An analysis of the structural and functional anatomy of the spine as viewed by Avicenna (980-1037 AD)

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Abstract:

Ibn Sina (famously known as Avicenna 980-1037 A.D) was a well-known physician, philosopher, encyclopaedist, mathematician and astronomer of his time. He also served as a politician, governor and administrator. His book the Canon of Medicine is one of the most famous books in the history of medicine. Ibn Sina emphasized the importance of anatomy in diagnosis and treatment of diseases. In the article we present an analysis of the contributions made by Avicenna on the anatomy and functions of the vertebra and spine. The descriptions made by Ibn Sina are to a large extend congruent with modern anatomy and its importance in understanding movement and movement disorders of the spine in the modern day.

Key words: Ibn Sina, Canon of Medicine, spine, vertebra, spinal cord

Introduction: life and history of Avicenna

Fig 1. Drawings of Galen (left), Avicenna (Abu Ali al-Hussain ibn Abdallah ibn Sina, 980–1073 AD) (middle) and Hippocrates (right).

Ibn Sina, also known as Hakim Bu Ali, Abu Ali, Pur Sina, Ibn Sina, Bin Sina, Sheikh or- Raeis and Sheikh Ali (Fig 1) in the Arab world and as the Latinized 'Avicenna' in the West, was born in 980 AD in Bukhhara and died in 1037 in Hamadan (now Iran). He was a well-known physician, philosopher, encyclopaedist, mathematician and astronomer of his time (Asimov, 1986). He also served as a politician, governor and administrator (Naficy, 2005). Avicenna was a gifted child who educated himself in various fields including medicine and philosophy. By the age of 10, Ibn Sina had become an expert in the study of the Quran and different earth sciences. He studied philosophy by reading various Greek, Muslim, and other texts and learned metaphysics and logic under teachers which he later surpassed. He continued self-education and by the age of 17 he had mastered Islamic law, medicine, and metaphysics. At the same age of 17 he was able to treat and cure the king of Bukhhara, Nuh Ibn Mansur (Noor Ibn Mansoor) of an unspecified illness considered incurable by all well-known physicians of the time. In return, the king offered to reward Ibn Sina for his mighty work but Ibn Sina refused the prize and only asked to use the King's well stocked library. He gained immense knowledge from the use of the library, and by the age of 21 Ibn Sina was an accomplished physician who also worked as politician, governor and a clerk in administration. He later

left Bukhhara, for Jurjan, and then Ray, Hamadan and Isfehan where he wrote his famous book of medicine the *Al Qanun* (1030 A.D) also known as the Canon of medicine in the west (Asimov, 1986; Naficy, 2005; Shoja and Tubbs, 2007). The Canon became the standard of medical science and was at par with works of Hippocrates (460-377 B.C) and Galen (129-199 A.D) (Fig 1) in all libraries of European universities. The Canon consisted of five chapters which systematically classified all the available knowledge studied by ancient Greek and Muslim scientists in the following subject areas: anatomy, physiology and pharmacology (Books 1 and 2); pathology of diseases of internal organs and their symptoms according to Galen's classification (Book 3); fever (Book 4) and metaphysics (Book 5) (Avicenna, 1658). The Canon of medicine was translated into Latin by Gerard of Cremona in the 12th century (Naderi et al., 2003) and into Hebrew in 1279. The book, based on the temperamental and humoral theory of Hippocrates and Galen, remained the main textbook of medicine in Western medical schools until late 1650 (Shoja and Tubbs, 2007). Avicenna recommended that physicians and surgeons base their knowledge on the anatomy of the human body. Avicenna stated, "I believe that at the beginning, pupils should learn the general principles of medicine, both in theory and in practice. Analysis of diseases which affect different organs will precede the methods of keeping these organs in sound health. To satisfy this, we must first study the anatomy of these organs". Based on this premise, this review offers a critique of Avicenna's anatomy sections/ chapters on the spine and vertebra and their functions as presented in the Canon of medicine.

Materials and methods

This chapter presents extracts from the Canon of medicine on the anatomy and function of the vertebra and the vertebral column (spine).

Chapter: The Function of the Spinal Column (pg 63 – 64)

The vertebral column has four functions. It affords passage to the spinal cord which is essential to the life of animals. The purpose of the spinal cord will be described in detail under the heading spinal cord. Here it may briefly be mentioned that: (a) if the brain supplied all the nerves, it would be too big a burden for it. (b) If all the nerves have arisen from the brain, the nerves for the hands and feet would have to travel quite a long distance and thus be exposed to greater risks of injury and damage. The nerves would also be too weak to contract and expand the heavy muscles (of the leg and the thigh). Almighty God has therefore, granted this further benefit by providing a spinal cord from the lower part of the brain. (c) The

spinal cord arises from the brain like a canal from a spring so the nerves may reach both sides of the body and also go right up to the ends. (d) The source of the nerves has in this way been brought closer to the recipient organs.

The spinal cord has been protected by lodgement in a canal formed of hard bone. The vertebral column also gives protection to the important organs lying in the front. That is why is has been provided with hard prominences and spines. Like the central beam of a boat, the vertebral column provides a sort of foundation for the framework of other bones. This is the reason why it has been made particularly hard. In the human being, the vertebral column has been made into a strong and stable pillar so that on flexion, side to side movements, and on standing it should maintain its proper position. The vertebral column has been built of several irregularly shapes bones which are not as big as to make movement difficult. The intervertebral joints are also neither hard as to interfere with movement nor so loose as to make it sluggish.

Chapter: The Vertebrae (pg 64 – 65)

The vertebra is an irregular piece of bone with a central foramen for the spinal cord. On both sides it has four processes. The two processes on each side are placed one above the other. Sometimes a vertebra may have 6 processes with four on one side and two on the other. At times there may be even eight. These processes provide firm articulations with the processes of one vertebra entering into the corresponding depressions of the other. The processes also protect the vertebrae entering into the corresponding depressions of the other. The processes also protect the vertebrae against shocks and injuries.

Vertebrae are covered with hard, broad and long ligaments which are attached from below upwards to the full length of the vertebral column. The backs of the vertebrae have spinal processes and the sides' transverse processes. The vertebrae give protection to the structures like nerves, blood vessels and muscles which are placed lengthwise. The transverse processes of the vertebrae have smooth, glistening facets for articulation with the heads of the ribs.

Just as there are two smooth facets on each side of a vertebra, there are two rounded heads on each rib for articulating with facets to form joints. Some transverse processes are bifid and look like double

transverse processes. This peculiarity however, exists only in the cervical vertebrae. The advantages of this formation will be described shortly.

In addition to the vertebral canal, there are foramina for the passage of nerves and blood vessels. In some vertebrae, the foramina are within the substance of the vertebrae; while in others they are intervertebral, being formed of semicircular notches on the articular margins of the two adjoining vertebrae. These foramina may be large or small and may be present both above and below the vertebra or only on one side. They are located in the sides because at the back there would be no protection for the structures passing through them and in front these structures would be liable to damage from the movements of the spine.

If the vertebral column had no ligamentuous attachments, it would not have the strength and firmness which it now has. The vertebral processes of the spine which are of a protective nature are always covered with ligaments and tendons. The ligaments also keep the processes moistened with exudation, and thus, on the one hand, facilitate movement and on the other protect the local muscles. The articular processes of the vertebrae, being protected by fasciae and ligaments from all sides, make strong joints. The anterior ligaments from all sides, make strong joints. The anterior ligaments are stronger than the posterior ones because there is a greater need of forward movement than backward extension.

The space behind the vertebrae is formed by the stretched fibrous tissue and is filled with viscid exudation. Although this material is very little, it does help to provide rest and stability to the vertebral column. The advantage of the vertebral column being made of several vertebrae is that its movement is free and easy. This would not be the case if it had been made of a single bone.

Chapter: The Functions of the Neck (pg 65 – 69)

The neck has been designed to accommodate the trachea, which will be described in detail at its appropriate place. The bones of the neck, especially the atlas, are placed one above the other. They are smaller in size, particularly the atlas, which is supported by other vertebrae. A thing which is supported has always to be lighter than its support, especially if it is normally expected to move.

The spinal cord is thickest at its origin because of the large number of nerves arising from there. The vertebral canal here is also wider and the vertebrae thinner for the same reason. These two factors

ultimately produce weakness of the vertebrae at this place. This is, however, rectified by the measures already described.

The cervical vertebrae have also been made more compact than the other vertebrae. It should also be remembered that cervical vertebrae have thin bodies and shorter spinous processes to reduce the risk of injury which longer processes would have entailed. The transverse processes in these vertebrae are however big, as more movement than stability and do not have to carry as much load as the lower vertebrae. Hence, the joints of the cervical vertebrae are more loose and mobile than those of thoracic vertebrae. The weakness and laxity of the cervical spine have been compensated for by strengthening the joints with a complete cover of the muscles, blood vessels and nerves.

The upper and the lower articular processes of the cervical vertebrae are as big as those of the lower vertebrae. The bases of the articular processes of the cervical vertebrae are longer and the ligaments which cover them are looser. The foramina for the emergence of nerves are formed, as already described, by a union of two vertebrae. The thinness and smaller size of the cervical vertebrae and the larger size of their vertebral canal do not leave room for any other foramina than the foramina in the transverse processes of the cervical vertebrae for transmitting the vertebral artery. The cervical vertebrae will now be described in some detail.

The cervical vertebrae are seven in number. Their number, size and length are most appropriate for the body. There are eleven processes in each vertebra except the first: one spinous, two transverse, four articular processes, two pedicles and two arches making the total eleven. In some vertebrae, these processes are quite prominent while in others they are not so distinct.

Every transverse process splits into two and has a circle to complete with the semicircles of the adjoining vertebra. The first and the second cervical vertebra have some special characteristics which are not found in other vertebrae. The movements of the head to the right and the left sides are carried out in the joint between the head and the first vertebra and the forward and backward movements of the head occur between the first and the second vertebra. We shall first describe the joint between the head and the first vertebra.

On the upper side of the first vertebra there are depressions over the two articular processes to receive the two articular condyles of the skull. If one of the two condyles is elevated, and the other depressed,

the head gets tilted to that side. Since there is no more room in this vertebra for another joint, the next vertebra has been provided with a long hard process on the front i.e. on the inner side to enter the vertebral foramen of the first vertebra in front of the spinal cord.

The vertebral foramen of the first is in continuity with the vertebral foramen of the second vertebra, but the foramen of the latter is larger antero-posteriorly, rather than transversely to accommodate this additional structure.

This process of the second vertebra is known as the odontoid process. Near this process, the spinal cord is protected from pressure and injury by a covering of the ligaments arising from both the odontoid process and the spinal cord. After passing through the first vertebra, the odontoid process disappears in the foramen magnum. Forming a joint for the forward and backward bending of the head.

There are two advantages of the odontoid process: first of all, it gives good protection and secondly, it prevents the thin, anterior portion of the first vertebra from dislocation. The first vertebra has no spinous process as that would have made it too heavy and exposed it to shocks and injuries. The principle is that a process which is sufficiently strong to give protection from injury is also an invitation to damage of the delicate structures. Moreover, a spinous process in this vertebra would have damaged the large number of muscles and nerves surrounding the first vertebra. There is also no real need for it, as the first vertebra is well protected by the second vertebra. That is why is also has no transverse process. Besides, in this area there is a good packing of vessels and nerves arising from the brain and these leave no room for this process.

Another characteristic of this vertebra is that the nerves do not pass through the inter vertebral foramina at the sides of the vertebra but through the foramina on the top of the posterior part. If the nerves had come out near the condyles, they would be damaged by the movements of the joint. The case would be similar if they had emerged from the place where the articular processes of the second vertebra enter into the articular depressions of the first. It would not have been proper for them to arise from the anterior or the posterior parts of the first vertebra not from its sides which have been thinned for receiving the odontoid process. Hence, there is no other way for the nerves to emerge from the spine except from behind and slightly below and to the sides of the vertebral joints. Since these foramina are rather small, the nerves which pass through them are also very thin and fine.

In the case of the second vertebra, the nerves could not have emerged from above the vertebra because the movement and rotation of the first vertebra over the second would have caused damage. It was also not possible that these nerves should emerge from either above, behind or from the sides of the second vertebra because in that case both the first and the second cervical nerves would have arisen so close to each other that they would have joined together as one. Had the nerves emerged in this way, they would have become too weak and fine and thus would create the same difficulty as mentioned before. Hence, the only suitable place for the nerves to emerge is from foramina by the sides of the spinous process, where the first vertebra has also corresponding aperture and where its body can also participate.

The odontoid process of the second vertebra is firmly joined to the first with ligaments. The joints of the skull with the first and the second vertebrae are very loose and mobile as compared to the other joints of the vertebral column. The reason is that in these joints there is a greater need of movement for the head, the upper two vertebrae move like a single vertebra. Thus, when the head moves forward or backward, both the first and second vertebrae move together. Similarly, when the head tilts to the right or left side without any movement of the neck, both the first and the second vertebra move together as one. This is a summary of the various special features of cervical vertebrae.

Chapter: The Function and Anatomy of the Thoracic Vertebrae (pg 69 – 70)

The ribs articulate with the thoracic vertebrae and encase the lungs. Eleven of the thoracic vertebrae have spinous as well as transverse processes, but the twelfth vertebra has no transverse process at all. The spinous processes of these vertebrae are of unequal size, being particularly large and strong near the vital organs. The transverse processes of these vertebrae are very hard and strong as compared to those of the other vertebrae because they have to join with the ribs.

Thus, in the upper seven thoracic vertebrae, the spinous processes are enormous in size and the transverse processes exceptionally thick for a thorough protection of the heart. The tubercles over the transverse processes of the vertebrae up to the ninth have been made short and broad to correspond with the heads of the ribs.

The upper articular processes of these vertebrae have facets for articulation with the tubercles on the under surface of the vertebrae above, so that the lower articular process of each vertebra has a tubercle to articulate with the smooth facet on the vertebra below. The spinous processes of the upper vertebrae

are directed slightly downward, but the spinous process of the tenth thoracic vertebrae is strong, straight and erect.

The articular surfaces of this vertebra are smooth and free from tubercles and articulate with the vertebrae both above and below. The vertebrae below the tenth have depressions on their upper surface for articulating with the processes on the lower surface of the vertebra above. The spinous processes of these vertebrae have been directed slightly upwards for a purpose which will be described later. There is no transverse process in the twelfth vertebra as the twelfth rib does not articulate with it, hence, there appears to be no need for it and the necessary protection has been given in some other beneficial manner to it.

It is necessary for the lumbar vertebrae to be of larger size and stronger joints to carry the weight of the upper vertebrae, hence, they have more articular facets and processes than the other vertebrae. The first lumbar vertebra which articulates with the twelfth thoracic closely resembles it. The articular processes of the first lumbar vertebra are larger because this vertebra has a surplus of bone available from the absence of transverse processes.

There are two reasons for this. The posterior part of the diaphragm is attached to the twelfth thoracic vertebra. Moreover, the vertebrae above the twelfth, being small, have no need of larger articular processes for additional strength as their long transverse and spinous processes are a sufficient compensation. Since the thoracic vertebrae are larger than the cervical vertebra, the vertebral canal progressively decreases in size from above downward until the tenth thoracic vertebra comes to have a small vertebrae foramen and the remaining thoracic and lumbar vertebrae are so small that they are unable to accommodate the whole spinal cord. That is why they have the foramina on either side to let out the lumbar and sacral nerves.

Chapter: The Anatomy of the Lumbar Vertebrae (pg 70)

Lumbar vertebrae are five in number. They have spinous processes and broad transverse processes. Their articular processes are flat like the protective transverse processes. In collaboration with the sacrum, lumbar vertebrae form a base and a pillar for the whole spine. They also support the pubic bone and provide exit for the nerves to the legs.

Chapter: The Anatomy of the Sacrum (pg 70)

There are three vertebrae in the sacrum. These are very hard and have strong joints and broad transverse processes. Foramina for the nerves are placed rather posteriorly to avoid obstruction to the hip joint. The pieces of the sacrum are just like the lumbar vertebrae.

Chapter: The Anatomy of the Coccyx (pg 71)

The coccyx is made of three cartilaginous vertebrae which are devoid of processes. They are small; hence, the nerves pass through the intervertebral foramina as in the cervical vertebrae. There is only one nerve which emerges from the side of the third coccygeal vertebra.

Chapter: The Final Description of the Function of the Vertebral Column (pg 71)

In the description of the various bones of the vertebral column, its advantages have been dealt with to some extent. Here it may be mentioned that the vertebrae of the spinal column jointly act as a single bone. They have the best possible shape, i.e. cylindrical to withstand hits and jolts. The spinous processes of the upper vertebrae are directed downward and those of the lower upwards.

The spinous process of the tenth vertebra lies in the centre. The central position is, however, not in accord with the number of vertebrae, but with the length of the spinal column. When the spine is moved to the right or left side or backwards or forwards, it does so by inclining from the centre to the opposite side.

In this way, the upper or lower portion of the spine can bend sideways or forwards with the end of the spine brought close to each other. In order to facilitate this, the vertebral column has been provided with articular facets rather than larger tubercles. To bring the vertebrae in close contact with each other, the margins of the upper vertebrae are directed downward and of the lower vertebrae upwards. The surfaces of the articular tubercles in the upper vertebrae face somewhat downward, while in the lower they face upwards to facilitate movement.

Results and discussion

The anatomic information presented by Ibn Sina in his book, the Canon of medicine made the basis for modern day systemic anatomy. The most common clinical anatomy textbook used today in most medical universities, “Clinically Oriented Anatomy” by Moore and colleagues, (2014) adopted the style of

anatomy presented in the Canon of medicine where the structure of an organ or region is described first followed by clinical and or functional aspects. Most of the anatomy information presented by Ibn Sina on the spine and various vertebrae is accurate, although it is not well known; however how much of it is original, and also based on his own knowledge. This is because anatomic dissections on humans were prohibited in Islam, his information might have been generated from clinical observations (Naderi et al., 2003) and or from animal dissections.

In our analysis of the vertebral spine, we first note that Ibn Sina's classification of the vertebral column into cervical, thoracic, lumbar, sacral and coccygeal is congruent with modern anatomic descriptions and also that the weight and size of the individual vertebra reduces from below upwards to serve for stability and mobility. Here in we analyse each and every chapter in the Canon of medicine which covered the anatomy of the spine and vertebra.

On the anatomy the vertebra in general, Ibn Sina noted that they have processes which offers muscles, ligament attachments and also protection to the vital structures and organs such as the spinal cord. He also noticed that the individual vertebral bones were stacked one on top of the other to facilitate free movement in relation to each other (Avicenna, 1658). This information is vital as a fixed vertebral column will be more susceptible to fractures especially on application of external pressures, accidents and in mobility sports. Injuries to the vertebral column often involve the spinal cord and in most case they happen when the body is placed in limiting environments such as automobiles. The only in-accurate information presented by Ibn Sina on this section was that intervertebral foramina may be placed on one side of the vertebra; these are paired structures and they carry segmental nerves on both sides. Errors like these may be regarded as typographical, as he also noted that they also exist of both sides which in line with modern descriptions of anatomy. In addition Ibn Sina noted the presence and importance of the moisture/ fluid on ligaments in bringing about the smooth movement of joints and the slide between two structures. In modern anatomy, this moisture is referred to as the synovial fluid which helps to lubricate the joints (Moore et al., 2014)

The cervical vertebra was accurately explained except the anatomy of the C2 (axis). Of most importance was the description of the movement between the head, atlas and axis between the atlanto-occipital joint and atlanto-axial joints. Here Avicenna noted that the lateral flexion (sideways) movements happens between the head (occipital condyles on the skull) and C1 (atlas), and the anterior and posterior

(nodding) movements happens on the joint between head and the C2 (axis). He further stated that "during the anteroposterior and lateral movements of the head, the first and second cervical vertebrae act as a single bone and move together". These descriptions are to a large extent true with only slight omission of the C1 on the nodding movement, which in this movement acts together with the skull as a single unit against the C2 vertebra (Moore et al., 2014)

In addition, structurally the C1 vertebra lacks the body and Ibn Sina noted that the odontoid process of C2 reinforces the C1's anterior arch and therefore acts as the body of the same bone. Functionally, Ibn Sina realised that the odontoid process supports and reinforces the weak anterior arch of the C1 and is covered by a strong transverse ligament of the atlas (Moore et al., 2014). Here the wisdom of God, can be also be appreciated as the compensatory mechanism of the odontoid process to the absences of the body of the atlas, offers additional protection to the vulnerable spinal cord form the front. Biomechanically, the cervical vertebra is more mobile as compared to the rest of the spine; this is accorded by small vertebral bodies, wider and horizontally oriented articular facets and also relatively larger intervertebral discs than vertebral bodies (Moore et al., 2014). Ibn Sina also noted this greater mobility of this segment of the vertebral column. Lastly and of most importance is Avicenna's observation of the wider vertebral canal in superior cervical vertebra and interpolated that this was important for the accommodation of many nerves in this region. In modern anatomy this region of the cervical spine has wider/ roomy vertebral column especially from C3-C7 to accommodate the cervical spinal enlargement which gives rise to the brachial plexus (a plexus of nerves) to the upper limbs (Moore et al., 2014)

On the thoracic and lumbar segments, Avicenna's descriptions are correct except on the anatomy of the 12^{th} vertebra where is stated that it lacks the traverse process because the 12 rib does not articulate with it. The 12^{th} thoracic vertebra has a short transverse process with no costal facets (Gunn, 2012) but as Avicenna stated earlier it is relatively of no use as the 12^{th} rib does not articulate with it. Generally the weight of the individual thoracic vertebra increases downwards to form what Ibn Sina referred to as the "pillar" which intern will support the body weight above. However the vertebral canal was observed to decrease in size from above downwards (Avicenna, 1658). This is because only the *cauda equina* occupies this canal and most nerve roots have exited it as well.

The sacrum and coccygeal segments were not accurately presented in Ibn Sina's Canon of Medicine. Firstly, Avicenna stated that the sacrum consists of three fused bones and sacral foramina are only

placed posteriorly. This is not correct as the sacrum has in most cases five fused bones with both anterior and posterior sacral foramina for the passage of anterior and posterior rami (Moore et al., 2014; Gunn, 2012). Secondly, the coccyx was viewed inaccurately as being composed of only three fused bones with no projections (Avicenna.1658). The coccyx consists of 3-5 fused bones with first bones bearing projections facing upwards (Moore et al. 2014; Gunn, 2012). Interestingly, Ibn Sina identified a large coccygeal nerve related to the coccyx and this nerve innervates the skin overlying the bone itself (Moore et al., 2014).

Overall, Ibn Sina noted the importance of the vertebral canal in protecting the vital spinal cord and the individual bony projections on the vertebra in protecting the surrounding structures like nerves, blood vessels and muscles from direct impact. The transverse process, for example protects the spinal ganglions located closer to the intervertebral foramina and these structures are involved in initial sensory processing from the body surface and also the nerve roots before they enter the subcostal groove in the thoracic segments or between muscles in the neck, lumbar, and coccygeal regions. Furthermore the spinous process of the thoracic vertebra projects downwards, producing an interlocking like structure. This arrangement in line with Avicenna's assertions helps to protect vital organs like the aorta, the heart and lungs posteriorly for penetrating objects during fights and or accidents. Lastly, Ibn Sina presented the importance of the 10^{th} thoracic vertebra in acting as the centre of movement (axis) the vertebral column during sideways and anterior and posterior displacements.

Conclusions

A greater part of the anatomy the spine by Avicenna is considered accurate today. This section emphasizes the association between the size and shape of the vertebra in their function of support, protection and movement of the vertebral column. The spine is also divided into cervical, thoracic, lumbar, sacral and coccygeal. Biomechanical movements between joints and the vertebral column as a whole are also presented.

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