

Anatomical concepts of the musculoskeletal and peripheral nervous system as viewed by Avicenna in the Canon of Medicine

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Introduction

Avicenna, Arabic Ibn Sīnā, in full Abū ‘Alī al-Ḥusayn ibn ‘Abd Allāh ibn Sīnā (born 980, near Bukhara, Iran (now in Uzbekistan) died in 1037 in Hamadan, Iran. He was a Muslim physician, the most famous and influential of the philosopher-scientists of the medieval Islamic world. He was particularly noted for his contributions in the fields of Aristotelian philosophy and medicine. 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. The current review was intended to analyse and compare Ibn Sina's treatise on the anatomy of musculoskeletal system with modern descriptions. In addition Ibn Sina's description of anatomy within the context of temperament, structure and function are highlighted.

Skeletal system

General description on bones and joints

Avicenna affirmed that bones and cartilages offer support and protection to body structures and vital organs and also facilitate movement. He distinguished between compact bones and spongy/ cancellous bones. He mentioned that compact bones are made up of an outer cortical bone and a central marrow cavity. Taking into account that in Tibb theory bones have a cold and dry temperament, bone marrow provides moisture to counteract the dryness produced by exercise (Bakhtiar, 1999). He classified joints into four types and gave their examples as follows: Type I joints have a large joint space which allows a greater range of movement such as the shoulder joint. Type II joints have small joint space with reduced range of movement for example the tarsal joints. Type III were described as embedded joints with no movement permitted for example joints between teeth and their sockets. Type IV are sutural joints which are saw-like with serrations, an example of these joints are the joints found

between flat bones of the skull. Avicenna's classification of joints concurs with descriptions of synovial joints, gomphosis on alveolar surfaces and sutural joints in modern anatomical texts.

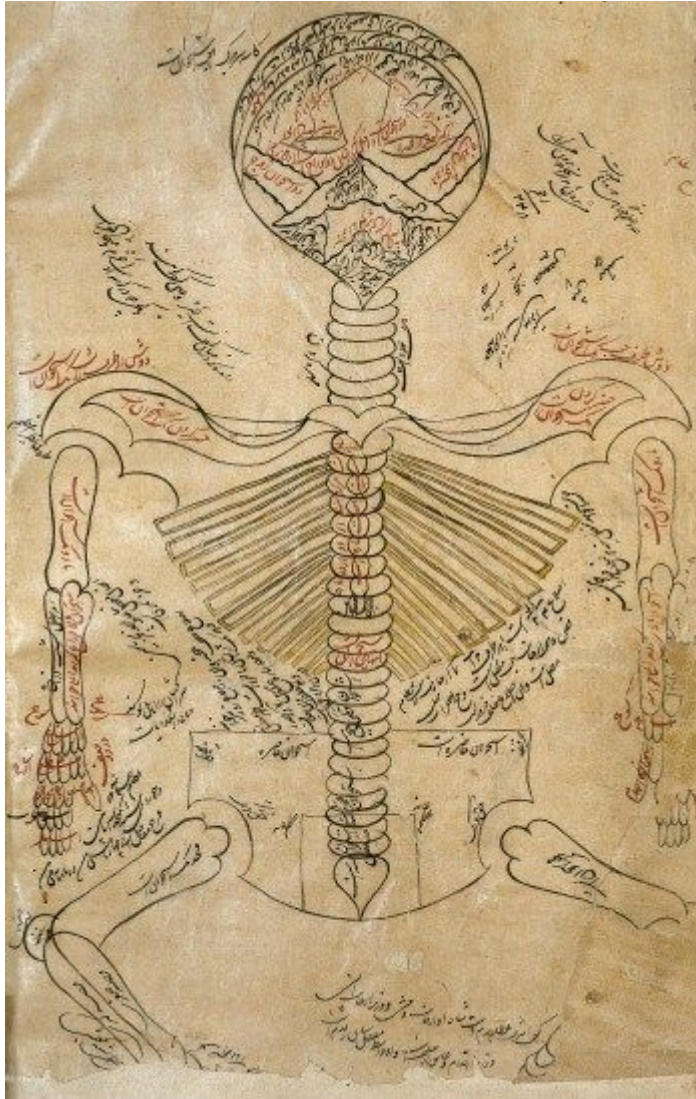


Fig 1. the skeletal system according to Avicenna in the Canon of Medicine. Image adopted from the Welcome library.

Cranium

Avicenna stated that the cranium is made up of several bones which vary in density and thickness. The bones of the cranium protect brain and made light in weight to reduce pressure

on the brain (Bakhtiar, 1999). He also mentioned that the skull bones have foramina for the passage of nerves and vessels. Avicenna described accurately the topography of the bones of the skull vault. He affirmed that the frontal bone is located in front; behind it are two parietal bones which are above the temporal bones and the occipital bone which is more compact protects the back of the brain posteriorly (Bakhtiar, 1999). He noted that the bones of the skull were joined by sutures which he described and named. Avicenna described accurately the coronal, sagittal, lambdoid and squamosal sutures. The squamosal suture was regarded as a false suture that lacks serration but made up of overlapping temporal and parietal bones (Bakhtiar, 1999).

Spine

Avicenna meticulously described the bones of the vertebra including their biomechanical properties. For full reviews see Naderi et al., 2003; Keskinbora et al., 2016 and Mazengenya and Bhikha, 2016 (in press). He classified the spine into cervical, thoracic, lumbar, sacral and coccygeal. This classification is similarly used today in modern anatomic descriptions (Naderi et al., 2003). The classification of the spine into various segments was based on the variations of the size and shape of each vertebra. He also explored the biomechanics, movements and disorders of the spine such as kyphosis.

Rib cage and sternum

Avicenna mentioned that the skeletal components of the rib cage protect the respiratory organs, heart, upper part of the stomach and intestines (Bakhtiar, 1999). He further stated that the rib cage was expandable increasing the diameter during inspiration and also when the stomach is full. The upper seven ribs are attached to the sternum anteriorly and the arrangement offers support to vital thoracic organs (Bakhtiar, 1999; Gunn, 2012; Moore et al., 2014). Avicenna classified ribs into true ribs (1-7) and false ribs (8-12). He describes

false ribs as floating ribs that are not directly attached to the sternum or those that lack contact with the sternum in front (Bakhtiar, 1999). Structurally the head of each rib has two articular facets for articulation with demi-facets on the vertebral bones (Bakhtiar, 1999, Gunn, 2012). Avicenna also noticed the articular tubercle on the angle of the rib which articulates with the transverse process of the corresponding vertebra.

Avicenna described the sternum as a flat bone with outer layer of cortical bone and the core made of cancellous bone (Bakhtiar, 1999). The sternum consists of three segments which include the manubrium sterni, body and xiphoid process (Gunn, 2012, Moore et al., 2014). The body of the sternum is made up of four sternabrae which are fused by cartilaginous joints which ossify with advancing age (Williams and Warwick, 1980; Gunn, 2012; Moore et al., 2014). Avicenna also noticed that the sternum was made up of various pieces joined together by cartilage to facilitate thoracic expansion during respiration (Bakhtiar, 1999). He also mentioned that the xiphoid process was cartilaginous in nature and functions to protect the epigastrium (Bakhtiar, 1999). The various segments of the sternum become fully ossified by the age of 25 years (Gunn, 2012; Moore et al., 2014).

Clavicle and scapula

Avicenna affirmed that the clavicle has concave and convex parts. The hollow space behind the convex inner part provides passage for neurovascular structures (Bakhtir, 1999). The clavicle articulates medially with the sternum on the clavicular notch of the manubrium sterni and laterally with the scapula on the acromion process (Gunn, 2012; Moore et al., 2014). According to Avicenna the lateral articulation between the clavicle and the scapula reinforces the shoulder joint (Bakhtiar, 1999).

Avicenna described the scapula as thin and flat medially and thick on the lateral edge where it articulates with the rounded head of the humerus (Bakhtiar, 1999). He mentioned the

acromion and the coracoid processes of the scapula and suggested that their functions were to prevent dislocation of the shoulder joint (Bakhtiar, 1999). The spine of the scapula reinforces and protects the scapula posteriorly. According to Bakhtiar, (1999) the scapula serves two functions related to the protection of the chest wall posteriorly and facilitation of movement of the arm.

Humerus and the shoulder joint

Avicenna mentioned that the humerus forms the bone of the arm. He described the humerus as cylindrical bone with a convex head, a shaft and a distal part with prominences (Bakhtiar, 1999). The head of the humerus articulates with the shallow glenoid cavity of the scapula to form the shoulder joint. Avicenna described shoulder joint as a loose movable joint which frequently dislocates (Bakhtiar, 1999). He also described four ligaments contributing to the strength and stability of the shoulder joint. Of the four ligaments he accurately described the anatomy of the joint capsule surrounding the joint and the tendon of the longhead of the biceps muscle although he did not state its name. On the distal aspect of the humerus, Avicenna noted that the medial prominence/ epicondyle was not involved in joint formation and it was responsible for protecting nerves and vessels (Bakhtiar, 1999). The ulna nerve passes behind the medial epicondyle of the humerus to enter the forearm (Moore et al., 2014). At this point the nerve is only covered by overlying skin posteriorly and is vulnerable to crushing injuries especially when the medial epicondyle hits on a hard surface with the elbow joint flexed. Avicenna further mentioned the trochlea, the lateral prominence, the anterior and posterior depressions (olecranon and coronoid fossae) and their involvement in the formation of the elbow joint. Following Hippocrates he classified the elbow joint as a hinge joint (Bakhtiar, 1999).

Radius and ulna

Avicenna affirmed that the forearm consist of two bones joined together along their length. He noted that the radius supinates and pronates the forearm, whereas the ulna participates in flexion and extension of the elbow joint (Bakhtiar, 1999; Afshar 2011). Avicenna described the anatomy and movements of the elbow joint in detail. The head of the radius has a depression that articulates with the capitulum of the distal humerus and is held in this place by a ligament (Bakhtiar, 1999; Gunn, 2012). According to Avicenna's descriptions of the proximal end of the ulna it can be construed that the proximal ulna bears the olecranon process, trochlear notch and coronoid process. Avicenna also described the flexion and extension movements of the elbow joint. He also stated that hyperextension is limited by the lodging of the olecranon process into the olecranon fossa. Distally the styloid processes of the both the ulna and radius were described and their contribution to the attachment of ligaments that support the wrist joint.

Wrist and hand

The anatomy of the wrist bones was described accurately in the Canon of Medicine. Avicenna reported that they are seven carpal bones arranged in two adjoining rows. The proximal row containing three bones whereas, the distal row has four bones. He noted that bones in the proximal row articulate with distal end of the radius and ulna bones and participate in flexion and extension of the wrist joint (Bakhtiar, 1999). He further described the eighth bone of the wrist which is the pisiform bone as a bone located out of the general alignment of the wrist bones and only offers protection to the ulna nerve (Bakhtiar, 1999).

In his description of the hand, Avicenna not only mentioned the correct number of metacarpals and phalanges but also provided insights into the perfection of creation with respect to structure and function. He stated that "metacarpals provide a concave surface for

the hand that enables the hand to retain liquids and firmly surround objects” (Bakhtiar, 1999). In addition, Avicenna argued why there should be only three phalanges in each finger. He mentioned that “if there had been more than 3 phalanges, the fingers would have obtained a greater range of movement but they would be weakened in strength. If the phalanges had been 2, the fingers would have become stronger but the range of movement would have been restricted; while the fingers need greater movement and nominal strength (Bakhtiar, 1999). The thumb was described separately from the rest of fingers and its description was based more on functional aspects rather than anatomical relationships with other fingers. Avicenna described the position of the thumb as being appropriate for apposition with other fingers, providing strength of the grasp (Bakhtiar, 1999).

Pelvic bones

Avicenna described the pelvic bones as forming a bony ring made up posteriorly by the sacrum, laterally by the two hip bones and anteriorly by the fusion of the two pubic bones. In addition he identified and described the three parts of the hip bone and their articulations as follows: the ileum bone lies outwards and articulates posteriorly with the sacrum; the pubis lies anteriorly and articulates with the bone of the other side through a strong joint and the ischium lies posteromedial to the ileum and contains the acetabulum a depression which articulates with the convex head of the femur (Bakhtiar, 1999). From his descriptions of the pelvic girdle some errors can be revealed especially on the anatomic features of some bones and also on their topographic relationships. The acetabulum for example is a feature borne by all three parts of the hip bone (Gunn, 2012; Moore et al., 2014) and not the ischium alone. However despite these errors, Avicenna associated the pelvis with the functions of support of the upper body and lower limbs and protection of the pelvic organs such as the urinary bladder, uterus and spermatic cord.

Thigh

Avicenna affirmed that the femur is the largest bone of the body. He described the proximal end of the bone bearing a convex head which fits in the acetabulum of the pelvic bone. He mentioned that the shaft of the femur is convex laterally and concave medially (Bakhtiar, 1999) with medial concavity offering protection to nerves and vessels from direct impact. Distally the femur has two condyles which articulate with the tibia to form the knee joint (Bakhtiar, 1999; Gunn, 2012). On the knee, Avicenna noticed that the joint was strengthened by an internal ligament and two external ligaments located medial and lateral to the joint. In modern descriptions the internal ligaments consists of anterior and posterior cruciate ligaments which limit anterior and posterior displacement of the joint while the external ligaments are referred to as medial and lateral collateral ligaments protecting the joint from medial and lateral displacements (Moore et al., 2014). Avicenna also mentioned the patella and described it as an oval bone that protects the knee joint from direct blows from the front during walking and sitting positions (Bakhtiar, 1999). According to Moore et al. (2014) the patella is a sesamoid bone located within the quadriceps femoris tendon that functions as a fulcrum on the knee joint.

Tibia, fibula and the foot

Avicenna mentioned that the tibia is larger than the fibula and is located medially. The fibula was described as a small bone of the leg with no articulations to the femur but participating in the formation of the ankle joint (Bakhtiar, 1999). In addition, the tibia and fibula are united by a strong interosseous membrane allowing them to function as a unit (Moore et al., 2014).

Avicenna described the skeleton of the foot and adaption to standing and gripping on uneven surfaces. He mentioned that the foot consists of 26 bones made up of 7 tarsal, 5 metatarsal and 14 phalanges (Bakhtiar, 1999). He also noted the presence of a variable number of

sesamoid bones in the foot. He described and named the talus, calcaneus and cuboid accurately including the joints they make. He attributed the foot's ability to grasp and adapt to uneven surfaces on the large number of bones making foot. In addition, the foot's ability to grasp on uneven surfaces can be attributed to the arrangement of the foot bones making two longitudinal arches and a transverse arch (Gunn, 2012; Moore et al., 2014).

Muscular system

Avicenna contributed immensely to myology. His descriptions revolutionized the understanding of muscle functions, their effect on bones to produce movement and also the effect of nerves on muscle contraction and relaxation. Ibn Sina managed to differentiate between nerves, tendons and ligaments as separate anatomical structures (Bakhtiar, 1999; Al-Qattan, 2006; Aciduman and Belen, 2009; Afshar, 2011) a description that contradicted Galen's earlier assumptions that nerves and tendons of the same nature (Rang, 2000). He stated that, "The nerves are derived from the brain or spinal cord. The brain receives sensation through nerves. The nerves provide power and voluntary movements to muscles. The tendons exit from muscles. When muscles are relaxed the tendons become loose and the limb extends. When muscles contract the tendons become tight and the limb flexes" (Bakhtiar, 1999). However he did not precisely describe the origin and insertion of muscles and also their nomenclature. Precise and fine anatomical descriptions can only be achieved by undertaking dissection on cadavers. During Avicenna's time human dissections were prohibited under Islamic law (Shoja and Tubbs, 2007; Afshar, 2011) and hence modern readers must be impartial in their judgments.

Muscles associated with the head and neck region.

Avicenna described muscles of facial movement distinguishing those that open and close orifices on the face such as the eyes, mouth and nostrils and that wrinkle the skin for example

the skin of forehead during frowning. He noted that facial muscles had not bony attachments but rather inserted into the skin and hence move it. In the orbit, Avicenna precisely described the six extra-ocular muscles and their functions (Shoja and Tubbs, 2007). He described the four muscles involved with the elevation, depression, adduction and abduction of the eyeball and that they arose from a common origin at the back of the eye. He also mentioned the relationship between the common tendon of origin of the four muscles with the optic nerve (Bakhtiar, 1999). In addition to the muscles mentioned above, Avicenna described two oblique muscles which participate in the rotation of the eyeball (Bakhtiar, 1999). Although he did not provide the names of the extra-ocular muscles in the Canon of Medicine it can be construed that his descriptions referred to the following muscles: superior rectus, inferior rectus, medial rectus, lateral rectus, superior oblique and inferior oblique muscles.

The muscles related to mastication and masticatory movements were partially described. Avicenna described the function of the two temporalis muscles in elevating the jaw and closing the mouth. He also described two other muscles one of each side that provides force on closing the mouth (Bakhtiar, 1999). The descriptions of the muscles can be interpreted as those of the masseter in modern anatomic literature. Avicenna described precisely the digastric muscle, its origin, structure, insertion and action in retracting and opening the lower jaw. He also noticed the effect of gravity and hyoid muscles in assisting the opening of the lower jaw (Bakhtiar, 1999). Avicenna described the nodding and sideways movements of the head and mentioned that the movements were produced by two muscles acting as single unit and/or independently. Muscles associated with larynx were also mentioned in the Canon of medicine and like the rest of the region their names were not provided. Reviews of these muscles have been laid out by various authors (Chitsaz and Ashktorab 2007; Mazengenya and Bhikha, 2016 (unpublished)). Avicenna described the actions of the salpingopharyngeus and palatoglossus in elevating the larynx and pharynx during deglutition (Bakhtiar, 1999).

Thoracic muscles

Avicenna gave an account of the function of primary respiratory muscles and those assisting in forced respiration. Generally he asserted that respiratory muscles act by expanding and contracting the thoracic wall (Bakhtiar, 1999). He described muscles assisting in respiration as those muscles originating from the scapula and the cervical vertebra and inserting onto the thoracic wall. He also described the intercostal muscles and precisely described the obliqueness of the fibers of the inner thoracic muscles (transverse thoracic muscle).

Limb muscles

Avicenna described the muscles of the upper limbs according to the region, muscle groups and the joints they act upon (Bakhtiar, 1999; Afshar, 2011). He described 5 adductors and 5 abductors of the arm region. The abductors of the arm were described as muscles originating from the scapula and inserting on the humerus. In modern anatomic description it can be construed that Avicenna referred to the rotator cuff muscles and the deltoid. He described the adductors as originating from the thoracic wall and the iliac crest and the description befit those of the pectoral muscles and latissimus dorsi muscle. The forearm muscles were described as extensors, flexors, supinators and pronators. The wrist muscles were identically described although movements like supination and pronation are not permitted at the wrist. Muscles of the hand were described as extrinsic, where their origins are in the forearm and muscles the muscles having long tendons covered by a membrane, and intrinsic, which are located in the hand itself. Avicenna noted that they were 18 intrinsic hand muscles and the finger flexors were arranged as superficial and deep layers (Bakhtiar, 1999).

In the lower limbs, Avicenna described the flexors and extensors of the thigh. He mentioned that hip extensors were strong and associated them with an erect posture (Bakhtiar, 1999). He also described other movement permissible at the hip joint such as abduction, adduction and

circumduction. Avicenna mentioned knee flexors and extensors, and the insertion of knee joint extensors into the patella. The muscles of the foot were described as foot raisers located in front of the leg and those that lower the foot being located in the posterior compartment of the leg and inserting through the tendocalcaneus (Bakhtiar, 1999).

Nervous system

Cranial nerves

Most of Avicenna's descriptions of the structure and function of nerves was adopted from Galen a physician and anatomist in the second century A.D. Hence Ibn Sina considered that nerves hollow and distributed "animal spirit" to the various part of the body (Shaw, 1992). He also considered nerves to be either hard (motor) or soft (sensory) in consistency and regarded their functions as such. Based on this premise of hollowed nerves Ibn Sina regarded the olfactory tracts as excretory organs to facilitate the removal of waste from the brain ventricles not as nerves conveying the olfactory sense. Ibn Sina embraced the classification of cranial nerves from Galen (Table 1). Ibn Sina identified that cranial nerves consisted of seven pairs of nerves excluding the olfactory nerve (Shaw, 1992; Bakhtiar, 1999; Shoja and Oyesiku, 2014). The cranial nerves were identified, numbered and characterized based on the opening through which they exited the skull (Shoja and Oyesiku, 2014). Galen's classification placed the glossopharyngeal, vagus and spinal accessory nerves all traversing the skull though the jugular foramen into the sixth pair. The same was done for the facial and vestibulocochlear nerves because they exit the skull through the internal acoustic meatus. The trochlear and the abducens nerves were also not mentioned.

Avicenna described the optic nerves as the first pair of nerves penetrating in each eye and partially crossing at the optic chiasma. His discovery of the partial crossing of optic nerve fibers at the optic chiasma was novel and contradicted Galen's views of total crossing.

According to Crossman and Neary (2015) the optic nerve (second cranial nerve) originates in the retina of the eye, partially crosses at the optic chiasma and projects as the optic tract to the lateral geniculate body. The oculomotor nerve was described as the second pair of nerves but accurately described its innervation to the extra-ocular muscles which are involved in the movement of the eye (Bakhtiar, 1999). The oculomotor nerve innervates the following eye muscles: superior rectus, inferior rectus, medial rectus, inferior oblique and the levator palpebrae superioris (Moore et al., 2014; Crossman and Neary, 2015).

The trigeminal nerve and its divisions were described in the Canon of Medicine as the third and fourth pairs representing the sensory and motor roots respectively. The smaller fourth nerve (motor root) was described as joining the third pair soon after its origin from the hind brain. The three major divisions of the trigeminal nerve can be identified from his description, including the ophthalmic division to the forehead, the branches of the maxillary division to the upper teeth, nose, and palate, and the branches of the mandibular division such as the inferior alveolar, lingual, auriculotemporal and pterygoid nerves.

Ibn Sina described the fifth pair of nerves as a double pair consisting the vestibulocochlear and facial nerves in modern terminology (Shaw, 1992). The vestibulocochlear nerve (first part) was associated with conveying the sense of hearing and facial nerve (second part) was associated with motor and special sensation to the tongue. Ibn Sina described the course and distribution of the facial nerve as “ the second part, smaller than the first, comes out of the petrous bone hole and it is called the blind cecum because it is very twisted and curved intending to lengthen the range between the origin and the end. The nerve takes benefit from the far distance from its origin to gain hardness, so when it comes out it associates with the nerve of the third pair, where most of them are heading to the cheek and wide muscle and the rest of them go to the temporal muscles” (Bakhtiar, 1999). In modern anatomic descriptions

the facial nerve after traversing the stylomastoid foramen distributes widely to the all muscles of the facial expression of the same side.

Ibn Sina recognized that the sixth pair of nerves consisted of three functionally different components representing the glossopharyngeal, spinal accessory and vagus nerves in modern terminology. He noted that the three components emerge from a single foramen, enveloped by a common sheath and they seemed like a single nerve (Bakhtiar, 1999). He described one component to supply the root of tongue and the pharynx (glossopharyngeal), and the second component goes down to the shoulder joint and supply the flat muscles of the scapula (trapezius). The third component (vagus) was described as accompanying the carotid artery in the neck and giving superior laryngeal, recurrent laryngeal branches to the structures of the larynx. He also noted that the vagus nerve distributes to the viscera in the thorax, pierces the diaphragm and innervates abdominal contents. Avicenna described the seventh pair nerves (hypoglossal) as the last, arising from the border between the brain and the medulla oblongata and distributes to the muscles moving the tongue. He described the association between hypoglossal nerve the ansa cervicalis and the branches to the infrahyoid muscles.

Table 1. Classification of cranial nerves, comparing between modern and Galenic views (adopted from Shoja and Oyesiku, 2014).

Modern classification		Galen's classification
I.	Olfactory nerve	Not mentioned
II.	Optic nerve	First pair
III.	Oculomotor nerve	Second pair
IV.	Trochlear nerve	Not mentioned
V.	Trigeminal nerve	Third and fourth pairs
VI.	Abducens nerve	United with second pair
VII.	Facial nerve	Fifth pair
VIII.	Vestibulocochlear nerve	Fifth pair
IX.	Glossopharyngeal nerve	Sixth pair
X.	Vagus nerve	Sixth pair
XI.	Accessory nerve	Sixth pair
XII.	Hypoglossal nerve	Seventh pair

Spinal nerves

Avicenna described spinal nerves as nerves originating from the spinal cord, passing through intervertebral foramina and carrying both motor and sensory components. He believed that the motor and sensory roots of spinal nerves originated separately from the spinal cord and that the spinal cord consists of two separated parts the “hard and soft”, motor and sensory parts respectively, similar to the brain (Bakhtiar, 1999). The spinal nerves were regionally segmented into cervical, thoracic, lumbar, sacral and coccygeal similar to modern descriptions (Fig 2). Avicenna attempted to describe individual courses of spinal nerves and

the structures that supply with less accuracy. Descriptions of muscle innervations and root values of nerves precisely require sophisticated dissection and track studies which were not permissible during Ibn Sina' time. However, Ibn Sina described accurately the innervation of thoracic intercostal muscles, abdominal muscles and the neurovascular plane between the anterior abdominal muscles. He also described the formation of the lumbar sacral plexus and its distribution to the muscles of the lower limbs.

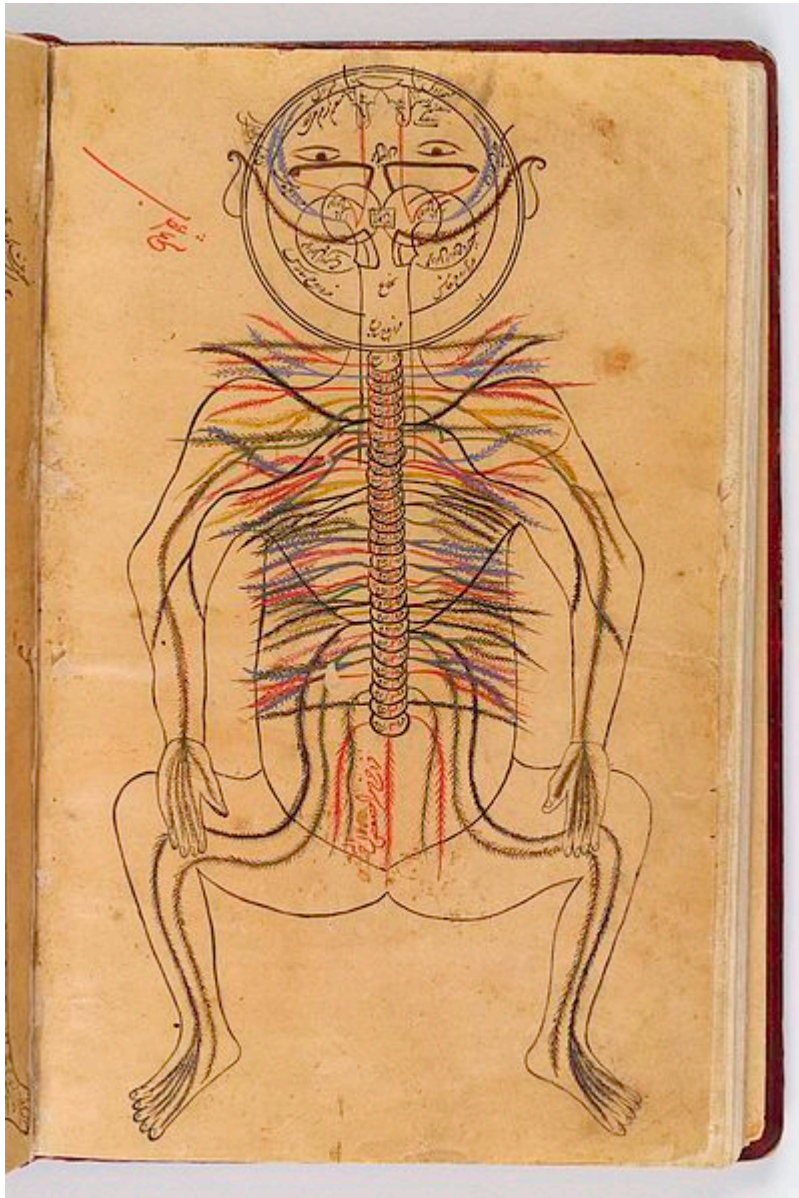


Fig 2. Topography of nerves as viewed by Ibn Sina in the canon of medicine. Image adopted from https://commons.wikimedia.org/wiki/File:Nervous_system,_Avicenna,_Canon_of_Medicine_Wellcome_library

Summary

Avicenna presented factual information on the topography, functional and applied concepts in the musculoskeletal system. Most of his descriptions laid foundations for modern specialized fields such as clinical anatomy, osteology, myology, neurology and biokinetics. The information written in the 11th century has enhanced the osteological studies and their applied sciences.

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