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HISTORY OF MORPHOLOGY

Revisiting Avicenna's (980–1037 AD) anatomy of the abdominal viscera from the *Canon of Medicine*



Revisiter l'anatomie des viscères abdominaux selon le Canon de la Médecine d'Avicenne (980–1037 AD)

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Summary Avicenna (980–1037 A.D) was the most influential Iranian physician and philosopher in the medieval era. Avicenna composed and compiled treaties on various aspects of medicine in his famous book the *Canon of Medicine*. Avicenna's treaties have inspired countless debates in all fields of medicine including basic medical sciences. In his treaties, Avicenna adopted the practical approach to the descriptions of the human body and the diseases associated. He made substantial contribution to the medical literature and medical education through his observations and clinical studies. In the current treaties we analysed the anatomy extracts on the topographic and functional anatomy on the abdominal viscera including the gastrointestinal tract presented in the *Canon of Medicine* and compared to them to extant anatomical textbooks, particularly those adopted in modern curriculums. We found that Avicenna described fairly the anatomy and topographic relations of the abdominal viscera and associated digestive organs. Avicenna's anatomy contributed immensely to the evolution of anatomical sciences and related medical disciplines despite being written 1000 years ago.

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Résumé Avicenne (980–1037 après J.-C.) était le médecin et philosophe iranien le plus influent de l'époque médiévale. Avicenne a rédigé et rassemblé plusieurs traités sur divers aspects de la médecine dans son célèbre livre le *Canon de la Médecine*. Les écrits d'Avicenne ont provoqué d'innombrables discussions dans tous les domaines de la médecine, y compris les sciences médicales de base. Dans ses ouvrages, Avicenne a opté pour la description pratique du corps humain et des maladies observées. Il a considérablement contribué à la littérature et à l'éducation médicale à travers ses observations et études cliniques. Dans les traités actuels,

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nous présentons une analyse des extraits d'anatomie topographique et fonctionnelle des viscères abdominaux, y compris la description du tractus gastro-intestinal du *Canon de Médecine* et en les comparant à celles des manuels anatomiques actuels, en particulier ceux adoptés dans les *curricula* modernes. Nous avons trouvé qu'Avicenne décrit assez bien l'anatomie et des relations topographiques des viscères abdominaux et des organes digestifs associés. L'anatomie d'Avicenne a beaucoup contribué à l'évolution des sciences anatomiques et des disciplines médicales connexes malgré des écrits d'il y a 1000 ans.

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Introduction

Ibn Sina, known as Avicenna in Western societies (980–1037 A.D) was the most influential Iranian physician and philosopher [1–3]. He was born in Bukhara, an ancient Persian city in 980 AD and died in the year 1037 AD in Hamadan, Iran [3–5]. Avicenna authored the *Canon of Medicine*, a textbook which became the most famous medical encyclopaedia of the medieval era until the 16th century [6]. The book was adopted as the main medical reference textbook in the Middle East and Western universities [4]. In his treatises, Avicenna adopted the practical approach to the descriptions of the human body and diseases associated [7]. This experimental approach was adopted as the domain in the medical and scientific practise till date. In addition, he emphasised the importance of learning the anatomy of the human body and encouraged physicians to consider the normal anatomy of organs in their diagnosis [8–11]. Avicenna compiled all the medical information available to him from his predecessors such as Aristotle, Galen and Abubakr Muhammad Ibn Zakaria Razi (also known as Razes 865–925 AD) and supplemented with his own information gained from surgical practice and observations. There is no consensus as to whether Avicenna performed human cadaver dissections or undertook it in secret considering that during his time human dissections were prohibited in the Muslim religion [4]. However his findings about the human body were to a larger extent correct and novel for his time.

Avicenna's treatises have inspired countless debates in all fields of medicine including basic medical sciences. In basic medical sciences such as anatomy, several studies have been reported to date analysing the validity of Avicenna's concepts in modern curriculums [1,4–6,8,12–15]. Conforming to the ancient Persian and Greek medicine (*Unani-Tibb*) philosophy, Avicenna advocated for the prevention of disease rather than cure for the maintenance of health [16,17]. In the human body the concept of temperament extends from cells to tissues, organs and finally to each individual resulting in a unique temperament [8,17]. This is broadly characterised as four humours which are produced by the liver, namely; sanguineous (bloody), phlegmatic, bilious (also known as choleric) and melancholic; each with its unique overall qualities [8,17,18]. The *Tibb* philosophy states that as long as the overall quality of the humours is in agreement with the overall quality of the temperament of

an individual, homeostasis (or harmony) will be maintained [8,17]. Whilst the overall quality of an individual's temperament is fixed, the overall quality of humours is subject to change arising from the lifestyle factors such as food and drink, environmental air and breathing, movement and rest, sleep and wakefulness, and emotions and elimination [19].

Part sixteen (16) of the third book in the *Canon of medicine* describes the anatomy of the gastrointestinal system and associated viscera and introduces concepts on some mechanical diseases of the intestines such as volvulus and intestinal obstruction. Avicenna noted that the aetiology of the two conditions was mainly from the tearing of the ligaments (mesenteries) [10,11,20,21], which supports the intestines from the posterior abdominal wall [22,23]. Besides, Avicenna hypothesised that the overall length and thickness of the intestines was related to the efficiency for digestion, absorption and evacuation of faeces [10,21]. In addition the structure and functional correlations of accessory digestive organs and some abdominal organs were established in the *Canon of Medicine* (Fig. 1). The current study analysed the descriptions of the anatomy of the digestive tract, accessory organs and some abdominal organs as viewed by Avicenna in the *Canon of Medicine* and compared them to modern extant anatomy literature, particularly to the medical textbooks commonly used in medical schools.

The oesophagus

Avicenna recognised that the oesophagus consists of both muscular and mucosal layers with the latter being thrown into folds. He described the mucosa of the oesophagus as folded vertically to allow for easy passage of food during swallowing [10,11,21]. According to Avicenna, the longitudinal folds of mucosa create a suction pressure gradient that pulls the food bolus downwards into the stomach during swallowing [10,11,21]. Avicenna mentioned only the circular layer of muscle on the outer wall of the oesophagus, which he described as orientated horizontally and perpendicular to the longitudinal folds of mucosa [10,11,21]. He also stated that the upper portion of the muscular layer consists of skeletal muscle, which helps to move the trachea upwards during swallowing [10,11,21].

In modern anatomy, the oesophagus is a fibromuscular tube extending from the pharynx to the stomach and

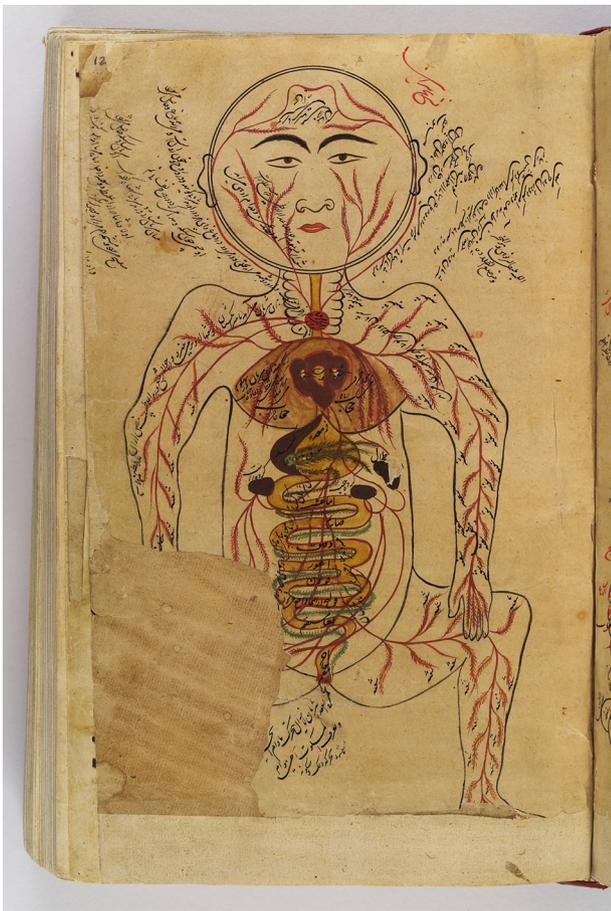


Figure 1 Avicenna's drawing of the gastrointestinal system in the *Canon of Medicine*. The image was obtained internet open source courtesy of Wellcome library.

conveys ingested food [23]. The submucosa and the mucosa in the empty oesophagus form longitudinal folds that give the lumen an irregular outline [24]. During swallowing the longitudinal folds of mucosa temporarily disappears and reappear thereafter [24]. The muscular layers of the oesophagus consist of two layers; the outer longitudinal and inner circular layers [23]. The outer longitudinal muscle layer of the oesophagus consists of striated muscle in its superior third; the inferior third is composed of smooth muscle, and the middle third is made up of both types of muscle tissues [23,24].

Avicenna described the topographic relations of the oesophagus to other cervical structures concisely. He mentioned that the oesophagus is located in front of the cervical vertebrae and behind the trachea where it gains protection from both structures [1,5,10,11,21]. Avicenna further mentioned that the oesophagus descends into the thorax slightly on the left side from the first thoracic vertebra (T1) to the fourth thoracic vertebra (T4) and at the level of the fourth thoracic vertebra (T4), the oesophagus shifts slightly to the right to make way for the arch of the thoracic aorta [10,11,21]. At the oesophageal hiatus, Avicenna mentioned that the oesophagus is surrounded by a ligament, which raises it during the movements of the diaphragm and prevents compression and damage of the thoracic aorta and the accompanying nerves respectively [10,11,21].

In modern descriptions, the oesophagus within the thorax and distal to the arch of the aorta, shifts back to the left side and pierce the diaphragm at the level of the 10th thoracic vertebra [23]. In addition, the oesophagus is attached to the margins of the oesophageal hiatus by the phrenico-oesophageal ligament, which permits independent movement of the diaphragm and the oesophagus during respiration and swallowing [23]. Below the diaphragm, the oesophagus shifts further to the left side of the 11th and 12th thoracic vertebra and dilates to form the cardia of the stomach orifice [23].

Avicenna described the relationship between the oesophagus and the vagus nerves throughout their course from the neck to the stomach. He mentioned that nerves from the brain descends on either side of the oesophagus, pierce the diaphragm together with the oesophagus and twist around it just before the stomach and innervate its orifice [10,11,21]. The two vagus nerves descend as right and left trunks to the oesophagus, at the oesophageal hiatus, they become anterior and posterior gastric branches, which supply the oesophagus and the cardiac region of the stomach together with contributions from the thoracic sympathetic trunks [23]. According to Avicenna, the innervation to the cardiac region of the stomach senses hunger and the need for nutrition and informs the brain of an individual or animal. In modern understanding the feeling of hunger is driven by a complex interaction of chemical signals in the hypothalamus, which are triggered by the sight, smell, and or memory of food. An empty stomach also triggers the release of the ghrelin hormone, which is a neuropeptide hormone that regulates appetite and gastric feeling [25].

The stomach

Avicenna described the stomach as a continuation of the oesophagus below the diaphragm. He affirmed this by describing the similarity in the orientation of the mucosa between the oesophagus and stomach [10,11,21]. Avicenna described the pyloric part of the stomach as a continuation into the duodenum and also as a sphincter that regulates gastric emptying thereby facilitating digestion. Avicenna mentioned that the stomach has a greater curvature that is associated with a large artery and also the attachment of the peritoneum [10,11,21]. He described the blood supply to the greater curvature of the stomach through the right gastro-omental artery and its numerous branches. In addition, he stated that the peritoneum connects the stomach with other organs [10,11,21]. Avicenna mentioned that the liver and the spleen lie to the right and under (posterior) to the stomach respectively. The close relationship of the stomach to the other abdominal organs was regarded as a vital source of heat under the temperamental theory and the heat helped in the digestion of food [10,11,21].

In modern terms, the stomach represents a dilated portion of the alimentary tract between the oesophagus and the small intestines (duodenum), which is specialised for the accumulation of food and prepares it for both chemical and mechanical digestion [23]. Avicenna accurately described the topographic anatomy of the stomach and its related organs.

The peritoneum

According to Avicenna, the peritoneum consists of an outer layer (parietal) which reinforces the abdominal wall in addition to abdominal muscles and the inner (visceral) layer which covers abdominal contents [10,11,21]. This description of the peritoneum persists in modern anatomy whereby the parietal peritoneum lines the abdominopelvic wall and the visceral peritoneum invests the visceral structures [22,23]. The two layers of the peritoneum are in essence made up of one continuous layer lining the abdominopelvic cavity during embryological development; the separation into parietal and visceral layers comes into effect after the invagination of developing of organs into the abdomen through the posterior layer of the peritoneum [22,23]. Avicenna described this arrangement and mentioned that the inner and outer layers of the peritoneum attaches at the diaphragm and both layers fuse at the posterior abdominal wall [10,11,21]. Furthermore, Avicenna described the deep inguinal rings in relation to the peritoneum and their functions of conveying blood vessels through the anterior abdominal wall, particularly spermatic arteries in males. Avicenna cautioned that if the deep inguinal ring is larger than normal, intestines can herniate through it. In modern literature the congenital (indirect) inguinal herniation is defined as the passage of intestinal loops through the deep ring into the inguinal canal following increased intra-abdominal pressure [22,23]. Congenital inguinal herniation is more common in males than in females and is associated with intestinal torsion, compression of testicular arteries and necrosis of testicular tissue.

In agreement with modern anatomic descriptions, Avicenna noted that the aorta and the inferior vena cava were located behind the parietal peritoneum (retroperitoneal). He also stated that all digestive organs were covered by the peritoneum. Although in modern anatomy some sections of the abdominal organs such as the duodenum have large sections (second and third parts) which are retroperitoneal. Besides, Avicenna stated that peritoneum attaches the stomach to other organs and specifically described the greater omentum, emphasising on its broad distribution and its fat composition [10,11,21]. Avicenna ascribed the function of heat production to the greater omentum and suggested that the heat facilitates digestion in the stomach thereby maintaining the temperament of the organ. Structurally, the peritoneum forms ligaments and mesenteries that support abdominal contents against each other and from the posterior abdominal wall respectively. It also helps to distribute blood vessels and nerves to visceral organs [22,23].

The liver, gall bladder and spleen

The liver was observed to lie on the right side of the body and its topographic and functional anatomy was well elucidated in *Canon of Medicine*, particularly its relations to the stomach and the right dome of the diaphragm. Avicenna described the intimate relationship of the convex surface of the liver to the right dome of the diaphragm and suggested that the dome shape of the diaphragm allows for free movement of the diaphragm and also acting as fan over the liver

[10,11,21]. He also described the covering of the convex surface of the liver with the lower ribs. Besides, Avicenna described the attachments of the liver to the stomach and the diaphragm through the omentum, and ligaments respectively. The liver is attached to the diaphragm through the reflections of the visceral peritoneum on the diaphragm and the liver, which forms the anterior and posterior coronary ligaments [23]. In addition, the falciform ligament attaches it to the anterior abdominal wall and conveys the left umbilical vein during embryologic development [22,23]. Avicenna described the connections of the liver to the heart through the inferior vena cava [10,11,21]. The concave surface of liver corresponds to the visceral surface in modern anatomic descriptions and according to Avicenna the inferior vena cava exits this surface to supply blood to the rest body while the portal vein brings nutrient rich blood from the intestines and enters the concave surface of the liver. In the *Canon of Medicine*, the shape and overall description of the gross structure of the liver compares to that of the carnivores (particularly the dog), with five lobes indicating that Avicenna performed animal dissection instead of human cadavers a practise, which was forbidden during his time. This description of the structure of the liver can be traced back to Galen (200 A.D) and was carried over during Avicenna's time. However, Avicenna further analysed the structure and innervation to the liver. He mentioned that the parenchyma of the liver has no nerves and these were distributed on the tough membrane covering the liver. The tough membrane alluded to by Avicenna is the Glisson's capsule named after Francis Glisson following his book on the liver in 1659. On its nature and function, Avicenna regarded the liver as a blood forming organ and hence its reddish brown colour. In addition, Avicenna mentioned that the functions of the liver were associated with the production of four humours including clean blood, water, yellow bile (bilious humour) and black bile (atrabilious humour). He stated that the humours will be distributed as clean blood to the rest of the body through vessels; water through the branches of the inferior vena cava to the kidneys; yellowish bile to the gallbladder through the common hepatic duct and the black bile to the spleen through vessels [11,21,26]. Avicenna opined that the analysis of urine can determine the health of the liver and that the liver indirectly contributes to the production of urine [10,21,26]. The liver is the central organ of metabolism and its waste by-products are filtered and excreted by the kidneys as urine.

Avicenna mentioned the gallbladder and described it as a sac, which receives bile from the liver [10,11,21,26]. Topographically, Avicenna stated that the gallbladder lies on the concave surface of the liver closer to the stomach. In agreement with modern anatomy, Avicenna described the biliary tree although he did not mention the anatomical names of its tributaries. He mentioned that bile from the liver is channelled to the gallbladder through deep vessels and excreted to the duodenum. In addition, he described the anatomic variations of the presence of either major and minor or both duodenal papillae in different people. Avicenna suggested that bile is used for cleaning extra foam from the intestines and for the purification of blood. Biochemically, bile helps with the emulsification of fats during digestion and increases their absorption; it also facilitates the absorption of the fat-soluble substances, such as the vitamins A, D, E, and K [27].

Besides its digestive functions, bile also serves as the route for excretion of bilirubin; a by-product of red blood cells recycled by the liver [27]. The anatomy of the human spleen was not well enumerated in the *Canon of Medicine*. Instead, the tongue like shape described by Avicenna corresponds to the bovine spleen suggesting that he studied the anatomy of this organ in animal models. Despite the lack of the knowledge of the lymphatic system, Avicenna understood the function of the spleen in fighting diseases [2]. He mentioned that the spleen receives black bile (atrabilious humour) from the liver and also digest residues from burned blood (sanguineous humour) thereby cleaning the blood. Apart from immunological functions, the spleen is involved in the filtration of blood removing dead red blood cells from the body [24].

Intestines

Avicenna presented elaborate information on the anatomy of the intestines, dividing them into six parts in correct sequence whose names are still returned in modern anatomy including duodenum, jejunum, ileum, caecum, colon and the rectum. He opined that the length, twisting course and varied thickness of the intestines were adaptations for effective digestion, absorption and holding of waste. Avicenna associated the smaller lumen of the upper part of the intestines (small intestines) with effective digestion and absorption of nutrients. Avicenna mentioned that bile ducts open into the duodenum and this corroborates the modern descriptions where the major and minor duodenal papillae empty into the second part of the duodenum [23]. Avicenna analysed the similarities and differences on the structure and vascularity of the duodenum, jejunum and ileum and concluded that the jejunum and ileum contain circular folds of mucosa (*plicae circulares*) whereas the duodenal mucosa lacks them. He suggested precisely the function of *plicae circulares* in slowing the flow of chime along the intestines and increases the efficiency of digestion and absorption. In addition, Avicenna mentioned that the jejunum has abundant blood vessels including branches of the portal vein. According to Moore et al. [23] the jejunum has great vascularity; consisting of large, tall and closely packed circular folds of mucosa than the ileum. The caecum and colon were described as the most dilated parts of the intestines and were ascribed the functions of collecting and maturation of stools and absorption of excess materials [10,11,21,26]. He mentioned that the caecum was a blind pouch lying on the right side of the body and has higher chances of herniation [10,11,21,26]. Besides, he observed the continuous distribution of the tributaries of the portal vein on the colon and affirmed that absorption takes place in the colon. In modern anatomy, the large intestines are involved in the absorption of excess water from indigestible residues and prepare and store faeces temporarily [23]. Avicenna described the rectum as a straight and dilated tube leading into the anal canal. In addition, he described the topography of the rectum as positioned anterior to the sacral bones and closely associated with external musculature of the pelvic floor, which aid in defecation.

Conclusion

Avicenna expounded on the structural, topographic and functional anatomy of the digestive and associated organs fairly and comparable to modern anatomic descriptions. He emphasised on the topographic relationship of organs in maintaining their temperament and efficiency. He also recommended on the importance of the anatomy and health of the intestines to physicians for effective treatment of various illnesses.

Author contributions

PM and RB conceptualised the research topic and carried out literature search; PM wrote the initial manuscript; PM and RB revised the manuscript and PM and RB approved the final draft of the manuscript.

Disclosure of interest

The authors declare that they have no competing interest.

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