



A critical appraisal of Ibn Sina's treatise on vascular anatomy: Comparison with modern Anatomic descriptions

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Introduction

The circulatory system and its underlying mechanism remained a mystery until the 7th century C.E (Azizi et al., 2008). Several theories were described in relation to the heart and vessels although there was no understanding of the cardiovascular functions. Circulation of blood was first mentioned in ancient Chinese literature in their traditional medicine but was not associated with associated with the plumbing of the heart instead it was caused by opposing forces of *Yin* and *Yang* (Azizi et al., 2008). Aristotle and ancient Indians regarded the heart as source of nervous system, emotions and control mechanism of rest of the body. Hippocrates (460-370 B.C) thought that the liver and the spleen were responsible for the production of blood which will then travel to the heart for warmed and or cooled by air from the lungs (Figure 1)(

Azizi et al., 2008; Aird, 2011; Zarshenas and Zargaran, 2015). Aristotle (384-322 B.C.) described the three chambered heart but noticed that blood filled with breath leave the heart through a large vessel called the aorta (Azizi et al., 2008).

Physiologically the earlier concepts about circulation were based on the refinement of ingested food in the liver to produce blood which will be distributed in veins throughout the body where it will be assimilated and incorporated into flesh (Aird, 2011). Venous blood, in addition to nutrition also contained other humours, including yellow and black bile (Aird, 2011). In ancient Greek medicine *Unani*, the *humoral theory* is based on the hypothesis that each individual has an ideal humoral balance which is made up from the four humours namely blood (sanguinous), phlegm (serous), yellow bile (bilious), black bile (melancholic) (Emtiazy et al., 2012). According to *Unani* (Tibb) philosophy as long as the ideal humoral balance of an individual is maintained, health (homeostasis) will prevail (Gir et al., 2013; Mosaddegh et al., 2013).

In modern medicine the concepts of blood circulation by William Harvey (1578-1657 AD) are regarded as a turning point, however a lot of information has been disregarded prior to Harvey. In addition as Harvey stated “there is no science which does not spring from pre-existing knowledge” (Aird, 2011). Thus in this article we shall present and analyse the anatomical concepts written by Ibn Sina (980-1037 AD) in his famous book the Canon of medicine and compare them to modern understanding in human anatomy.

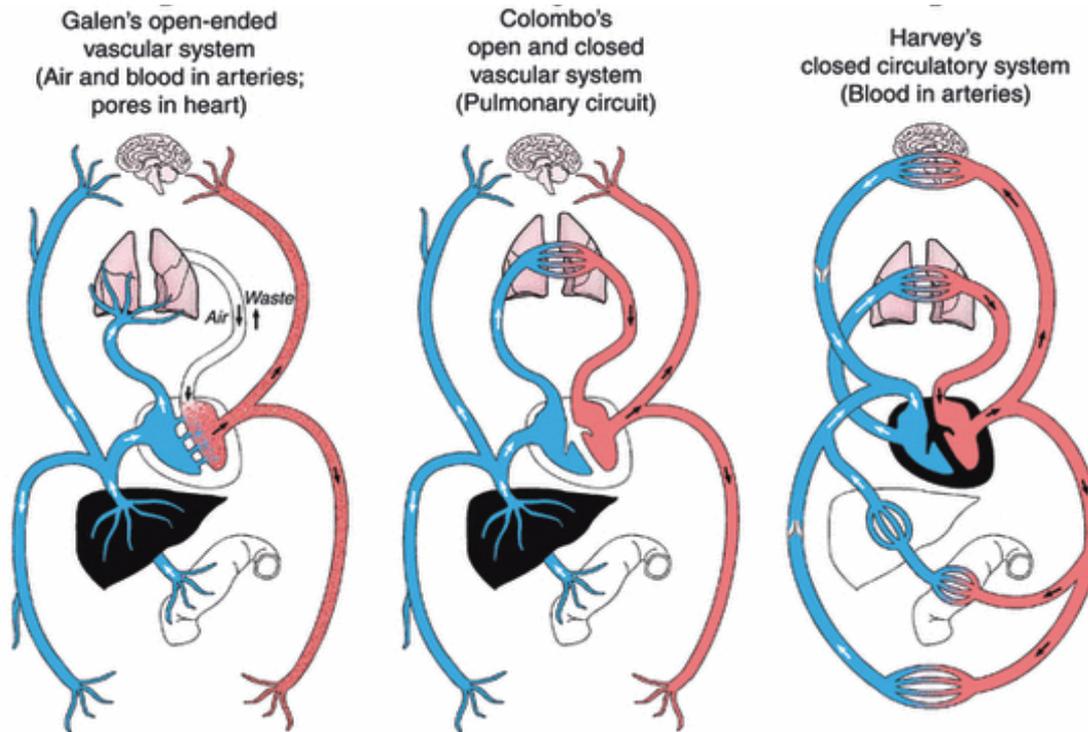


Fig 1. Schematic drawings of the circulatory system over time showing Galen, Colombo and Harvey's descriptions. Colombo's description demonstrates arteriovenous anastomoses in the lung and derives from Ibn Sina's concepts.

Brief biography of Avicenna

Abu Ali al-Hossein ibn Adbullah Ibn Sina (known as Avicenna in the West) was born in a village near Bukhara in August 980 and passed away in Hamadhan in June 1037 (Soheil, 1958). He was the greatest physician in Persia. He also served as philosopher, astronomer, administrator and governor (Elgood, 2010). He composed the *Al-Qānūn fī al-ṭibb* (*The Canon of Medicine*), which is among the most famous books in the history of medicine. Avicenna's penchant for categorizing becomes immediately evident in the *Canon*, which is divided into five books. The first book contains four treatises, the first of which examines the four elements (earth, air, fire, and water) in light of Greek physician Galen of Pergamum's four humours (blood, phlegm, yellow bile, and black bile). The first treatise also includes anatomy. The second treatise examines etiology (cause) and symptoms, while the third covers hygiene, health and sickness, and death's inevitability. The fourth treatise is a therapeutic nosology (classification of disease) and a general overview of regimens and dietary treatments. Book II of the *Canon* is a "Materia Medica," Book III covers "Head-to-Toe Diseases," Book IV examines "Diseases That Are Not Specific to Certain

Organs” (fevers and other systemic and humoral pathologies), and Book V presents “Compound Drugs” (e.g., theriacs, mithridates, electuaries, and cathartics). Books II and V each offer important compilations of about 760 simple and compound drugs that elaborate upon Galen’s humoral pathology.

Anatomy and functions of the arteries

General description

Ibn Sina described arteries as vessels originating from the top part of the left cavity of the heart, consisting of two covering layers and capable of pulsation. He suggested that the inner layer of the arteries was susceptible to damage by direct abrasive forces of flowing blood and also by pulsations (Bakhtiar, 1999). On the heart two major vessels sprout out of the right and left ventricular infundibulum leading into the pulmonary artery and aorta respectively (Moore et al., 2014). Arteries are organised in three major tunics: 1. tunica intima is the innermost coat which consist of inner lining of endothelial cells, loose connective tissue (subendothelium) and external layer of elastic fibers forming the internal elastic lamina. 2. The tunica media is the middle coat which consists of variable amounts of collagen and elastic fibers and smooth muscle cells. 3. Tunica externa or the adventitia constitute the outer layer and made up of mainly connective tissue. Arteries are further classified into large sized elastic arteries, medium sized muscular arteries and small sized arteries and arterioles (Kierszenbaum and Tres 2015). This classification depends on the closeness to the heart and the pressure of blood carried by the arteries. This description is consistent with Avicenna who noticed that the thickness of the arteries varies with the demands subjected to a vessel. He suggested that aorta was thicker and larger because it has to deliver blood to large and distant organs while the pulmonary artery (termed it venous artery) was thinner because it only served the lungs (Bakhtiar, 199).

Anatomy of the pulmonary artery.

Consistent with previous scholars Galen (129-207 C.E) and Abu Bakr Mohammed Zakariya Razi, known as *Rhazes* (865-925 C.E), Ibn sina erroneously described the pulmonary artery as a thin walled artery consisting of a single coat and he named it *venous artery* (Azizi et al., 2008; Aird, 2011). However he correctly described some aspects of the artery such as its origin from the thin walled part (right ventricle)

of the heart, presence of the semilunar valve at its origin to prevent backflow of blood and distribution of comparatively low pressure blood to the lungs (Bakhtiar, 1999; Moore et al., 2014). In addition he also mentioned that the vessel also carries nutrient rich blood to the lungs (Bakhtiar, 1999).

Anatomy of the Aorta

Avicenna described the aorta as the biggest artery in the body. Its term 'aorta' was coined by Aristotle (384-322 B.C) (Forouhi, 2000). Avicenna mentioned that at the aortic origin the vessel is guarded by three valves which prevent back flow during diastole. He also discussed their temperaments by stating that "three membranes and their intermediate thickness work best, two membranes would be thicker and four membranes would be thinner" (Bakhtiar, 1999). He further postulated that in order to achieve best functions in any structure or organ there is a need to balance the qualities of individual's elements (humours). Expounding from Razes' (AD) descriptions, Ibn Sina described coronary circulation. He described the first branches of the aorta and their distribution to the heart muscles as follows: the first and larger branch of the aorta encircles the heart and also supplies it and the second branch supplies the muscle on the right side of the heart (Bakhtiar, 1999). The description is congruent to the anatomical disposition of the right and left coronary arteries including their origin from the ascending aorta.

Branches of the aorta

Ibn Sina described the branching of the aorta into ascending and descending branches. From his description of the branches of the ascending aorta including its arch the following arteries were insufficiently described: brachiocephalic trunk which he described as ascending branch towards the manubrium and gives off the two carotid arteries to the neck and a third branch to supply structures around the sternum, first ribs, upper six cervical vertebrae, clavicle, scapula and structures within the arm (Bakhtiar, 1999). These erroneous descriptions help us to understand the difficulties and limitations of human dissection during these times. Resources and technical expertise were not as ubiquitous as they are today and modern readers are urged to avoid drawing biased judgements when reading some of the information in Canon of medicine. The aortic arch gives three branches: the brachiocephalic trunk, left common carotid and left subclavian arteries (Moore et al., 2014).

Anatomy of Carotid arteries

Avicenna mentioned that the carotid arteries from each side of the neck divide at the upper end of the neck into anterior and posterior branches (Bakhtiar, 1999). The anterior branch further divides into a deeper branch which supplies the tongue and the deeper muscles of the jaw and a superficial branch which courses superficially in front of the ear to supplies through several branches to the temporal muscles and scalp (Bakhtiar, 1999). He also mentioned the anastomosis between branches from opposite side in the scalp. The posterior branch ascends through the neck and enters the cranial cavity through the foramen in the temporal bone. In the cranial cavity the posterior branch of the carotid artery forms a network at the base of the brain and end by giving branches to the brain matter, pia- arachnoid and ventricles of the brain (Bakhtiar, 1999). Ibn Sina's description clearly delineates the carotid tree in the head and neck region of the human. According to Moore et al. (2014), the common carotid artery bifurcates at the level of the upper boarder of the thyroid cartilage in the neck into the external and internal carotid arteries. The external carotid artery lies anterior to the internal carotid and it gives branches which supply the neck, upper and lower jaw and tongue musculature. On the face the artery continues in front of the ear imbedded in the substance of the parotid, further divides into maxillary artery to the upper jaw and related structures and the superficial temporal artery which distributes to the temporal region and scalp except the forehead region. Contrary to Avicenna's assertions that the posterior branch of the carotid artery gives a small branch to the joints and muscles of the neck, the internal carotid artery ascends the neck and enters into the cranial cavity through the carotid canal in the petrous part of the temporal bone without giving a branch in the neck. However, Avicenna described the termination of the internal carotid artery into the arterial circle (circle of Willis) at the base of the brain correctly. He further postulated that the arterial network at the base of the brain facilitates maturation of blood before the brain can assimilate it. In line with the theory of temperament, blood from heart is hot and the brain is of cold temperament so for the blood to be of value to it, it has to be cooled through a network of vessels at the base of the brain. However in contemporary neuroanatomy, the circle of Willis apart from facilitating an efficient source of blood to the brain it also helps to equilibrate pressure between the vertebral and carotid arterial systems (Crossman and Neary, 2015).

Anatomy to the descending aorta

Consistent with modern anatomic descriptions, Avicenna mentioned that the descending aorta for a greater part descends on the left side of the oesophagus and the vertebral column and further distally it shift towards the right (Bakhtiar, 1999; Moore et al., 2014). At the level of the 12th thoracic vertebra the descending aorta pierces the diaphragm to enter the abdominal cavity. Ibn Sina stated that the aorta on crossing the diaphragm it fixed by fascia to the thoracic vertebra to avoid constriction from the contractions of the diaphragm (Bakhtiar, 1999). According to Moore et al. (2014), the aorta pierces the diaphragm at the aortic hiatus which lies at the level of the 12th thoracic vertebra; the aorta at this level is intimately surrounded by the left and right crura of the diaphragm. Avicenna described and categorised the branches of descending aorta in the thoracic cavity into four groups which include branches to the each rib, trachea, lungs and the vertebra (Bakhtiar, 1999). The descending aorta gives rise to branches which are orientated in three planes (embryonic vascular planes) which include 1, anterior unpaired visceral branches to the oesophagus 2, lateral paired visceral branches to the lungs and 3, posterolateral paired parietal branches to the intercostal spaces except to upper two intercostal spaces. On branches to the vertebra, he stated that each branch passes between the ribs to enter the vertebral column and reach the spinal cord (Bakhtiar, 1999). The lumbar and sacral segments of the spinal cord receive blood from the descending aorta through the artery of Adamkiewicz which arises from the left side of the descending aorta between the T8 and L1 vertebral levels in about 70% of cases (Lazorthes et al., 1971; William and Warwick, 1980). When damaged or obstructed, it can result in anterior spinal artery syndrome which is associated with loss of urinary and faecal continence and impaired motor function of the legs; sensory function is often preserved to a degree (Wan et al., 2001).

On or below the level of the diaphragm, Ibn Sina stated that the descending aorta gives branches to the stomach, liver and spleen (Bakhtiar, 1999). This description is consistent with the branching pattern of the coeliac trunk at the level of the 12th vertebra and below the diaphragm where it branches into the left gastric artery, common hepatic artery and the splenic artery to supply the corresponding organs (Moore et al., 2014). In addition Ibn Sina mentioned a branch from the artery to liver which goes to supply the gallbladder (Bakhtiar, 1999). According to Moore et al. (2014), the hepatic artery proper gives off the

cystic artery to the gallbladder. Ibn Sina also described branches to the small intestines and colon which correspond to the Superior mesenteric artery and its branches. The blood supply to the kidneys and associated suprarenal gland was explicitly described in the Canon of medicine. Avicenna mentioned two arteries from the descending aorta to the kidneys which are involved in absorption of excess water from the blood and an additional smaller artery which distributes to the renal capsule. The suprarenal glands receive blood from three sources which include the inferior phrenic arteries, abdominal aorta and renal arteries. The smaller artery to the renal capsule alluded to by Ibn Sina corresponds to the middle suprarenal artery. Avicenna described the origin of the right testicular artery from the descending aorta and left testicular artery from the left renal artery demonstrating an anomalous pattern of the gonadal vasculature. Gonadal vessels often present with various patterns in different population and numerous patterns pertaining to origin, course and number have been recorded in literature (e.g. Asala et al., 2001; Mazengenya, 2015). Towards the terminal bifurcation of the abdominal aorta, Avicenna described branches to the rectum. The inferior mesenteric artery stems from the abdominal aorta at L3 vertebral level and gives branches to the large intestines including the rectum (Moore et al., 2014). Ibn Sina mentioned that the descending aorta terminates by dividing into right and left branches which enter the pelvis and thighs. He described the point of bifurcation as representing the Greek letter lambda. The abdominal aorta terminates into the common iliac arteries which will subsequently give the internal iliac artery to supply the pelvis and its contents and the external iliac artery which continues into the lower limb. Avicenna described the branches to the pelvic organs which include the bladder and the uterus and also noted the anastomoses between arteries from opposite sides (Bakhtiar, 1999). To demonstrate his explicitly medical expertise, Ibn Sina studied the anatomy of the gravid uterus and its blood supply and he mentioned that the uterine arteries become prominent during pregnancy adjusting to the increased demands of blood from the developing foetus and then shrink after child birth. In the lower limb region, Ibn Sina described the course and distribution of the femoral artery. He mentioned that the femoral artery gives a muscular branch to the thigh muscles and the artery continues into the leg and feet towards the big toe. In the thigh the femoral artery gives the profunda femoris artery to supply the thigh musculature and the artery continues into the leg and foot regions of the lower limb. Avicenna described the accompanying

veins which are associated with femoral artery along its course in the lower limb and postulated that arteries and veins are capable of exchanging the moisture with each other (Bakhtiar, 1999). The relationship between arteries and accompanying veins has been shown to benefit exchange of heat through counter-current multiplier mechanism (Bazett et al., 1948) and also to facilitate venous pumping through the aid of pulsating arteries (Hall, 201). The counter-current multiplier system facilitates conservation of heat between warm arterial blood and cold venous blood from the extremities. In testes the relationship between the testicular arteries and the pampiniform venous plexus helps to maintain a temperature below the body temperature preparing an environment conducive for sperm production.

Anatomy and functions of veins

According to Avicenna all veins originate from the liver and they carry nutrient rich blood to the rest of the body (Bakhtiar, 1999). He also highlighted the differences between veins and arteries. For example, veins are located in both superficial and deep locations, whereas arteries are always deep. Arteries pulsate, veins do not. The covering tunics of arteries are denser than that of veins because arteries carry blood with high pressure. The blood in arteries is thinner, warmer and contains breath/spirit (Bakhtiar, 1999, Aird, 2011). Generally Ibn Sina misconceived the pattern of blood flow in the veins by stating that all veins originate from the liver. It is from this misconception that he described veins as draining away from the liver and not towards it and also veins have branches instead of tributaries. This idea was also carried over from Galen who described open ended circulation where blood flows to organs, become consumed and contribute to the formation of flesh. But Avicenna modified Galen's views and hinted on closed circulation by describing arteriovenous anastomoses, artery to artery anastomoses. In this review we ignored the direction of flow blood according to Ibn Sina but we maintained the pattern and distribution of the venous channels and compared them to modern understanding.

Ibn Sina described the two major venous systems which include the portal vein- which drains nutrient rich blood from the intestines and accessory digestive organs to the concave surface of the liver and the vena cava- which arises from the convex surface of the liver and distributes blood to the rest of the body (Bakhtiar, 1999).

Anatomy of the vena cava

According to Ibn Sina, the vena cava originates from hair-like veins which anastomose freely with branches of the portal vein in the substance of the liver and exit the convex surface of the liver and divides into ascending and descending veins (Bakhtiar, 1999). The ascending vena cava pierces the diaphragm and divides into two major branches. One branch enters the right ventricle of the heart and the other branch ascends to supply the head and neck, the upper limbs and intercostal spaces (Bakhtiar, 1999). He further mentioned that the descending vena cava supplies structure below the diaphragm. From the above description it can be deduced that Ibn Sina developed his concept from previous misconceptions from earlier scientist/ anatomists like Galen, Hippocrates and hence the erroneous interpretation of the venous pattern in this region. According to Moore et al. (2014), the inferior vena cava drains blood from the structures below the diaphragm including abdominal contents, pelvis region and lower extremities to the right ventricle of the heart whereas the superior vena cava drains receives blood from the upper limbs, head and neck and the thoracic region and drain into the right ventricle of the heart. Blood from the right ventricle is then channelled to the lungs through the pulmonary artery. However, Avicenna described the venous drainage of the face through the external jugular vein and he stated that the vein receives branches from the face, tongue muscles, jaws and associated muscles and the region of the ear. Ibn Sina also described the internal jugular vein and he traced it back into the confluences of sinus in the occipital region. He mentioned that “The internal jugular vein drains the structures inside the skull and its membranes and the at the occipital region blood from various areas of the membranes of the brain meet in a spacious place” (Bakhtiar, 1999). In the upper limbs Ibn Sina described the venous patterns of both deep and superficial veins without clear elaboration but he mentioned the communication between the basilic vein and the cephalic vein in the cubital fossa through the median cubital vein. The median cubital vein is widely used for venesection in most clinical procedures.

Anatomy of the inferior vena cava

As mentioned earlier on, Avicenna misinterpreted the direction of flow of blood in the venous system. For easy of discretion we will follow the inferior vena cava distally and describe its tributaries as its branches

and compare with modern structural anatomy. Ibn sina mentioned that the inferior vena cava gives a larger branch to the left kidney will divide into branches to the renal capsule and substance of the kidney. Similar to renal arteries the branch to the capsule is a suprarenal vein draining the suprarenal gland. The right kidney receives several veins which stem independently from the inferior vena cava (Bakhtiar, 1999). He also described the origin of gonadal veins from the left renal vein on the left and inferior vena cava on the right and sometimes both gonadal veins arise from the right and left renal veins respectively. The above description highlights the anatomical variations of the renal and gonadal vessels often encountered in surgery and autopsy dissection and these variations can be explained based on the intricate development of gonads, kidneys and their vasculature (Mazengenya, 2015).

Distal to renal veins the inferior vena cava gives off branches to the lumbar vertebra and associated abdominal muscles (Bakhtiar, 1999). In accordance with Griessenauer et al. (2014) Ibn Sina noticed that the inferior vena cava serves the spinal cord through intervertebral veins. He also described the termination of the inferior vena cava at the level of the 5th lumbar vertebra into two common iliac veins. Ibn Sina explicitly described the tributaries of the internal iliac vein in both males and females. He mentioned branches from the uterus, bladder (fundus and neck), rectum and sacrum, vagina and penis. He further traced the distribution of the external iliac vein into the lower limb and also into the anterior abdominal wall and epigastrium. In the epigastrium Avicenna described the anastomoses between veins from the chest wall and breast region with those from the external iliac/femoral vein and suggested that the anastomoses might serve as a link between the female breast and the uterus (Bakhtiar, 1999). In this discretion it can be construed that Avicenna wanted to establish the bases of erotic stimulation, growth of breast during menstrual cycle and pregnancy since the functions of hormones was still obscure. According to Moore et al. (2014) the anterolateral abdominal wall receives blood from the superior epigastric; inferior epigastric; superficial and deep circumflex vessels and these vessels anastomose freely in the umbilical and epigastric regions. Lastly Ibn Sina described the superficial and deep veins of the lower limb and their communication. He also described the location and distribution of the greater and small saphenous veins medial and lateral to the leg respectively. He stated “that the medial vein (greater saphenous) runs medially and reaches the dorsum of the foot and the big toe” (Bakhtiar, 1999).

Conclusion

Although most of the anatomic descriptions of the vascular system by Avicenna in the Canon of medicine draw similarities from his predecessors, he introduced his own findings especially the description of closed circulation contrary to Galen's closed circulation. Ibn Sina noted anastomoses between arteries of different sides on organs such as the brain, scalp, uterus and bladder. He also described arteriovenous anastomoses on brain, vein to vein anastomoses in the umbilical and epigastric regions and also between deep and superficial veins in the limbs. Clinically if the communication between superficial veins and deep veins in the limbs is blocked a condition called varicose veins develops and often associated venous emboli. Additional significant contribution was that of the topography of arteries in relation to veins especially where he described the closeness of arteries and veins in order to exchange and preserve heat in lower limbs.

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