

A systematic review of Ibn Sina's (Avicenna) studies: reflections on anatomy

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SUMMARY

Ibn Sina made significant and long-lasting contributions to almost all fields of science, with an influence spanning over many centuries. Ibn Sina's medical masterpiece, *Al-Qanun (Canon)* may be considered as a compilation of his medical knowledge. Although the *Canon* was influenced by other prominent figures of ancient medical traditions, who were appraised throughout the text, it also included a considerable deal of original writings. Following the footsteps of previous traditions, the *Canon* also presented genuine observations and descriptions of diseases that had not been published before, showing Ibn Sina's ability for synthesizing existing knowledge with his own view in such a way as to influence the practice of medicine for centuries. The *Canon* is divided into five sections, each of which focuses on separate topics of medicine. The first book may be regarded as the most comprehensive one, discussing the four basic humors, i.e. the blood, phlegm, yellow bile, and black bile. The book also includes detailed anatomical descriptions. Similarly, in other sections of the *Canon*, anatomical changes that may occur in relation to pathological or disease states have also been described. Through this book, the reader can witness the significant and fundamental contribution to the science of anatomy as well as to the other fields of medicine. In this article, representative examples of his contribution will be presented. The *Canon* has been a funda-

mental textbook in schools of medicine in Europe and in other places in the Eastern World since the 12th Century up to the end of the 17th century. Not surprisingly, in Bologna, Padua and other locations throughout Europe, Sina's *Canon* has been a great inspiration for many scientists including Andreas Vesalius and William Harvey, among others.

Keywords: Ibn Sina (Avicenna) – Anatomy – Medicine – *Al-Qanun (Canon)*

INTRODUCTION

The earliest descriptions of anatomy in papyrus writings date back to 3000-2500 BC. Alcamaeon of Croton reported his anatomic experiences on animals in around 500 BC, and Erasistratos and Herophilus of Alexandria performed the first systemic anatomic dissection on humans. On the other hand, the work of Hippocrates (460-377 BC) is based on speculative ideas rather than empiric observations on the body (Ball, 1910). During the medieval ages, the powerful and authoritarian Roman Catholic Church placed much higher importance over the care of the soul than the body, with depreciation of the actual treatment of physical illnesses. Dissection on human bodies was disallowed in both Greek and Roman medicine, a tradition subsequently followed by Christianity and Islam. Thus, the knowledge of the human body was solely based on accumulation of information over centuries from the observations and interventional dissections performed in the battlefield as well as from tissue separation, ripping, or resection procedures performed during other types of surgi-

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cal interventions. Also, curious physicians could perform secret dissections on their patients after their death in chambers where they were kept until burial. A review of Ibn Sina's *Canon* reveals a certain amount of resemblance to modern description of anatomical details, for instance with respect to the order and number of certain layers of some organs (e.g. of the cornea), suggesting that he might have performed dissections on the human body.

Galen (130-200 AD), probably the most charismatic anatomist of the antiquity, was a physician first in Alexandria and then in Rome. He carried out anatomical dissection studies on animals and his understanding regarding anatomy had a great influence on the anatomists of the western world for centuries. Ibn Sina, known as Avicenna in the western world, wrote his *Canon of Medicine* in 1020s, based on the teachings of Galen combined with his own view on anatomy and medicine. This book also had a significant impact on a variety of scientific disciplines both in the Christian and Islam world. Ibn Sina had an extensive knowledge of anatomical descriptions of the previous Greco-Roman scientists before synthesizing this information with his own methods in *Canon* (Siddiquey et al., 2008). Physicians from the ancient Islamic world had an opportunity to contemplate the work of Hippocrates, Galen and other ancient Greek physicians. They were also exposed to the medical writings of Roman, Indian and Chinese scholars (Tschanz, 1997). Ibn Sina not only had the opportunity to discover the wide range of topics covered in Arabic writings, he also exploited the synthesis of the ancient knowledge originating from different sources in these Arabic writings. The first exam-

ples of such encyclopedic attempts include the previous work of el-Râzî's *Kitâb ül-Hâvî* (*Continens*) and Ali ibn Abbas's *Kitâb ül-Melikî* (*Liber Regius, Regalis Dispositio*). But that of Ibn Sina was the most popular one and clearly outperformed its antecedents.

With regard to content, the *Canon* contained the vast majority of the medical knowledge up to the 10th century. The writings of Ibn Sina were translated into other languages including Latin and were incorporated into the curriculum of certain European universities. The unique translation work of Constantine the African (d. 1087), in South Italy in Monte Cassino monastery, deserves a mention; and Stephen of Antioch and Gerard of Cremona (1115-1185) were two other recognized translators (Singer, 1957; Corner, 1964). After the advent of the printing press, *Canon* gained widespread recognition. Thus, it did not take too long to observe a superior understanding of medicine in the Islamic world as compared to the Western world, and the *Canon of Medicine* dominated the European medical schools until the 16th century. For instance, the traction and manipulation proposed by Ibn Sina as the principal forms of therapy for spinal disorders have been adopted as the main therapeutic approach in many centers (Abrams, 1978).

The contributions of Ibn Sina to different disciplines of science deeply influenced not only the medical practices in the Islamic world, but also European medicine (Zargaran et al., 2012). Arguably, the most remarkable aspect of his work is its holistic understanding of health, recognizing, for example, the influence of climate and diet on a person's physical condition (McGinnis, 2010). His most famous works involve writings in philosophy



Fig. 1. A drawing made by a European artist during the 16th century depicting Ibn Sina (with crown in the middle), Hippocrates and Galen as prominent figures of ancient medicine.

and medicine. In the 14th century, although Theoretical Medicine, Practical Medicine and Surgery were regarded as different disciplines in the Medical School of Bologna, *The Canon of Ibn Sina* was still used as a textbook due to its rich content in both theoretical and practical aspects of medicine and was used as a resource by students for lectures (Siraisi, 1987). Although Ibn Sina's work had a deeper influence on the practice of medicine, *Canon* also provided descriptions of the anatomy and physiology of organ systems followed by the description of their diseases and treatments. However, at those times practice and theory of medicine were separate disciplines, and accordingly, Raimondo de Luzzi (Mondino) subsequently became the first anatomy teacher in Bologna in 1306 to use human cadavers to teach dissection and became reference on this area (Singer, 1957).

Although the information presented in the book is partly a continuation of previous traditions including the medical teachings of the famous medical figures of the past, it also contains previously unpublished original medical observations and evaluations of his own, culminating into a long-lasting effect on the history of medicine (Fig. 1).

The *Canon* has five volumes. The first volume addresses the most complicated issues of the time: a) the four humours: blood, phlegm, yellow bile, black bile; and b) the three powers/nafs: psychic power/nafs, natural power/nafs, and the animalistic power/nafs. This first volume also presents information on the human anatomy (Hashim, 1981). Section four of Volume I is a 20-page long description of human anatomy. Also in other volumes and parts of *Canon*, detailed anatomical information is provided in conjunction with pathological conditions and diseases of organs. In addition to systemic anatomical descriptions, specific surgical anatomical definitions are also provided within the context of the science of surgery (ilm alm-ciraha).

SOME EXAMPLES FOR THE CONTRIBUTION OF IBN SINA TO THE SCIENCE OF ANATOMY

His general view on nerves, vessels, and the heart

Ibn Sina places a special emphasis on correlating the theoretical information in the minds of physicians and surgeons with careful observations on human body. He proposes that muscles can only move with the supporting nerves, and that the sense of pain is experienced through the nerves. He even pointed to the absence of observable nerves within the structure of the spleen and kidneys, although he mentions that they are covered with nerves. Another pathological description pertains to the swelling of the proximal parts of a gland when an obstruction occurs at a secretory canal (Farhadi et al., 1996).

In his view, the respiration serves the purpose of

taking air into blood and exhaling the noxious mist. He describes three valvular structures at the aortic outlet which open when the heart contracts to pump blood into body and then close upon return of the heart to the resting state to prevent the backward flow of blood back into the heart chambers (Al-Qattan, 2006). Actually, this observation predated William Harvey's demonstration of the circulation of the blood by six centuries.

He also states that with respiration, air enters through invisible pores in the skin and lungs, while lungs play the major role in respiration. In his view, the mechanical power required for this process is initiated by the contraction and expansion of the heart. This explanation was adopted by William Harvey in the 1600's when he described the circulation (Goodrich, 1997).

Ibn Sina provides detailed explanations of peripheral nerves. In addition, his anatomical theory for the function of the cerebellum and caudate nucleus are close to contemporary understanding (Goodrich, 1997). He also provided detailed and comprehensive explanations about vertebrae and their parts (Al-Qattan, 2006).

Anatomy of the eye

Ibn Sina is the first physician who introduced the concept of eye muscle tendon repair (Al-Qattan, 2006). He describes the visibility of objects as follows: "...it is not a beam of light that exits through the eye and hits an object, rather, it is the beams of light that is emitted by an object and passing through the transparent part of the eye, i.e. the lens; thus, making vision possible" (Al-Qattan, 2006). Ibn Sina not only described the eye anatomy, but also elaborately defined the six extraocular muscles and the trigeminal nerve. His work on the eye made important contributions to the anatomical knowledge and health of this organ (Price, 2001).

In contrast with previous descriptions, Ibn Sina realized the fact that nerves and tendons actually represent two different anatomical structures (Al-Qattan, 2006). Even in modern medical practice, the distinction between nerves and tendons is of great significance in surgery, dissection, or clinical examination.

Central Nervous System

Ibn Sina writes the following: "The brain has three parts. Frontal, middle, and rear. The most delicate of these is the frontal part, which deals with the most important and strongest emotions. The middle part is not that active, and the rear part is more active and executes a higher number of functions as compared to the middle part" (Ibn Sina, 1980). This description is surprisingly in concert with the current division of the anatomical parts of the brain, i.e. proencephalon, mesencephalon, and rhombencephalon. The frontal lobe has centers for speech, intellectual abilities, thoughts,

and the will power. The rhombencephalon contains specialized vital centers. Ibn Sina correctly sensed the location of vital centers almost 1000 years ago.

Galen used the term 'soul' in an Aristotelian sense and described a 'motor soul' and a 'sensory soul', which were not two different entities, rather they were supposed to have two different functions (Bennett et al., 2002). Nemesius (about 390 AD.), the Bishop of Emesa, developed the doctrine of the ventricular localization of all mental functions, rather than sole intellect. In contrast with the idea of Galen, he allocated the functions of perception and imagination to the two lateral ventricles (the anterior ventricles), intellectual abilities to the middle ventricle, and posterior ventricles to memory (Bennett et al., 2002).

As Ibn Sina states: "The brain and the spinal cord are divided into two equal parts throughout the body. As in the case with the paralysis of the arms-legs, or paralysis of the face, if one side is injured, the effects are observed in one half, leaving the other half healthy (Ibn Sina, 1980)." From a functional anatomical viewpoint, these descriptions are largely accurate.

He mentions that "the sense of smell starts in nipple-like protrusions (i.e. olfactory region) within the split part of the brain." Accordingly, the sense of smell originating from the olfactory receptor cells of the nerve, reaches the brain at the basal surface of the frontal lobe through the olfactory tract. His expression of this is as follows: "The first of the cranial nerve couples relates to sense of smell, and starts in the nipple like small protrusions under the frontal part of the brain (Ibn Sina, 1980)."

Also described by him is the crossing of the left and right optic nerves at the optic chiasm (Ibn Sina, 1980). Therefore, the visual information provided by each eye is superimposed in order to obtain a single visual perception. Visual sensory information from each of the optic nerve cross at the level of the chiasm as to be conveyed to the contralateral lateral ventricle (Ibn Sina, 1980). As an explanation for obtaining a single image from two different source of visual sensory stimuli, he proposes that the third and fourth ventricles serve as unification chambers (Warwick et al.).

Ibn Sina also provides detailed descriptions of hydrocephalus (Aciduman et al., 2007).

Osteology and spine

In addition to his work on bone fractures and subluxations, Ibn Sina also studied tendon injury and repair using his knowledge on human anatomy. In contrast with previous understanding, Ibn Sina for the first time claimed that tendon ruptures could be repaired by suturing. Also Ibn Sina has a pioneering understanding regarding peripheral nerve injury (Sharafkandi, 1991; Mabee, 1994; Belen et al., 2009).

Ibn Sina holds the view that excessive pressure, applied while placing bandages for fractures could

prevent the blood circulation in the extremity, may cause severe pain even during rest, and may eventually require an amputation due to loss of vitality in the extremity. This description shows significant resemblance to the compartment syndrome first described 800 years later, i.e. in 1881 by Richard von Volkmann (1830-1889) (Chen et al., 2008; Belen et al., 2009).

He also emphasizes an association between the size and shape of a vertebra and its functions. Similar to current descriptions, he considers the spine in sub-sections: cervical, thoracic, lumbar, sacral and coccygeal. Then, he describes the anatomical characteristics of the vertebrae and their parts in each section. Although *Canon* has some inaccurate information on C2 and T12 vertebrae, as well as on the number of sacral vertebrae, the biomechanical characteristics of the vertebrae and the spine are successfully delineated.

His view on the biomechanical properties on the craniovertebral junction is remarkable. The different characteristics of atlas and axis are very well defined. "The head-atlas segment is responsible for tilting the head toward the sides, while C0-C2 segment allows backward-forward movement." "*One condyle tilts the head, while the other moves it upward*" (Naderi et al., 2003).

Some of Ibn Sina's anatomic descriptions may even be considered accurate today. For instance, in sections devoted to anatomy in *Canon*, the spinal anatomy is described in different parts (between sections 6 and 13), which has been adopted in following centuries by a number of scientists.

Genito-urinary system

Ibn Sina's descriptions reflect the status of the knowledge at his time (Pioreschi, 2006): "*The womb is between the urinary bladder and rectum, with its upper part being located above the urinary bladder. In virgins and women who have never given birth, the womb is smaller than those who became pregnant and delivered a baby... The neck of the womb ends somewhere close to the vulva and is analogous to the penis; slightly outwards is an accessory piece of skin called the clitoris, analogous to the foreskin of the penis.*"

Ibn Sina's "Canon of Medicine" has been used as a textbook in medical schools throughout Europe for centuries. Of course, although some of his tenets have been disproved, as a matter of fact, others have a significant similarity to modern medical teachings. For example, there are important similarities between the 30-page urinary examination section in *Canon* and the subjects covered in Campbell-Walsh's Textbook of Urology in terms of urinary sampling, urinary examination methods, and urine characteristics in healthy and diseased individuals (e.g. color, smell, consistency, sedimentation, volume, clarity, foaminess etc.). Also described by Ibn Sina was transperineal surgery,

warning surgeons between the close adjacency of certain anatomical structures such as the vasa deferentia, prostate gland, and the neurovascular bundle (Sina, 1593). In his view, the sphincter muscle receives high number of nerves for increased sensitivity. The inhibition of the sphincter occurs simultaneously with the contractions of the urinary bladder wall for urinary excretion (Abdel-Halim et al., 2003). It is remarkable to observe that Ibn Sina underscores the anatomical relationships between the posterior and outer surfaces of the urinary bladder and vasa deferentia and blood vessels (Hartke et al., 2007).

Ear, nose, throat, oral cavity, teeth

The anatomy, physiology and pathological conditions of the ear, nose, and throat have been extensively covered in Ibn Sina's *Canon*. For instance, the earlap is shaped like a funnel to collect the sound vibrations, while the external ear canal provides protection for the eardrum and keeps the external ear warm due to its narrow and sloped course. This shows the importance of administering warm ear drops. The eardrum is a tiny membrane responding to sound vibrations. That the hearing function was due to the sensitivity of the eardrum to the sound waves was first described by Ibn Sina. The anatomy of pharynx and larynx has also been explained in detail in *Canon*, including the laryngeal cartilages, ligaments, joints, and muscles with their role in different functions of the larynx (Ibn Sina, 1980).

Oral cavity, tongue, sense of taste, teeth hygiene and diseases, lips and gum diseases and a number of related factors have been described in separate sections of *Canon*. His writings on gum disease is as follows: "Tooth ache is the direct result of an ailment within the teeth. However, sometimes pain is due to the nerves or gums. A superficial pain involving only the jaw or if there is slight tingling sensation in the teeth, this is due to a nerve injury or disease". These statements help explain why tooth extraction cannot offer pain relief (Tabatabaei et al., 2012).

IBN SINA AS A TEACHER

The grandfather of Andreas, Peter Vesalius, wrote his thesis on certain works of Ibn Sina (Siraisi, 1987; Holomanova et al., 2001). Peter's son John Vesalius was the private physician of the Mary of Burgundy, wife of Maximilian I, and later he taught medicine at Louvain University. Since then, the children of Vesalius family were sent to Paris University for medical education. Andreas studied Ibn Sina's writings on tumors in his first year in Padua. An eager student, Andreas's incomplete university notes reflect a comparison between Ibn Sina's work with the classical works of Hippocrates, Galen, Paul of Aegina, and Aetius,

including some corrections of his own (Ball, 2013 (originally published in 1910)). In addition, many teachers at Montpellier had former acquaintance with the Islamic medicine at Salerno. For example, Roger of Salerno, the greatest Salernitan surgeon, has first gained his widespread reputation in Salerno around 1170, and then became the Chancellor of the medical school at Montpellier. He wrote "Practica Chirurgia" in 1180 (Stelmaschuk, 2001).

GENERAL VIEW

The author of the *Canon of Medicine*, the great clinician and teacher of his age, Ibn Sina gives an initial description of the anatomy of an organ system before discussing its diseases (Naderi et al., 2003). This approach pioneered by Ibn Sina has paved the way for modern clinical anatomy. He underlines the importance of studying the general principles of medicine and the need for a good knowledge of anatomy before analyzing the diseases in organs.

In the first volume of *Canon*, separate sections are devoted to anatomy. In addition, in several sections of this comprehensive encyclopedia, anatomical characteristics of an organ are discussed before the diseases.

Julius Hirschberg, in his book on the history of ophthalmology, states the following in the 9th section, where he discusses the influence of anatomical and physiological drawings of the eye by Islam scientists on European science (Schipperges, 1976): "A systematic review of the Islam-Arab surgery reveals that all information conveyed through ages from antiquity to that of Islamic scientists in the field of surgery have been contemplated in a propaedeutic manner. Although dissection of the human body is considered inappropriate according to Islam tradition, hundreds of monographs can be found in the books of Ali bin al-Abbas and Ibn Sina that do not belong to the Alexandria or Hellenistic school."

A recommendation by Ibn Sina to other physicians and surgeons was to examine the human body closely to obtain information (Naderi et al., 2003). Almost 600 years before William Harvey, who is considered the first to describe the systemic circulation, Ibn Sina observed that the aortic valve with its 3-leaflets opens during the contraction and closes during the relaxation of the heart, to prevent the backward flow of blood (Al-Qattan, 2006).

Dissection was considered an unpleasant duty, largely perceived by professors as an obligation. Before introduction of freezers or embalming techniques, the cadavers had an unbearable odor. Educational dissection was approved as a responsibility for medical schools by the Pope Clemens VII. Thus, the knowledge of anatomy before that time mostly relied on Islamic sources, and undoubtedly, on the writings of Ibn Sina (Singer, 1925). Ibn Sina's work has contributed to the transformation

of modern medicine in many fields as well as anatomy.

Medieval textbooks of medicine often include anatomical descriptions in reference to Ibn Sina's *Canon* (Nogales, 1980). Relatively newer and more accurate content of the anatomical knowledge of Ibn Sina has led some authors to suggest that he might have performed direct dissections on human cadavers (Farhadi et al., 1996). Since anatomical dissection in the Islamic tradition was banned, he was accused of grave robbery by his competitors.

Nancy G. Siraisi has collected her extensive studies on the content of the curriculum in European Medical Schools, particularly after year 1500, into the following book: *Avicenna In Renaissance Italy: The Canon And Medical Teaching in Italian Universities After 1500* (Siraisi, 1987). The information presented in the book indicates that approximately 80 to 90 lectures were held annually. For instance, Matteo Corti acquired information from Section 1, Volume 1 of *Canon* for a total of 63 lectures, while 77 lectures given by Girolamo Capodivacca were based on the information from Section 1, Volume 4 of *Canon*. Similarly, a 277-page volume was prepared by Bernardino Paterno using the information provided in Section 4, Volume 1 of *Canon*. As stated by Siraisi, lectures on therapeutic procedures also included content from. Siraisi also states that 80% of the printed lectures of Giambattista da Monte and long scholastic lectures of Gentile da Foligna were taken from *Canon*. These examples indicate that during the 16th century, Ibn Sina's teachings had a prominent part in the curricular content of medical schools at Padua, Bologna, and Pavia, and Ibn Sina's *Canon* was considered a major textbook. This curricular content in Padua suggest that in 4 of the 9 main professorship chairs concerned with medical theory, *Canon's* Section 1, Volume 1 was a major source of information (Siraisi, 1987).

Certainly, science is always subject to progression and change. Therefore, some information from *Canon* has been outdated over time. For example, discovery of pulmonary circulation by Ibn-un-Nefis (1213-1288) in 13th century disapproved the teachings of Ibn-Sina on blood circulation (Meyerhof, 1935; Shehatha et al., 2012). Although its teachings have been partly changed over time by its successors, *Canon* was quite influential in Europe in its handbook format and used as a textbook in European universities until 18th century (McGinnis, 2010).

Thus, Andreas Vesalius (1514-1564), William Harvey (1578-1657) and other scientists studied Ibn Sina's *Canon* extensively during their education at universities in Bologna, Padua, Pavia and elsewhere.

The aim of the present work was to shed light on the contributions of the work of Ibn Sina on the science of anatomy. In fact, major changes or con-

flict may have occurred with advances in science that can be documented with corroborated efforts of anatomists, historians of medicine, and clinicians.

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