



The structure and function of the cardiorespiratory apparatus.

An analysis of historical vignettes by Ibn Sina in the Canon of Medicine

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Introduction

Ibn Sina, also known as Avicenna in the West, is regarded as one of the greatest physicians, thinkers and medical scholars in history (Hajar, 1999; Rahman and Hussein, 2013). In volume three of his famous book, the Canon of Medicine, Ibn Sina explained explicitly the anatomy, function and pathophysiology of the diseases affecting the heart and lungs. On the anatomy and function of the heart, Ibn Sina regarded the heart as an organ which controls the function of other organs, including the brain (Tayab, 1986). He

also referred to the heart as a point of origin/ source of the vital power. Avicenna's views on the role of the heart contradicted those of earlier philosophers like Aristotle who associated the heart with functions of sensation, pain, pleasure and nutrition (Rahman and Hassan, 2013). On the contrary, Ibn Sina assumed the heart is the source of psychic and emotional activities and also involved in the supply of blood and/or breath to every part of the body (Tayab, 1986). Avicenna contributed significantly to cardiology, where he initially described blood circulation and valvular functions (Loukas et al., 2016). His most important contribution is the correct description of the pulse when he stated that, "every beat of the pulse comprised two movements and two pauses. Thus, expansion: pause: contraction: pause" (Avicenna, 1658; Bakhtiar, 1999; Hajar, 1999). The interpretation of the cardiac pulse is still being emphasised in medical training as an important diagnostic tool for cardiac dysfunction.

Ibn Sina also discussed in detail the anatomy of the lungs and the various diseases and treatments associated with the respiratory system during his time. On the mechanics of respiration, Avicenna described the events which take place during normal inspiration and expiration, structures involved, and also forced respiration (Hashemi and Raza, 2009). Ibn Sina described the various diseases, aetiologies and treatments of respiratory disorders, and he also cautioned on the contagiousness of tuberculosis (Hashemi and Raza, 2009). In the present critique we analyse the functional and anatomic descriptions of the heart, airways and the lungs as viewed by Ibn Sina in the Canon of Medicine, and compare them to modern anatomy texts.

Materials and methods

This chapter presents extracts which focus on the anatomy and function of the cardiorespiratory system from Volume 3 of the Canon of Medicine written by Ibn Sina and translated by Bakhtiar, (1999). The chapters are outlined as shown below:

- On Description of the Larynx, Trachea and Lungs 379-383
 - On the Larynx
 - On the Trachea
 - On the Lungs
 - On the chest
- On the description of the heart 505-507

Discussion

The respiratory system consists of a system of interconnected air passages and the lungs. The respiratory system is closely related to the cardiac system both structurally and functionally. In this critique we will discuss the anatomy of the respiratory system first, followed by the cardiac system. The lungs are connected to upper respiratory apparatus (the nose, oral cavity, pharynx and larynx) by the trachea. The trachea as viewed by Avicenna consists of a series of tracheal rings which are closer to a half circle (Avicenna, 1658). He further noted that the trachea is positioned anterior to the oesophagus and the part closer to the oesophagus posteriorly is membranous, to allow for distension during swallowing (Bakhtiar, 1999). Superiorly, the trachea connects with oesophagus through the upper portion of the larynx and inferiorly the trachea divides into two parts which penetrate the right and left lungs (Bakhtiar, 1999). According to Ibn

Sina, the larynx is made up of three cartilages joined together by muscles and membranes (Avicenna, 1658). He also observed that the larynx contains vocal cords inside, which are responsible for the production of voice and obstructing of the breath in groaning sounds (Avicenna, 1658; Bakhtiar, 1999). These anatomic descriptions of trachea and larynx complement well with modern anatomy. Slight variations can be regarded as errors of omission emanating from lack of finer dissections, since technical development was still beginning during Ibn Sina's time. According to Moore et al. (2014), the trachea communicates superiorly with the larynx at the level of sixth cervical vertebra (C6) in the neck. Inferiorly it stretches into the thorax where it terminates by diving into the left and right bronchi at the level of the intervertebral disc between the fourth and fifth thoracic vertebra (T4/T5). Structurally, the larynx is made up of nine small and large cartilages which are connected by joints, membranes and muscles (Williams and Warwick, 1980; Moore et al., 2014). In agreement with Ibn Sina, the vocal cords function in both voice production and preventing entrance of food particles and water during swallowing into the respiratory tract (Williams and Warwick, 1980). The trachea is made up of the incomplete circular cartilages posteriorly, the deficient is completed by the trachealis muscle, an involuntary smooth muscle (Moore et al., 2014). On its function, Ibn Sina concurred with modern anatomic descriptions that it serves a conduit or air passage between the lungs and outside environment (Bakhtiar, 1999; Moore et al., 2014). In addition Avicenna noted that tracheal rings serve to prevent collapse of the tracheal tube, and to also act as a shield protecting the vital neck structures from the front, especially the muscular oesophagus posteriorly.

Physiologically, the terminal bronchioles are closely related to the blood vessels (venules and capillaries) (Moore et al., 2014). This arrangement increases the surface area for gaseous exchange between the lung tissue and the blood vessels. Considering the period at which Avicenna wrote, his treatises on microscopic dissection was not common, hence he only noticed the closeness of branches of the trachea, arteries and veins in the lung tissue.

According to Avicenna the lung is made up of “slack and wobbly airy flesh that is created from the moist diluted and gentle blood” (Bakhtiar, 1999). The slackness and wobbliness nature of lungs enable them to take in air during breathing. Physically, Ibn Sina observed that each lung occupies a separate compartment in the chest cavity (Bakhtiar, 1999). The partitioning of the chest wall is made up of a wall of double membrane stretching from the sternum anteriorly to the vertebral column posteriorly. In current anatomy text books, the mediastinum is described which represents the partitioning of the space in the middle of the thoracic cavity into three major spaces which houses the great vessels and the heart (Moore et al., 2014). Lateral to this space on both sides the thoracic cavity contains the lungs (Moore et al., 2014) a description which complements Avicenna’s assertions. Concurrent with modern anatomy, Ibn Sina affirmed that the left lung has two parts/ lobes while the right lung has three (Avicenna, 1658; Bakhtiar, 1999). The right lung is larger than the left and it is divided by the oblique and horizontal fissures into three distinct lobes while the left lung only has the oblique fissure hence it has two lobes (Moore et al., 2014).

Avicenna noted that lung tissue is porous and white in colour, to which he ascribed the porousness with the functions of dispensability during inspiration and the white colour being as the result of less blood than air in the lungs (Avicenna, 1658; Bakhtiar, 1999). According to Moore and colleagues, the terminal bronchioles of the lungs leads into respiratory bronchioles which are characterised by numerous air sacs called alveoli surrounded by pulmonary and bronchiole capillaries and pulmonary venules (Moore et al., 2014). The arrangement of the alveoli and associated blood vessels represent a respiratory unit where oxygen is extracted from the alveoli into the blood vessels and carbon dioxide is excreted from the blood vessels into the alveoli and subsequently into the atmosphere during expiration. In line with this philosophy, Ibn Sina opined about respiration and stated that “respiration serves the purpose of taking air into the blood and exhaling the noxious mist” (Avicenna, 1658). Structurally the lung tissue is light, soft and spongy with elastic recoil nearly to a third of its original size (Williams and Warwick, 1980; Moore et al., 2014). Ibn Sina’s descriptions on the lungs not only influenced the anatomy and physiology of these organs but also their pathology and surgical interventions. In support of these assertions Avicenna noted that each lung is divided into parts which are functionally independent (Bakhtiar, 1999). He stated that “the lung is in two parts because if one part of it is damaged, the other part will perform its own function and the function of the other one as well” (Avicenna, 1658; Bakhtiar, 1999). In modern anatomic descriptions each lobe of the lung is further divided into structurally and functionally distinct units referred to as bronchopulmonary segments and these segments can be surgically removed during partial pneumonectomy (Moore et al.,

2014). In addition pathologies of the lung can be localised to a focal point i.e. the bronchopulmonary segment, to the whole lobe and the whole lung (Moore et al., 2014). Partial and or total pneumonectomy has become increasingly popular because of any increase in acquired lung diseases emanating from life style such as smoking and living in populated environments.

Apart from the fact that lungs facilitate gaseous exchange between the internal environment and the atmosphere, Ibn Sina proposed that the lungs also prepare and serve the air to the heart (Bakhtiar, 1999). The air from lungs will help to moderate the animal's heart beat and driving the vital energy (Bakhtiar, 1999). Avicenna also opined that the lungs help to cool the heart by each beat (Avicenna, 1658). This is analogous to the wings of a bird and its body where the wings represent the lungs and the body or torso represent the heart and as the lungs flap they bring a cool breeze to the heart keeping it cooler from its hot temperament. In addition the lungs also surround and cushion the heart from the thoracic wall and also protect it from penetrating objects (Bakhtiar, 1999).

On the sensation of lungs, Ibn Sina noted that the lungs are surrounded by a neural membrane which is sensitive, and enables the lungs to perform their function (Avicenna, 1658). In modern anatomic descriptions the sensitive neural membrane can be compared to the pleural membranes both parietal and visceral pleurae which are sensitive to general and visceral sensation respectively. The parietal pleura is closely applied to the thoracic walls and is innervated by phrenic nerves and intercostal nerves while the visceral pleura which is closely applied to the lung tissue is innervated by the

autonomic nervous system through the vagus nerve and sympathetic chain (Williams and Warwick, 1980; Moore et al., 2014).

On the anatomy of the heart, Ibn Sina reported that the heart is located in the thoracic cavity, more on the left side compared to the right side, and surrounded by a thick membrane which offers protection from injury (Bakhtiar, 1999). In agreement with Ibn Sina's assertions, the heart is found in the thoracic cavity, covered by a double layer of pericardium and located in the middle mediastinum and oriented to the left (Williams and Warwick, 1980; Moore et al., 2014). In addition, the outer fibrous pericardium is a tough membrane which offers protection to the heart (Moore et al., 2014). Although the heart is surrounded by the tough pericardium, the membrane allows enough space for the heart to expand during diastole and contract during systole (Bakhtiar, 1999; Moore et al., 2014). Structurally, Avicenna concurred with Aristotle's views that the heart has three ventricles, the right, middle and left ventricles (French, 1978; Bakhtiar, 1999). The middle ventricles was ascribed the function of acting as passage way between the two right and left ventricles and also as storage of nourishment to the heart (French, 1978; Bakhtiar, 1999). The function of the middle cavity as a communication passageway between the right and left ventricles might be linked to Galen's views, where he noted a porous interventricular septum linking the right and left ventricles (French, 1978). Ibn Sina also noted that the heart had two ear-like structures at the site of entrance of blood vessels, and that the left ventricle was thicker than the right, since they carry different functions (Bakhtiar, 1999). These anatomic descriptions about the heart were not entirely erroneous; one would argue that the three chambered heart observed by Ibn

Sina was at that stage during the embryonic partitioning of the heart where two atria have already partitioned into two and the interventricular septum is still forming. On the other hand this can be contentious considering that accurate medical imaging devices were not yet popular to enable viewing of the various stages during embryonic development. However the adult heart has four chambers two atria and two ventricles, separated by the interatrial septum and interventricular septum respectively (Williams and Warwick, 1980; Moore et al., 2014).

The ear-like structures are auricular appendages which are remnants of the embryonic atria. They are located close to the site of entrance and exit of the great vessels of the heart on its superior border (Moore et al., 2014). The left ventricle of the heart pumps blood to the rest of the body and its walls are thick in order to enable it to generate much needed force, while the right ventricle only pumps blood to the lungs, and hence its walls are thinner (Moore et al., 2014). Functionally, Avicenna described, correctly, that the heart fills with blood during diastole. In addition he observed that the aorta contained at its origin three valves, which open when blood flows into the aorta during contraction, and closes during relaxation of the heart. This prevents back flow of blood into the left ventricle (Bakhtiar, 1999). Ibn Sina's description of the circulation of blood between the heart and lungs and also to the rest of the body set the ground stage for Ibn al-Nafis (1288 A.D) who later refined and described the pulmonary circulation, which is popularly regarded as a discovery by William Harvey in the West.

Conclusion

Whilst Ibn Sina's anatomy of the lungs and the heart as described in the Canon of Medicine is not as accurate as it is today, he contributed greatly to the knowledge of the cardiorespiratory system. Some of the techniques like pulse taking and assessment of breathing are still valuable in modern medical practice. However, his anatomy on the structure and positioning of the lungs and the heart brings an added dimension that illustrates perfection in the creation of the human body (Yahya, 2001). This is illustrated in Ibn Sina's description of the larynx where the vocal cords function in both voice production and preventing entrance of food particles and water during swallowing into the respiratory tract; as well as his description that the lungs surround and cushion the heart from the thoracic wall and also protect it from penetrating objects.

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