behind the pancreas near the duodenum, near the common bile duct and the aorta, and along the origins of the celiac artery and the superior mesenteric artery. The tail of the pancreas is drained by the splenic nodes (Figure 3). Pancreatic cancer often spreads via the lymphatic system, particularly from the head of the pancreas. Lymphatic drainage is a key factor in pancreatic cancer metastasis, with most patients presenting with lymph node involvement at diagnosis, except in cases with splenic node involvement. This extensive lymph node involvement contributes to the poor prognosis of pancreatic cancer (Itani et al., 2021).

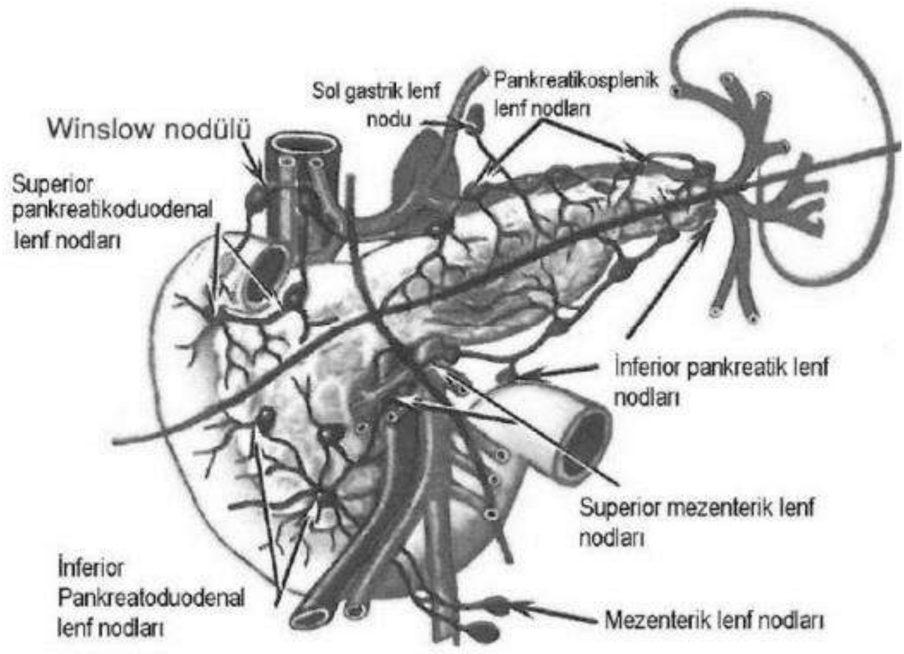

Figure 3: Lymphatic drainage of the pancreas:

1.1.4 Ductal anatomy of the pancreas

The pancreas secretes its exocrine products into the descending part of the duodenum via two ducts: the pancreatic duct and the pancreatic access duct (Figure 4.). The pancreatic duct, also known as the Wirsung duct, originates at the tail of the pancreas (cauda pancreatis) and runs parallel to the back of the pancreas until it reaches the head of the pancreas (caput pancreatis). Along its course, between 20 and 30 smaller branches open into the pancreatic duct at vertical angles. After reaching the head of the pancreas, the main pancreatic duct continues its path downwards and backwards together with the common bile duct. About 15 millimeters into the wall of the descending duodenum, the pancreatic duct may either merge with the common bile duct or open independently into the large duodenal papilla (Bezuidenhout et al., 2024).

When these two ducts merge, they form an extension either outside or inside the duodenal wall. In addition, their joint presence creates a longitudinal fold in the duodenal mucosa, the so-called plica longitudinalis duodeni, when they cross the descending duodenum. The last section of the pancreatic duct is enclosed by the pancreatic duct sphincter, which consists of smooth muscle fibers. The diameter of the pancreatic duct varies depending on its position within the pancreas: it measures around 3.5 mm at the pancreatic head (caput pancreatis), 2.5 mm in the body (corpus pancreatis) and narrows to around 1.5 mm in the tail (cauda pancreatis).

In addition to the primary pancreatic duct, the pancreas may have a secondary duct, the so-called pancreatic ductus accessorius or Santorini duct, which occurs in 4-10 % of people. This accessory duct originates from the main pancreatic duct at the level of the pancreatic neck (collum pancreatis), is 5-6 cm long and typically opens into the small duodenal papilla, which is located about 2 cm above the large duodenal papilla.

The sphincter of Oddi is another important component of the pancreatic duct system. This sphincter structure, defined by Boyden in 1957, is located where the bile and pancreatic ducts meet. It consists of a complex arrangement of smooth muscle fibers that regulate the flow of bile and pancreatic juice into the duodenum. The length of the Oddi sphincter can vary considerably depending on the course of the ducts along the duodenal wall and is between 6 and 30 millimeters (Fisher et al., 2015).

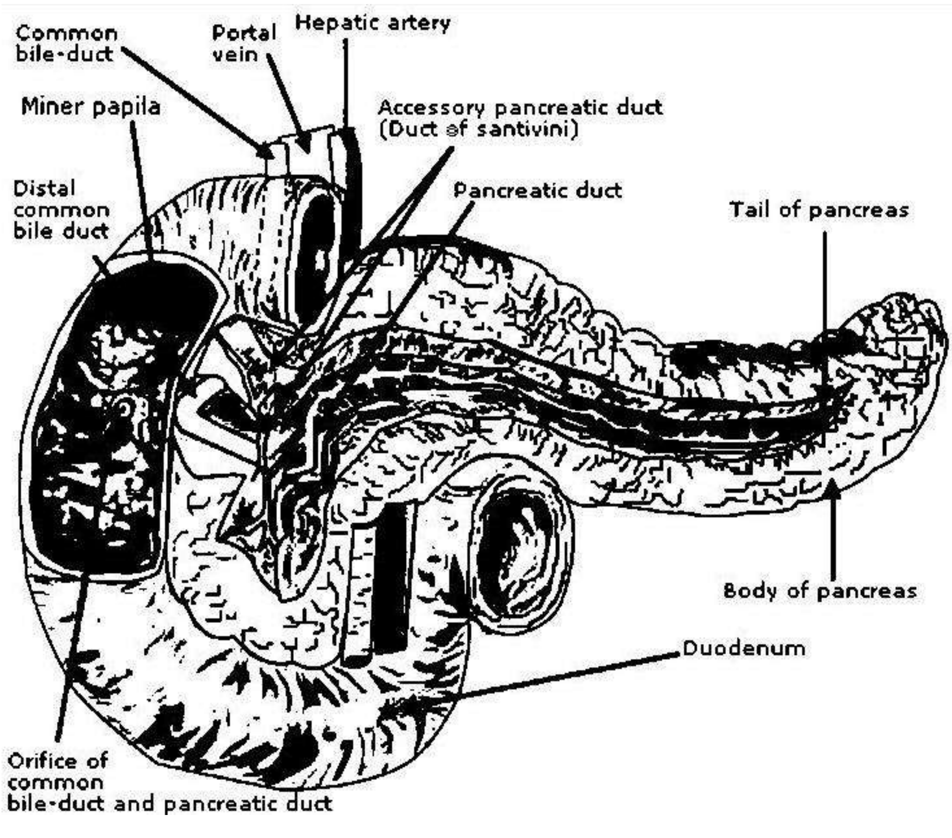

Figure 4: Pancreas duct anatomy (Snell, (2007).

1.1.5 Histology of the pancreas

The pancreas, which develops from the endoderm, plays a crucial role in the regulation of protein and carbohydrate digestion and in the maintenance of glucose homeostasis. The exocrine component of the pancreas accounts for about 80 % of the total tissue mass and consists of a complex network of ductal and acinar cells. These cells are responsible for the production of digestive enzymes such as trypsinogen, chymotrypsinogen, carboxypeptidase, deoxyribonuclease, ribonuclease, triacylglycerol lipase, phospholipase A2, elastase and amylase, which are transported into the gastrointestinal tract.

The acinar cells are organized into functional units that align along the ductal system and synthesize zymogens in response to stimuli from the stomach and duodenum. These enzymes are then secreted into the ductal lumen. Centroacinar cells are located near the ductus within the acinar units and play a role in the function of the ductal system.

The endocrine part of the pancreas, on the other hand, regulates metabolism and blood sugar levels by releasing hormones into the bloodstream. This part of the pancreas consists of the islets of Langerhans, which are made up of four different types of endocrine cells (see Figure 5.). Within the islets, the α cells produce glucagon, the β cells produce insulin, the D cells secrete somatostatin and the PP cells release pancreatic polypeptide (Henry et al., 2019).

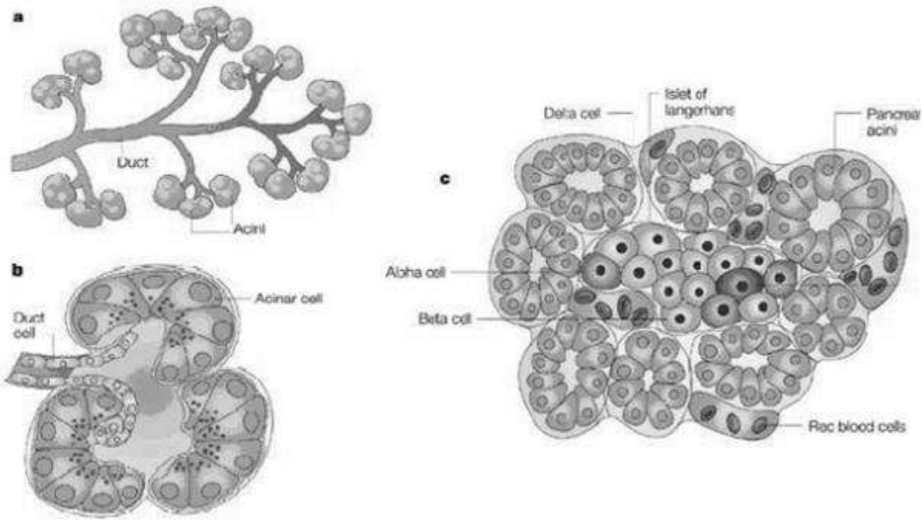

Figure 5: Pancreas histology (Snell, 2007).

1.1.6 Pancreatic anomalies

Annular pancreas: Annular pancreas refers to a condition in which a band of pancreatic tissue partially or completely surrounds the duodenum. The incidence of this abnormality is reported to be around 1 in 2,000 births. It can occur in isolation or together with other congenital defects and primarily affects the second part of the duodenum, although in rare cases the third part may also be affected. A distinction is made between:

(a) Extramural subtype: in this form, the ventral pancreatic duct surrounds the duodenum without merging into the main pancreatic duct, resulting in obstructive symptoms.

b) Intramural subtype: Here the pancreatic tissue is fused with the muscle fibers of the duodenum, resulting in numerous small ducts that open directly into the duodenum. This subtype is often associated with the finding of ulceration of the duodenum (Karayalcin, 2001).

Ectopic pancreas: Ectopic pancreas is characterized by the presence of pancreatic tissue at sites outside its typical anatomical location and occurs in approximately 0.6 to 13.7% of the population. In 95% of cases, ectopic pancreatic tissue is found in the upper gastrointestinal tract, particularly in the stomach (26-38%), duodenum (28-36%) and jejunum (16%). Less frequently, they can occur in the ileum, gallbladder, bile ducts, colon, spleen, omentum, bladder, thorax, abdominal wall and Meckel's diverticulum. Most cases are asymptomatic, although symptoms may vary depending on the location and size of the ectopic pancreas, leading to pancreatitis, peptic ulcers, dyspepsia, gastrointestinal bleeding, pyloric stenosis, biliary duct obstruction and jaundice (Harrington et al., 2021).

Pancreatic agenesis: Total or partial pancreatic agenesis is caused by a developmental defect that occurs in the fifth week of pregnancy. This rare congenital condition severely impairs intrauterine growth as it is associated with permanent diabetes mellitus and malabsorption and often leads to fetal death. Partial agenesis may be asymptomatic due to the functional reserve of both the exocrine and endocrine components of the pancreas (Turkvatan et al.,2013).

Pancreas divisum: Pancreas divisum occurs when the ductal structures of the dorsal and ventral segments do not fuse during embryonic development. In this case, the ventral duct, which is responsible for draining most of the pancreas, opens into the duodenum via a thin duct network or from the small papilla and drains less than 20 % of the pancreas. The dorsal duct is responsible for drainage into the large papilla. The pancreas divisum is observed in about 2 % of the normal population (Amseian,, 2024).

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CHAPTER 5

PANCREATICODUODENECTOMY STANDARD TECHNIQUE

Op. Dr. Yuksel Dogan

Historical Background:

Historical background: The development of pancreaticoduodenectomy, a highly complex surgical procedure, was characterized by major challenges. Its history dates back to the late 19th century when mortality rates were alarmingly high, but over time these rates have been reduced to less than 2%. The refinement of this procedure parallels advances in surgical techniques and technological innovations. This demanding procedure requires first-class surgical training and exceptional technical expertise. In recent decades, profound improvements have been made in pancreaticoduodenectomy, leading to changes in standard surgical procedures, particularly in the 1960s and 1970s. As a result, more and more surgeons and medical centers are now performing this procedure routinely (Cameron et al., 2006).

Key Milestones:

- **1898:** Codivilla performed the first documented pancreaticoduodenectomy for pancreatic cancer, in which parts of the pancreas, duodenum, distal stomach and bile duct were removed. The procedure included a Roux-en-Y gastrojejunostomy and a cholecystojejunostomy, but the pancreatic stump was not closed. Unfortunately, the patient died on day 18 from cachexia due to steatorrhea (Schnelldorfer et al., 2008).

- **1899:** Halsted successfully resected an ampullary carcinoma by removing parts of the duodenum and pancreas during gallstone surgery (Howard J et al., 1999).
- **1900 and 1904:** Mayo-Robson and Koerte removed cylindrical parts of the duodenum in ampullary carcinomas, but none of the patients survived.
- **1907:** Desjardins performed a two-stage radical resection of the duodenum and pancreatic head on cadavers. He also suggested reimplanting the pancreatic stump into the intestine.
- **1908:** Sauve (attempted a single-stage operation on cadavers and proposed various methods of treating the pancreatic stump, including sewing it into an abdominal wound to form a fistula.
- **1912:** Walter Kausch was the first to attempt to resect most of the duodenum and a significant part of the pancreas en bloc. However, due to the prevailing medical thinking at the time, he did not perform a complete duodenectomy and continued with pancreaticoduodenostomy.
- **1914:** Hirschel performed the first single-stage partial resection, removing the duodenum, ampulla, pancreatic head and a segment of the bile duct. Continuity was restored by integrating the pancreatic duct into the duodenal resection with

a rubber tube and performing a posterior gastroenterostomy. The patient's jaundice improved and he survived for a year, but no autopsy was performed to determine the cause of death or the whereabouts of the tube.

- **1918:** Dragstedt et al. demonstrate the possibility of survival after total duodenectomy in dogs.
- **1922:** Tenani performs a successful two-stage resection of an ampullary carcinoma. After a difficult postoperative recovery, the patient survived for three years.
- **1935:** Whipple, Parsons and Mullins publish a report on three patients from Columbia Presbyterian Hospital in New York. The two-stage procedure involved radical resection of the duodenum and pancreatic head for ampullary cancer. One patient died shortly after the operation, while the other two survived for several months before succumbing to cholangitis and liver metastases.
- **1937:** Nemenyi performed a one-stage partial resection of the duodenum, similar to Kausch's technique, while Brunschwig was the first to perform a radical pancreaticoduodenectomy, in which the pancreatic head was completely removed in a two-stage procedure.
- **1940:** Brinkhaus discovered that vitamin K in combination with bile salts can reduce bleeding in patients with jaundice. Trimble, unaware of the Whipple procedure, performed a similar radical resection at Johns Hopkins and added a distal gastrectomy to avoid extrusion of the duodenal stump. In the

same year, Hunt introduced pancreaticojejunostomy to prevent leakage of the pancreatic stump.

- **1946:** Whipple published his decades of experience, suggesting changes to his original technique and advocating a single-stage procedure. He later published his memoirs on this approach in 1963 (Hall et al., 2023).

Pancreaticoduodenectomy, also known as the Whipple procedure, is a major surgical procedure to remove tumors in the head of the pancreas. It is also used to treat injuries to the pancreas and duodenum or chronic pancreatitis. During surgery, the head of the pancreas is usually removed together with the duodenum, proximal jejunum, gallbladder and sometimes part of the stomach, as the blood supply to the upper gastrointestinal tract is interconnected (Warshaw et al., 2005).

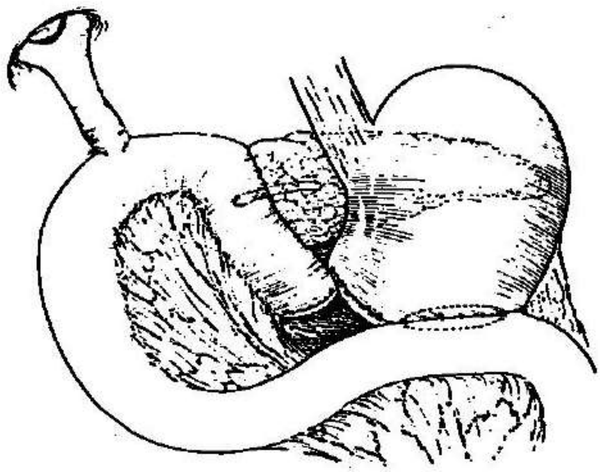

Figure 1. Standard Whipple Operation (Hall et al., 2023).

In the standard Whipple operation (see Figure 1), the distal part of the stomach (antrum), the first and second parts of the duodenum, the head of the pancreas, the common bile duct and the gallbladder are usually removed en bloc. The surrounding lymph nodes are usually removed as part of the procedure (lymphadenectomy). However, more extensive lymph node removal has been shown to provide no additional benefit and the standard procedure involves a more conservative approach (Jiang et al., 2019).

Surgical Standard Technique:

Pancreaticoduodenectomy (PD) usually begins with either a vertical incision in the midline or a bilateral subcostal incision, followed by the use of a self-retaining retractor for optimal exposure. The first step is a thorough examination to determine the extent of the disease and whether the tumor is resectable. Staging laparoscopy is now commonly performed, either as a stand-alone procedure or in combination with PD to assess resectability (Jiang et al., 2019). The liver is carefully inspected and palpated for possible metastases, and if suspicious areas are found, intraoperative ultrasound can be used for further assessment. The parietal and visceral peritoneum, the treitz ligament, the omentum and the entire small and large bowel are also examined for signs of metastases. In addition, the celiac axis is examined for lymph node involvement and suspicious lymph nodes outside the intended dissection area are sent for frozen section biopsy. If metastatic cancer is confirmed, the PD procedure is aborted (Liu et al., 2006).

The porta hepatis is exposed by mobilizing the gallbladder and incising the cystic duct up to its junction with the common hepatic duct and the bile duct. Both the hepatic artery and the hepatic artery are examined for signs of tumor involvement. The duodenum and pancreatic head are then lifted out of the retroperitoneum using the Kocher maneuver. The duodenum is resected together with the pancreatic head as they share a common blood supply, mainly via the superior and inferior pancreaticoduodenal arteries. As these arteries run through the pancreatic head, removing only the pancreas would cut off the blood flow to the duodenum, which could lead to necrosis. If the blood supply to the duodenum is impaired, both organs must be removed together. In some cases, if the tumor involves the superior mesenteric vein (SMV) or extends to the fourth part of the duodenum, the Cattell-Braasch maneuver may be necessary, which requires extensive mobilization of the right colon and small bowel mesentery (Jiang et al., 2019).

The gallbladder is then carefully separated from the liver and the hepatic duct is severed near the junction of the cystic duct. Care is taken to ensure that the proximal bile duct is not clamped to avoid damage, while the distal bile duct is clamped or sutured to prevent bile or tumor cells from escaping. The bile duct is carefully pulled downwards while the dissection continues along the anterior surface of the portal vein. During all these steps, the right hepatic artery is identified and protected. The presence of an accessory right hepatic artery should also be checked to avoid injury. The gastroduodenal artery is then ligated to reduce the risk of postoperative erosion and bleeding. This step also helps to expose the anterior surface of the portal vein so that it can be more easily transected behind the pancreatic neck. The surgeon then identifies the portal vein above the pancreatic neck and the SMV below the pancreatic neck. A blunt dissection is performed to create a plane between the portal vein and the pancreatic neck, which is a critical step in the procedure. If a clear plane of dissection cannot be created between the portal vein and the pancreatic neck, the procedure may need to be aborted to avoid complications.

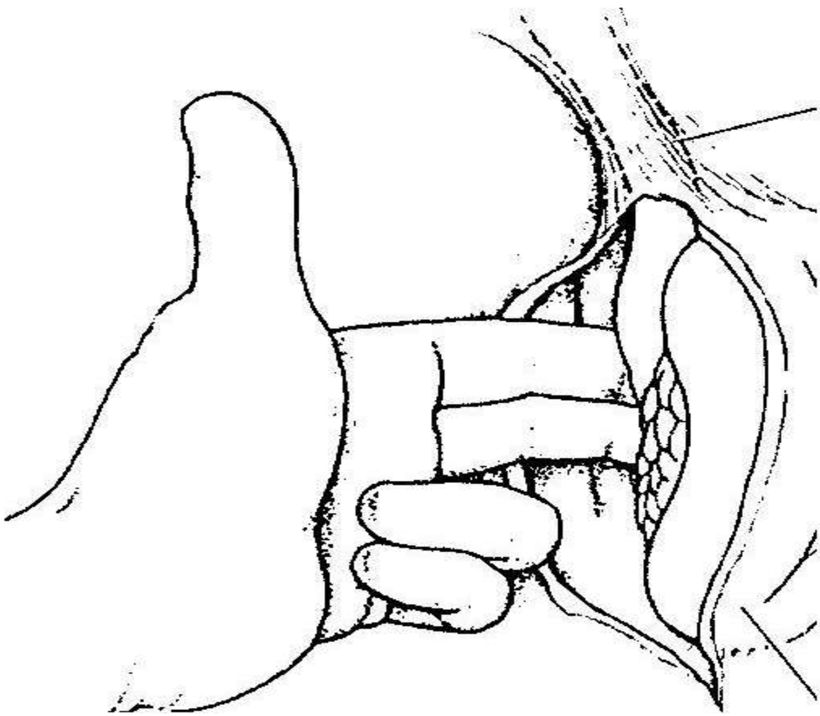

Figure 2. Kocher maneuver (Hall et al., 2023)

The comprehensive Kocher maneuver (Figure 2) should be used to visualize the SMV below the pancreatic neck. The superior mesenteric vein runs anterior to the third portion of the duodenum and is surrounded by adipose tissue as it receives inflows from the uncinate process and pancreatic neck, the great curve of the stomach, and the transverse mesocolon. The two ways to identify the superior mesenteric vein are to follow the middle colic veins to their confluence with the superior mesenteric vein or to follow the course of the right gastroepiploic vein to its confluence with the superior mesenteric vein, which is located just below the lower border. The level anterior to the superior mesenteric vein is established under direct vision and the splenic vein is preserved. The connection between the PV and the SMV should be clearly visible.

Vascular and surgical techniques in pancreaticoduodenectomy:

If vascular resection is required in pancreaticoduodenectomy, it is usually performed with the help of vascular surgeons. A segmental resection of the portal vein or superior mesenteric vein is usually performed, and the resulting vascular defect can be repaired using various methods. These include primary closure, patch repair or the use of autologous grafts, e.g. the internal jugular vein, the left renal vein, the splenic vein or the great saphenous vein, or synthetic grafts such as PTFE. After reconstruction, close postoperative monitoring of the portal vein is essential due to the risk of portal vein thrombosis.

In the Whipple operation, an antrectomy is performed in which the right gastric and gastroepiploic arteries are severed and the antrum is cut with a linear stapler. In pylorus-preserving pancreaticoduodenectomy, the proximal gastrointestinal tract is transected approximately 2-3 cm distal to the pylorus with a stapler. The jejunum is transected 15-20 cm behind the Treitz ligament and then displaced from left to right, dorsal to the superior mesenteric vessels. Below the neck of the pancreas, a Penrose drain is inserted into the tunnel created to elevate the neck of the pancreas and protect the portal vein below. The pancreatic neck is then cut with an electrocautery to create a free plane between it and the portal and mesenteric veins. Permanent sutures are placed on either side of the pancreatic remnant to control bleeding from the small pancreatic arteries in this area.

At this point, the specimen remains attached only to the uncinate process of the pancreas. The portal vein is separated from the superior mesenteric vein and the mesenteric artery by successively clamping, dividing and ligating smaller branches of these vessels. The specimen is then removed en bloc and the edges of the pancreatic neck, the uncinate process and the common hepatic duct are marked for pathological examination. The edges of the common hepatic duct and pancreatic neck are of critical importance and can be sent for frozen section analysis to order further resection if necessary. Once the specimen has been removed, metal staples are placed around the resection area so that targeted radiotherapy can be carried out postoperatively if necessary.

Reconstruction methods after pancreaticoduodenectomy:

Several methods are available for reconstruction of the gastrointestinal tract after pancreaticoduodenectomy. As a rule, the standard approach involves restoring continuity with three main anastomoses: first the pancreatic anastomosis (PA), followed by the biliary anastomosis and finally the reconstruction of the gastrointestinal tract. Pancreatic anastomosis is the most critical and delicate step as it plays an important role in reducing complications. PA can be performed with either the jejunum or the stomach as the recipient structure. Two main techniques for PA are the duct-to-mucosa anastomosis and the intussusception method.

In the duct-to-mucosa pancreaticojejunostomy, the anastomosis is created retrocolically between the remainder of the pancreatic duct and the side of the jejunum. In the intussusception technique, the pancreatic duct is invaginated into the lumen of the jejunum. There are several variations of these techniques, such as the modified Blumgart, modified Kakita or pancreaticojejunostomy anastomosis with ligation, but none of them have been shown to be superior in preventing pancreatic fistula formation (Berger et a., 2009).

After completion of PA, the next anastomosis is an end-to-side hepaticojejunostomy performed with interrupted, single-layer, absorbable sutures approximately 10-15 cm distal to the pancreaticojejunostomy. The final anastomosis is either a gastrojejunostomy (in patients undergoing a classic Whipple procedure with distal gastrectomy) or a duodenojejunostomy (in cases where the pylorus is preserved). This is done proximal to the jejunal loop, which passes through a defect in the mesocolon, typically 10-15 cm below the hepaticojejunostomy.

Once the reconstruction is complete, closed suction drains are placed near the pancreatic and biliary anastomoses and in the Morrison's pouch. A feeding jejunostomy is not always required and is at the discretion of the surgeon. Postoperative management begins on the first day with abstinence from food, which is gradually changed to clear liquids and then to a low-fat diet in small, frequent meals. The stomach is decompressed overnight with a nasogastric tube, which is usually removed the next day with normal elimination. The drains are gradually removed as elimination decreases, provided there are no signs of pancreatic fistula and the patient can tolerate a normal diet.

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