Chapter 1

A prelude to peristalsis, swallowing disorders and catheterisation

Mesmerizing phenomena characterizing the diverse universe are accurately described in the following quote:

"Man lacked the intended hands of the unseen forces that created the universe brilliantly, but the way he attempted and explored the mysteries with his limited talent and skill is no less splendid. The moment he opened his eyes, he observed, on the one hand, a line of stupendous beauty, and on the other were standing unyielding principles. Looking out of curiosity into the laws connecting things in nature, he tried to grasp ideas from them. His ventures passed on from one generation to another, and finally, he created an artificial world of his own." Sanjay Kumar Pandey

The principles that do not yield are the laws of nature, which could be analyzed or discovered but are not created. What we construct are mathematical formulations that may be approximate or exact depending on our skills and how seriously we attempt to unveil the law. That also depends on our knowledge of mathematics. For that reason, various dimensions of mathematics are added to the existing domain, and the formulations are corrected and modified in the course of investigation with the passage of time. We call those formulations mathematical models, which are mostly approximate to the laws of nature for various reasons, such as the complexities involved in the processes we try to model and the large number of factors influencing our phenomenon, apart from our knowledge of mathematics. It has been, therefore, rightly said that the man-made beautiful world is a consequence of the contributions made by several generations. Biology and medical sciences are not exceptions to mathematical formulations, which may sometimes appear unrealistic to the common man. Such models make an immense contribution to the medical world, help practitioners diagnose the cause of the illness, and provide remedial measures. The following section will give glimpses of these effects.

1.1 Peristalsis

Peristalsis is the involuntary contraction and relaxation of longitudinal and circular muscles throughout the digestive tract, allowing for the propulsion of contents beginning in the pharynx and ending in the anus (Fig. 1.1). True peristalsis is usually defined as a coordinated reaction in which a wave of relaxation precedes a wave of contraction. The waves can be short, local reflexes or long, continuous contractions that travel the whole length of the organ, depending upon their location and what initiates their action. Some electrochemical reactions are held responsible for this phenomenon. In fact, it is a reflex process. In the oesophagus, peristaltic waves begin at the upper portion of the tube (food pipe) and travel the whole length, pushing food ahead of the wave into the stomach (Kahrilas et al. (1988)). According to Misra (2006), the process of peristaltic transport underpins many bodily functions, including the swallowing of food through the oesophagus, the passage of chyme through the small intestine, colonic transport in the large intestine, the passage of urine from the kidneys to the urinary bladder through the ureters, spermatic flows in the ductus efferent of the male reproductive tract, the vas deferens and the cervical canal, and the movement of the ovum in the fallopian tube. Peristaltic motion has also been detected in the lymphatic vessels and the vasomotion of certain blood vessels, such as venules and arterioles. Additionally, biomechanical pumps are designed to prevent blood contamination or other similar fluids during the pumping process due to contact with the pump mechanism.

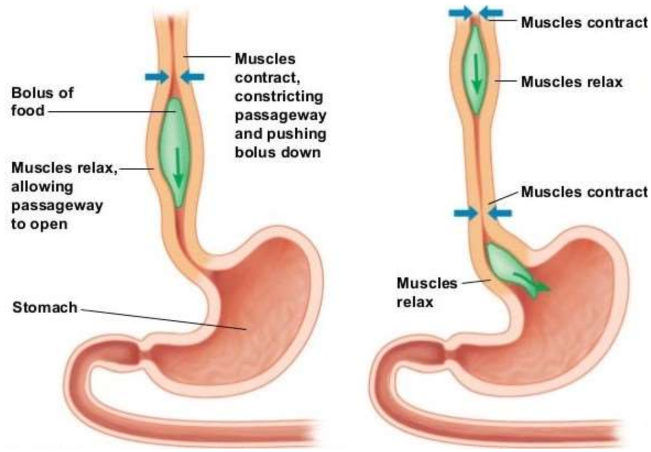


Figure 1.1: Peristaltic movement in an oesophagus. (Source: www.socratic.org)

1.1.1 Types of Peristalsis

Depending on the situation, such as swallowing initiation, distension of an oesophagus, diverse emetic stimuli, and different categories of flows in intestines, the following are the types of peristalsis (Kahrilas et al. (1988), Misra (2006)), we discussed.

- Primary peristalsis: Primary oesophageal peristalsis is a continuation of pharyngeal peristalsis, initiated by swallowing, and acts to move contents from the oesophagus into the stomach.
- Secondary peristalsis: Should primary peristalsis fail to move the entirety of the bolus into the stomach, distension of the oesophagus will initiate secondary oesophageal peristalsis until all contents are cleared. Various intra-esophageal stimuli, including air, mechanical distention, or water infusion, can physiologically trigger secondary peristalsis.
- Retro-peristalsis (or anti-peristalsis): The forceful removal of the gastrointestinal contents due to diverse emetic (a medicine or other substance which causes vomiting) stimuli. Physiologic retro-peristalsis occurs at the level of the duodenum to protect GI mucosa from acidic stomach contents and at the terminal ileum to allow for maximum absorption of water and nutrients. This can also be seen in cud-chewing animals, such as cows; reverse peristalsis can occur to bring the food back from the stomach to the mouth for re-chewing.

- Rush peristalsis: This type of peristalsis is typical of many physiological processes. This word mostly refers to the small intestine's flow.
- Mass peristalsis: It is similar to the rush peristalsis in the small intestine and is located in the large intestine. In fact, it is the primary movement of the large intestine.

1.1.2 Issues of concern

Peristalsis helps acid clearance, which empties the refluxed fluid from the oesophagus and is completed by titration of the residual acid by swallowed saliva. The peristaltic function is an important defense mechanism against gastro-oesophageal reflux disease. The myenteric plexus (the major nerve that controls gastrointestinal motility) must be active for effective movement of food through the digestive system. If the myenteric plexus is missing at birth, called Hirschsprung disease, or if a drug like atropine is used to block its nerve endings, peristalsis can be slowed down or stopped completely. Peristaltic dysfunction and oesophagitis have been described in the literature (Singh et al. (1992); Timmer et al. (1993); Kahrilas et al. (1986)).

1.2 Oesophagus

It is a tubular, elongated organ of the digestive system which connects the pharynx to the stomach. It follows a path that travels behind the trachea and heart, in front of the spinal column, and through the diaphragm before entering the stomach. The organ is typically about nine to ten inches (23cm to 25cm) long in fully grown adults, with sphincters at each of its proximal and distal extremities, a mucosa-lined lumen and connective tissue, and smooth muscle outer composition. The sphincter located anteriorly, the upper oesophageal sphincter (UES), allows for the single-direction passage of food into the oesophagus, and the lower oesophageal sphincter (LES) is to prevent reflux of substantial amounts of gastric contents back into the oesophagus (McCarty and Chao (2021)).

The UES, also termed the pharyngoesophageal sphincter, is a circular bundle of muscle tissue that normally remains closed in a contracted position. During the pharyngeal stage of swallowing, the muscular walls of the pharynx contract, providing a strong initial peristaltic motion of the bolus and sending the bolus through the UES with kinetic energy. The LES, also termed the cardiac sphincter and cardio-esophageal sphincter, is located slightly more than an inch (about 3cm) proximally from where the oesophagus meets the stomach. Similar to the UES, the LES is normally contracted and closed, primarily preventing stomach contents from entering the oesophagus body (McCarty and Chao (2021)).

1.2.1 Swallowing discomfort

When someone has difficulty swallowing, the food can get temporarily stuck between the upper and lower parts of the oesophagus or near the chest bone (sternum), leading to oesophageal obstruction. This can cause deep discomfort between the chest bone and the area between the shoulder blades (Tatum et al. (2007)). If the oesophagus stretches and thickens above the blockage, it can cause inflammation (oesophagitis).

Sometimes, the situation becomes an emergency when a lump of food gets stuck above a neoplasm (an abnormal mass of tissue), leading to complete obstruction. This can result in symptoms like vomiting, where swallowed food, saliva, and mucus are ejected. This ejection happens sooner after swallowing if the blockage is higher in the oesophagus (Roeder et al. (2004)). The vomited material might be blood-stained and undigested food. Offensive burping (eructations) may also occur.

1.2.2 Gastroesophageal reflux

Gastroesophageal reflux disease, as shown in the figure (1.2), is defined as reflux that causes troublesome symptoms, mucosal injury in the oesophagus, or both (Vakil et al. (2006)). In fact, most patients with gastro-oesophageal reflux disease show no abnormalities on catheterization. This subgroup is generally said to have non-erosive reflux disease. In developed countries, the prevalence of gastro-oesophageal reflux disease (defined by symptoms of heartburn, acid regurgitation, or both, at least once a week) is 10–20%, whereas, in Asia, the prevalence is roughly less than

5% (El Serag et al. (2009); Dent et al. (2005)). According to (Peery et al. (2012)), in the USA, this disease is the most common gastrointestinal diagnosis to prompt an outpatient clinic visit (8·9 million visits in 2009). The rising prevalence of gastro-oesophageal reflux disease seems to be related to the rapidly increasing prevalence of obesity.

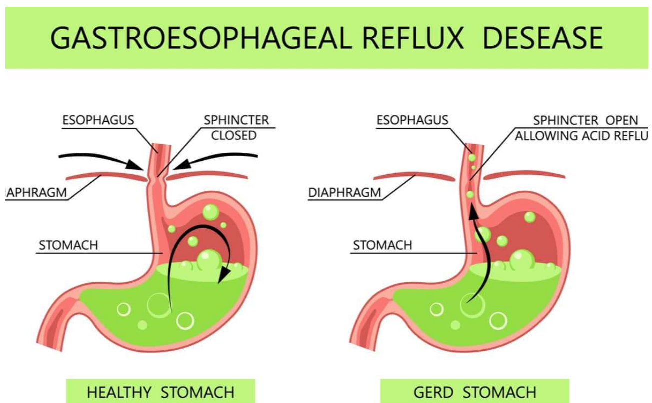


Figure 1.2: Diagram displays the reflux of acidic contents through the oesophagus from the stomach. (Source: www.socratic.org)

1.2.3 Oesophagogastric junction

According to Bredenoord et al. (2013), three components comprise the oesophagogastric junction: the lower oesophageal sphincter, the crural diaphragm, and the anatomical flap valve. This complex functions as an anti-reflux barrier. The lower oesophageal sphincter, sometimes the intrinsic sphincter, is a 3–4cm segment of tonically contracted circular smooth muscle at the distal end of the oesophagus. The resting tone of this muscle can vary in healthy individuals, from 10mm Hg to 35mm Hg relative to intragastric pressure. Moreover, temporal variation is considerable, with fluctuations after meals, activity, and sleep (Goyal and Rattan (1976)). The right crus of the diaphragm forms a sling that surrounds the distal oesophagus, creating a teardrop-shaped hiatal canal. This structure serves as an extrinsic sphincter by augmenting the high-pressure zone of the lower oesophageal sphincter (Mittal et al. (1988); Pandolfino et al. (2007); Mittal et al. (1989); Pandolfino et al. (2003)). As the flap valve disrupts and the lower oesophageal sphincter moves above the crural canal, the high-pressure zone loses its synergistic configuration, and both sphincters (lower oesophageal sphincter and diaphragm) become appreciably weaker (Kahrilas et al. (1999)).

1.3 Swallowing disorders in oesophagus

Swallowing disorders are conditions where a person has difficulty swallowing food, liquids, or saliva. This can occur at any stage of the swallowing process (Kahrilas et al. (1986)):

- Oral Phase: Difficulty chewing and moving food or liquid from the mouth to the throat.
- Pharyngeal Phase: Problems initiating the swallowing reflex and moving food through the throat.
- Oesophageal Phase: Issues in moving food from the oesophagus to the stomach.

There are various regions or causes of swallowing disorders, such as neurological disorders (e.g., stroke, Parkinson's disease, multiple sclerosis), structural abnormalities (e.g., esophageal strictures, tumors), muscle disorders (e.g., myasthenia gravis), infections or inflammation (e.g., esophagitis), aging. These causes resulted in several diseases, which are discussed below:

1.3.1 Hiatus hernia

In general terms, hiatus hernia refers to the herniation of elements of the abdominal cavity through the oesophageal hiatus of the diaphragm and into the mediastinum. Of the openings through the diaphragm, only the oesophageal hiatus is vulnerable to visceral herniation because it faces directly into the abdominal cavity and is directly subjected to the pressure stresses between the two cavities (Kahrilas et al. (1995)). Notably, the oesophagus does not tightly fill the hiatus because it needs to expand to accommodate luminal contents. Thus, the integrity of the hiatus depends upon the structures bridging the gap between the oesophagus and the surrounding crural diaphragm, making the detailed anatomy of this area of prime importance.

In the United States, hiatus hernia was listed as a primary or secondary cause of hospital admissions in 142 of 10000 patients between 2003 and 2006 (Roman and Kahrilas (2014)). However, the exact prevalence of hiatus hernia is difficult to determine because of the inherent subjectivity and diagnostic criteria. Consequently, estimates vary widely—for example, from 10% to 80% of the adult population in North America (Yu et al. (2018)). It is, however, accepted that the prevalence of hiatus hernia parallels that of obesity and that it increases with age. The typical symptom of a hiatus hernia is gastroesophageal reflux (heartburn, regurgitation). Dysphagia, epigastric or chest pain, and chronic iron deficiency anemia are less common symptoms. This clinical review summarises the current evidence for diagnosing and managing hiatus hernia.

1.3.1.1 Sliding hiatus hernia

There are four types of hiatal hernias. However, the sliding hiatal hernia (type 1) is the most common and accounts for up to 95% of all hiatal hernias. Type 1 hiatal hernia, also called sliding hiatal hernia, happens when the place where the oesophagus meets the stomach (the gastroesophageal junction) slides up into the chest cavity (Fig. 1.3). This occurs because the phrenoesophageal ligament, which usually keeps the junction in place, becomes too loose. The ligament stays intact, but the junction moves into the area behind the heart. With less of the oesophagus in the abdomen, the gastroesophageal junction is more likely not to work properly, leading to acid reflux (Oleynikov and Jolley (2015)).

1.3.1.2 Para-hiatus hernia

According to Armijo et al. (2019) and Arcerito et al. (2018), Type 2 to 4 hiatal hernias are true para-oesophageal hernias (PEHs) and are classified based on the gastroesophageal junction's location and what has herniated into the thoracic cavity. A type 2 hiatal hernia has a GE junction in the normal anatomic position, but a portion of the stomach, most often the fundus, has herniated through the hiatus

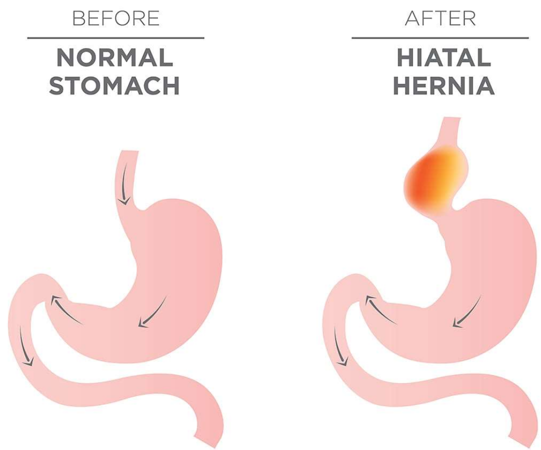


Figure 1.3: Diagram displays the condition of the normal oesophagus before and after the sliding hiatus hernia. (Source: www.socratic.org)

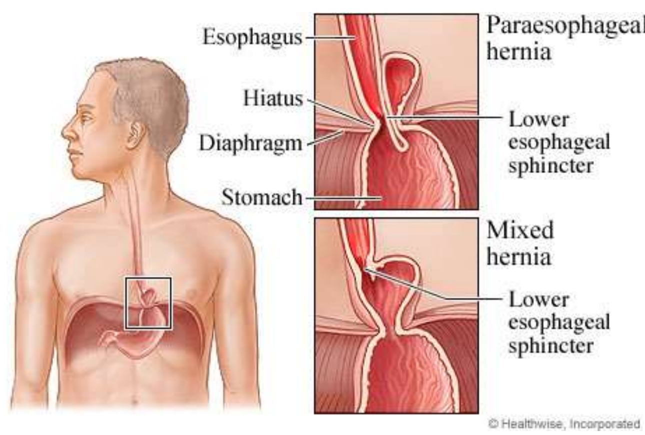


Figure 1.4: Diagram displays the paraesophageal and mixed hernia due to the weak function of the lower oesophageal sphincter and the hiatus. (Source: www.socratic.org)

(Fig. 1.4). Type 3, like type 2, has a portion of the stomach that has herniated through the hiatus but also has an abnormal position of the GE junction in the thoracic cavity. Type 4 has an abnormal GE junction position like type 1 and 3. However, another organ, most often a portion of the colon, has herniated into the thoracic cavity.

1.3.1.3 Symptoms of hiatus hernia

No symptom is specific for hiatus hernia. However, the presence of a hernia might be suspected with symptoms of gastroesophageal reflux, including heartburn, regurgitation, or dysphagia. In cases of paraesophageal hernia, dysphagia may be caused by the herniated stomach compressing the distal oesophagus, resulting in an extrinsic mechanical obstruction. Sliding hiatus hernia may also promote dysphagia secondary to stasis in the herniated stomach, functional obstruction at the level of the crural diaphragm, or both.

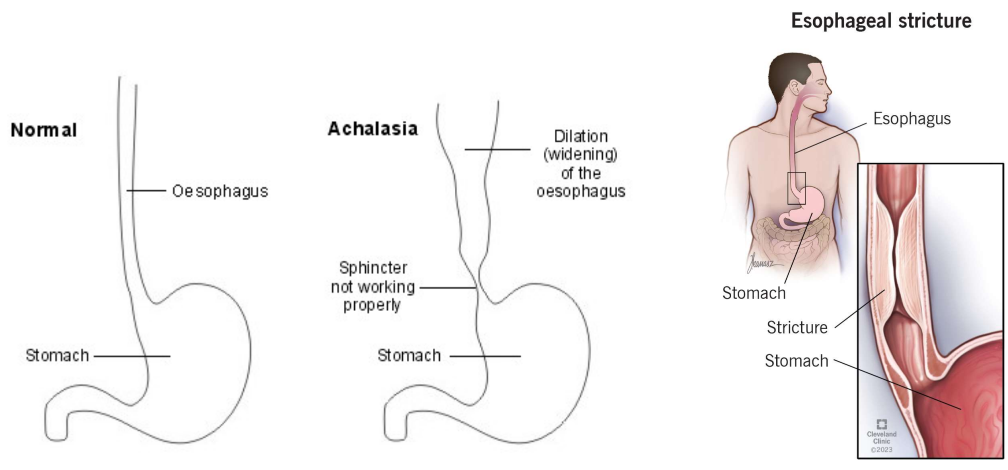
1.3.2 Achalasia

Achalasia is a primary oesophageal motility disorder characterized by incomplete relaxation of the lower oesophageal sphincter (LES) as shown in the figure (Fig. 1.5) and aberrant peristalsis in the oesophageal body (Jia et al. (2023)). It not only causes dysphagia and chest pain that impairs patients' quality of life but also leads to chronic oesophageal inflammation by food retention and eventually increases the risk of oesophageal cancer. Although achalasia was first reported in 1674, it is still not fully understood.

According to the research from Jia et al. (2023), achalasia is considered a rare motility disease, with an annual incidence and prevalence of 1.63/100 000 and 10.82/100 000, respectively. However, the data might be significantly underestimated due to difficulties in identifying patients with achalasia. It was estimated that approximately 27-42% of patients with achalasia used to be misdiagnosed because of their overlapping symptoms, such as heartburn and chest pain.

1.3.2.1 Symptoms of Achalasia

According to Romero-Hernández et al. (2018) and Savarino et al. (2022), the etiology and pathogenesis of achalasia cardia remain unclear; however, it is generally believed that the histological changes of the esophageal mucosa caused by the loss of oesophageal nerve cell function play a key role in its pathophysiology. Autoimmune



(a) (b)

Figure 1.5: Diagrams display the (a) geometrical changes in the shape of oesophagus before and after achalasia, (b) the contraction in the oesophageal muscles remain contracted due to the absence of peristalsis. (Source: www.socratic.org)

attack of esophageal myenteric nerves through cell-mediated and possibly antibody-mediated mechanisms may inhibit oesophageal smooth muscles, resulting in loss of nerve function and nerve fiber degeneration.

Pseudoachalasia, also known as secondary achalasia, refers to the esophageal motility disorder caused by dysphagia and weight loss due to gastric cardia tumors or infiltrating intestinal plexus tumors (gastroesophageal junction adenocarcinoma, pancreatic cancer, breast cancer, lung cancer, or hepatocellular carcinoma) (Ates and Vaezi (2015)).

1.4 Diagnosis and treatment

A hiatus hernia is typically identified during barium swallow examination, upper GI endoscopy, and high-resolution manometry.

1.4.1 Catheter as a first hand tool

A thin, rigid tube that is introduced through the nose or mouth in the oesophagus for the purpose of pre-diagnosis is called a catheter (Fig. 1.6). Catheters are among the most versatile and essential instruments used in cardiology. Where in the past they were designed as flexible tubes meant for monitoring or drug delivery, today catheters have evolved into more dedicated instruments with additional tip functionality. As such, a large variety of commercially available catheters exist, being adopted in several different treatments, including coronary stenting, repair of congenital heart defects, heart valve repair or replacement, and ablation of atrial fibrillation or ventricular tachycardia (Maisano et al. (2012), Joseph et al. (2013), Hascoet et al. (2013), Tobis and Abudayyeh (2015)).

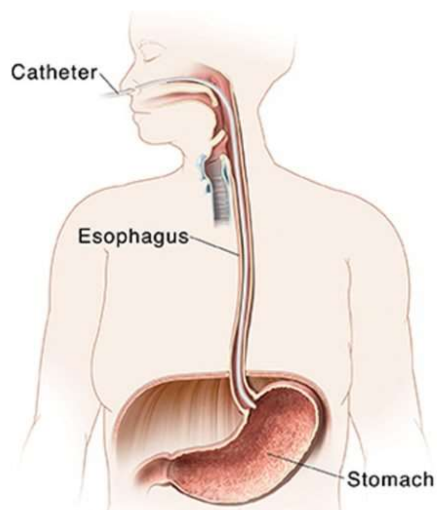


Figure 1.6: Diagram displays the introduced catheter in the oesophagus through a patient's nose up to the lower oesophageal sphincter. (Source: www.socratic.org)

1.4.2 Need of pre-diagnosis with catheter

For some years, patients may die with surgically operable oesophageal diseases such as Barrett's oesophagus, the presence of carcinoma, and certainly, many appear to be slow in growth. Perhaps too much optimism has been felt that long survival could be confidently expected if only the lesion could be removed without mortality

(Andolfi et al. (2016)). The oesophageal carcinoma in this organ behaves exactly like cancer in any other part of the alimentary canal, and about one-third disseminate early and rapidly. A pre-diagnosis approach to frequently remove such hindrances could be a better option to handle this situation (Kahrilas et al. (2008)).

1.4.3 Pre-diagnosis approach

Catheterisation techniques are used to perform pre-diagnosis in swallowing disorders, which also rules out the presence of other malignancies. Some of the approaches are discussed below:

1.4.3.1 Barium swallow radiography

Andolfi et al. (2016), state that this method provides important details on the amount of stomach herniation and the placement of the gastroesophageal junction. The study by Lebenthal et al. (2015) observed that barium swallow is still necessary to diagnose hiatal hernias. If the axial herniation is larger than 2 cm, hiatal hernias can be detected using this approach, according to Siegal et al. (2017). The extra advantage of studying bolus transit is offered by video-oesophagram, which the authors also suggest. The benefit of using barium swallow radiography to identify esophageal motility dysfunction, stenosis, and stricture associated with GERD is highlighted by Oleynikov and Jolley (2015). Radiation exposure is the primary drawback of this technique.

1.4.3.2 Esophagogastroduodenoscopy (EGD)

Contrary to barium swallow radiography, this approach has the benefit of real-time analysis of the mucosa of the oesophagus, stomach, and duodenum. This method is highly effective in identifying conditions such as erosive esophagitis, Barrett's oesophagus, Cameron's ulcer, and even lesions that may be cancerous (which must be reported in the event that a surgical procedure is taken in the future). In their clinical research, Collet et al. (2013) revealed that, particularly with regard to the organo-axial rotation of the stomach, it is frequently unable to visualize and appreciate a big hiatal hernia. It has also been suggested by Roman and Kahrilas (2014) that enlargement in the size of a hernia can happen with the excess air insufflation of the stomach. It's crucial to do a Barium swallow X-ray in addition to an endoscopic examination to accurately describe big hernias because endoscopic descriptions of these conditions are still not always ideal (Duranceau (2016)).

1.4.3.3 Oesophageal manometry

This technique is important in providing valuable information about the motility of an oesophagus. It has been observed by Andolfi et al. (2016) that to rule out achalasia or other motility disorders. One should go with oesophageal manometry before undergoing surgical interventions. According to Philpott and Sweis (2017), the prior diagnostic for hiatal hernia is favorable if the separation between the lower oesophageal sphincter and the crural diaphragm is about 2cm or more.

1.4.3.4 Balloon catheterisation

Understanding the mechanics of swallowing and achieving an accurate diagnosis is essential because effective management of dysphagia, a prominent symptom of achalasia, hinges on understanding its underlying cause. Pneumatic balloon dilatation, in particular, stands out as highly effective. Compared to procedures like oesophagrams or modified barium swallow studies (MBSS), it offers superior visualization of mucosal abnormalities and facilitates direct mucosal biopsies (Levine and Nielsen (1992)). However, limited information on its use as a primary treatment for pharyngeal dysphagia involves catheter insertion into the pharynx or oesophageal inlet (Solt et al. (2001)). This technique is increasingly used for managing oesophageal strictures across various gastrointestinal conditions. Balloon catheter dilatation has successfully treated both achalasia and oesophageal tumors (Choi et al. (2005), Tatum et al. (2007), Kim et al. (2008)). Blount et al. (2010) describe a procedure for managing oesophageal strictures using fluoroscopic guidance. Nurses insert a guide wire or feeding tube through the patient's mouth into the oesophagus, ensuring it passes beyond the stricture. A feeding catheter is then advanced into the gut, followed by an angiographic guide wire to navigate past the narrowed segment. Positioning the patient with a chin-tucked posture aids in correctly directing the tube or wire.

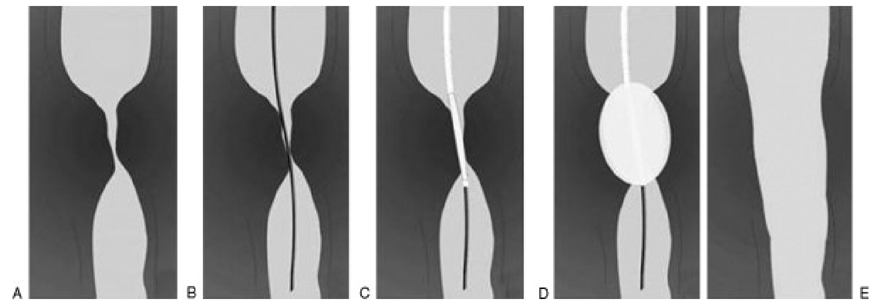


Figure 1.7: Diagram displays the introduced balloon catheter in the oesophagus affected with dysphagia. The different stages are reflected in the diagram, which shows the conditions of the oesophagus before and after the balloon catheterisation. (Source: www.socratic.org)

The next step involves advancing a balloon catheter over the guide wire to center it on the stricture. The balloon's diameter is chosen based on the stricture's size and the condition of the oesophagus, typically ranging from 6 to 20 mm in diameter for various types of strictures. Larger balloons, such as 18mm to 20mm in diameter, are commonly used in adults, while larger pneumatic balloons up to 30mm to 40mm in diameter are used for conditions like achalasia. Adjustments to balloon size may be made during the procedure based on the stricture's response to dilation.

According to Bhattacharyya (2014) and Wilkins et al. (2007), balloon dilatation may offer superior efficacy with a lower risk of oesophageal wall injury. However, initial endoscopy remains crucial for confirming diagnosis and ruling out malignancy. Each method presents distinct advantages and drawbacks, whether through its success rates, procedural simplicity, or complication risks. Treviso-Jones and Skidmore (2015) outlines various treatment options, including endoscopic pneumatic balloon dilatation (Fig. 1.7), Heller's cardiomyotomy, pharmaceutical therapies like nitrates and calcium channel blockers, and, more recently, Peroral Endoscopic Myotomy (POEM).

Endoscopic dilatation using bougie or balloon dilators is often successful in managing oesophageal strictures and other structural dysphagia, with myotomy considered for severe cases (Johnston (2017)). Achalasia can also be managed surgically or palliatively through endoscopic dilatation to improve quality of life (McCarty and Chao (2021)).

This study aims to assess the effectiveness of upper and lower oesophageal balloon catheter dilatation in severe dysphagia management.

1.4.4 Medical approach in the treatment of gastroesophageal reflux and sliding hiatus hernia

According to FA (1952), Kahrilas et al. (2008), Katz et al. (2013), basic medicinal interventions are sufficient for most patients to maintain acceptable control; therefore, surgery is unnecessary. It's usually not too difficult to avoid stooping, and there are easy ways to overcome the need to do so. It is recommended to sleep with your shoulders lifted on pillows or by blocking the head of the bed since these positions can provide significant relief. A limited, bland diet with small meals is best, and late meals should be prohibited. If discomfort persists, take a simple alkaline solution containing sodium bicarbonate before bed and after meals (Kahrilas et al. (2008)). A stringent basic ulcer regimen involving two-hour milk or semi-fluid meals is necessary if there is evidence of oesophagitis. Special hospital care is also necessary to prevent regurgitation. After every feeding, administer an antacid and a tablespoon of olive oil. However, it would be preferable to persuade a weak, old patient to continue on a restricted regimen rather than perform a big procedure. A patient who is severely disabled by this illness can become a joyful and well-integrated member of the community with the help of surgery (Katz et al. (2013)).

1.4.4.1 Design of catheter

The first malleable and elastic catheter was designed in 1779 by Bernard, a French jeweler and goldsmith. However, according to Kardeh et al. (2014), the design and development of a catheter are indebted to the works and theories of scientists from various civilizations. The Persian physicians described catheters and their different usages in their manuscripts. Their literature has valuable information about the miscellaneous treatment methods for gastrointestinal diseases, especially with catheters. These physicians pioneered the Iranian history of antique urology approximately ten centuries ago by providing many details about urethral catheterization. They mentioned catheters as a treatment of choice in specific bladder and urinary tract disease cases. Therefore, investigating gastrointestinal diseases was noteworthy information on the use of catheters and their development in a part of history that has significantly impacted modern medicine.

The best types of urinary catheters are made up of the softest skin types, such as the skin of marine animals or the tanned skin of usual animals. The tip of the catheter should be made up of tin or lead, and if the tin is very soft, it can be toughened by adding molten glass or white pyrite or by melting the tin several times in a mold casting and adding male goat blood each time. A retention balloon catheter, a more advanced rubber or woven fabric device, was developed in 1853. Modern urinary catheters, most frequently manufactured from latex, were introduced in the mid-1930s by Dr. Frederick B. Foley. Although synthetic polymeric bio-materials can achieve bio-compatibility to some extent, most available synthetic bio-materials have diverse side effects on human tissues and can be harmful in long-term use. However, some naturally derived bio-materials may achieve absolute bio-compatibility.

1.5 Fluids

A fluid is a substance that may flow, i.e., its constituent particles may continuously change their relative positions. Moreover, it offers no lasting resistance to displacement, however great of one layer over another. This means that if the fluid is at rest, no shear force can exist, i.e., a force tangential to the surface on which it acts. Depending on the flow, there are four types of fluid: rotational or irrotational, steady or unsteady, viscous or non-viscous, and compressible or incompressible. Moreover, based on the Newton's laws of viscosity of fluids, there are two types:

1.5.1 Newtonian fluid

A substance that is capable of flowing is termed fluid. Newtonian fluid is the real fluid for which stress is proportional to the strain rate. the constant of proportionality is known as viscosity. An equation describing Newtonian fluid behavior is given by

$$\tau = \mu\dot{\gamma},$$

where τ, $\dot{\gamma}$, and μ are shear stress, rate of shear strain, and viscosity coefficient, respectively. In other words, a real fluid obeying the Newtonian law of viscosity is called Newtonian fluid. A few examples are mercury, water, light oil, and some homemade food items.

1.5.2 Non-Newtonian fluid

A non-Newtonian does not obey the Newtonian law of viscosity. The non-Newtonian fluid's flow curve (shear stress versus shear rate) is non-linear or does not pass through the origin. Its effective viscosity is not constant at a given temperature and pressure but depends on flow conditions such as flow geometry, shear rate, etc. Most of the real fluids show non-Newtonian characteristics. Some examples are melted chocolate, honey, custard, toothpaste, raisin paste, polymer solutions, etc.

There are various types of non-Newtonian fluids. From the thesis point of view, we discussed only two of them: Micropolar fluid and Power-law fluid.

1.5.2.1 Power-law fluid

According to Bird et al. (1987), the power-law model is given by

$$\tau = \mu|\dot{\gamma}|^{n-1}\dot{\gamma},$$

where μ and n are the flow consistency index (effective viscosity $= \mu|\dot{\gamma}|^{n-1}$), and flow behavior index respectively.

If $n < 1$, the effective viscosity of the fluid diminishes with increasing shear rate, and the fluid is called shear thinning fluid (pseudoplastic). If $n > 1$, the effective viscosity of the fluid increases progressively with increasing shear rate, and the fluid is called shear thickening fluid (dilatant). The case $n = 1$, Newtonian case. One of the obvious disadvantages of the power-law model is that it fails to describe the viscosity of many non-Newtonian fluids in very low and very high shear rate regions.

1.5.2.2 Micropolar fluid

The term "simple micropolar fluid" was initially used by Eringen (1966). He claimed that the micropolar fluid described the microrotation effects of the microstructure model. After his initial study, this model caught the interest of numerous scientists, mathematicians, physicists, and engineers because the well-known Navier-Stokes theory did not previously describe the physical properties of suspension solutions, liquid crystals, animal blood, exotic lubricants, and fluid containing minor additives. They are crucial to engineers and scientists working on hydrodynamic-fluid problems and phenomena because they simulate fluids of particles floating in a viscous medium with randomly oriented particles (Lukaszewicz (1999)).

The equations governing the unsteady flow of an incompressible micropolar fluid ($a_c \leq R \leq H_1$) in the absence of body force and body couple as given by Devi and Devanathan (1975) are

$$\rho_c\Big(\frac{\partial w_r}{\partial t}+w_r\frac{\partial w_r}{\partial r}+w_z\frac{\partial w_r}{\partial z}\Big) = -\frac{\partial p}{\partial r}+\Big(\frac{2\mu_c+K}{2}\Big)\Big(\frac{\partial^2 w_r}{\partial r^2}+\frac{1}{r}\frac{\partial w_r}{\partial r}+\frac{\partial^2 w_r}{\partial z^2}-\frac{w_r}{r^2}-K\frac{\partial G}{\partial z}\Big),$$

$$\rho_c\Big(\frac{\partial w_z}{\partial t}+w_r\frac{\partial w_z}{\partial r}+w_z\frac{\partial w_z}{\partial z}\Big) = -\frac{\partial p}{\partial z}+\Big(\frac{2\mu_c+K}{2}\Big)\Big(\frac{\partial^2 w_z}{\partial r^2}+\frac{1}{r}\frac{\partial w_z}{\partial r}+\frac{\partial^2 w_z}{\partial z^2}\Big) + K\Big(\frac{\partial G}{\partial r}+\frac{G}{r}\Big),$$

$$\rho_c j\Big(\frac{\partial G}{\partial t}+w_r\frac{\partial G}{\partial r}+w_z\frac{\partial G}{\partial z}\Big) = -2KG+\Big(\frac{\partial^2 G}{\partial r^2}+\frac{1}{r}\frac{\partial G}{\partial r}+\frac{\partial^2 G}{\partial z^2}-\frac{G}{r^2}\Big)+K\Big(\frac{\partial w_r}{\partial z}-\frac{\partial w_z}{\partial r}\Big),$$

$$\frac{\partial w_r}{\partial r}+\frac{\partial w_z}{\partial z}+\frac{w_r}{r}=0,$$

where ρ_c, μ_c, p, t, w_r, w_z, G, j, K and γ are density, dynamic viscosity coefficient, pressure, time, component of velocity in r-direction, component of velocity in z-direction, non-vanishing component of the micro-rotation vector in the θ-direction, micro-inertia constant, coefficients of vortex viscosity and gyro-viscosity respectively. Note that in our case, $G = v_\theta$, w_θ, and $v_r = v_z = 0$.