

Original Article

Comparative quantitative analysis of osseous anatomy of the craniovertebral junction of tiger, horse, deer, and humans

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Abstract

Aim: To compare the osseous anatomy of the craniovertebral junction of a horse, deer, and tiger with that of a human being. The variation in the structure of bones in these animals is analyzed. **Materials and Methods:** Various dimensions of the bones of the craniovertebral junction of the horse, deer, and tiger were quantitatively measured, and their differences with those of human bones were compared and analyzed. **Results:** Apart from the sizes and weights, there are a number of structural variations in the bones of these animals that depend on their functional needs. The more remarkable difference in joint morphology is noticed in the occipitoatlantal joint. The occipitoatlantal articulation is remarkably large and deep, resembling a 'hinge joint' in all the three animals studied. The odontoid process is 'C shaped' in the deer and horse and is 'denslike' in the tiger and humans. The transverse processes of the atlas are in the form of large wings in all the three animals. The arches of the atlas are large and flat, but the traverse of the vertebral artery resembles, to an extent, to that of human vertebral artery. The rotatory movements of the head at the craniovertebral junction are wider ranged in the horse and deer as compared with those of the tiger and humans. The bones of the craniovertebral junction of all the three animals are adapted to the remarkable thickness and strength of the extensor muscles of the nape of the neck. **Conclusions:** Despite the wide variations in the size of the bones, the basic patterns of structure, vascular and neural relationship, and joint alignments have remarkable similarities and a definite pattern of differences.

Key words: Animals, atlas, axis, craniovertebral junction, odontoid process

INTRODUCTION

The anatomy of craniovertebral junction bones of the tiger,

horse, and deer was analyzed and compared with human bones. The evolutionary changes and structural alterations that have occurred due to the functional variations are clearly seen in the comparison. Understanding the anatomy of these animals clarifies the function of the various components of the bones of the craniovertebral junction. The evolutionary changes in the shapes and architectural design of the craniovertebral junction bones in each of these animals have been perfected to suit the job at hand.

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MATERIALS AND METHODS

Two dried bones each of the adult tiger, horse, and deer were

procured. One of the coauthors (S.A.G.) has a special permission from the Government of India to procure and handle cadavers of tigers for scientific purposes. The craniovertebral region bones were collected, and their major anatomical features were studied and compared with those of the adult human bones [Figures 1–4]. Palpation and visual examination of the bones were carried out. The shape, orientation, size, texture, foramina, and borders of each bone were studied and compared. A microcalliper was used for the measurements. Relationship of the vertebral artery and C1 and C2 spinal nerves to the craniovertebral junction were studied on the basis of literature survey.^[1-3]

RESULTS

The major anatomical features that were evaluated are summarized in Tables 1 and 2.

DISCUSSION

In quadrupeds, the cervical spine is a vertical part of the

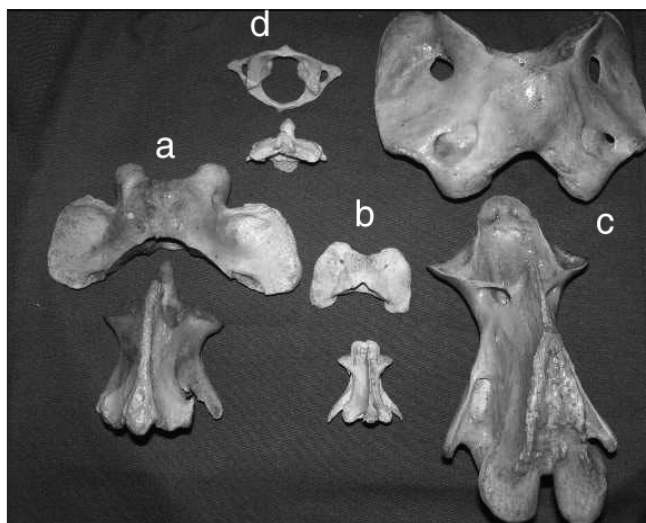


Figure 1:View of the posterior surfaces of the C1 and C2 vertebrae of tiger (a), deer (b), and horse (c). Note the differences in the sizes and shapes of the bones of each animal in relationship with the human bones (d)

Table 1:Analysis of C1 vertebra

Parameters	Humans	Horse	Deer	Tiger
Anteroposterior diameter of the superior facet of C1 (cm)	1.7	4	1	3
Transverse diameter of the superior facet of C1 (cm)	1.3	3	1.5	2
Anteroposterior diameter of the inferior facet of C1 (cm)	1.3	4	1.2	2.6
Transverse diameter of the inferior facet of C1 (cm)	1.2	4	1	3
Vertical height of the anterior arch of C1 (cm)	1.0	9	1.2	2
Vertical height of the posterior arch of C1 (cm)	0.7	16	1.7	3.8
Height of the superior facet of C1 (cm)	1.6	5	1.5	2.5
Anteroposterior diameter of the spinal canal at C1 (cm)	2.5	3.5	2	2.4
Transverse diameter of the spinal canal at C1 (cm)	2.3	5	1.9	3
Distance of the vertebral artery foramen from the midline (cm)	2.7	3	1.4	2.7
Horizontal length of the C1 anterior arch (cm)	3.5	8.3	2.2	6.5
Horizontal length of the C1 posterior arch (cm)	4.5	11	3.1	7.5
Length of the transverse process of C1 (cm)	0.4	9.7	3.8	5.0
Width of the transverse process of C1 (cm)	1.8	4.7	1.5	3.5

Table 2:Analysis of C2 vertebra

Parameters	Humans	Horse	Deer	Tiger
Anteroposterior diameter of the superior facet of C2 (cm)	1.3	5	1.6	2.5
Transverse diameter of the superior facet of C2 (cm)	1.4	3.5	0.9	2.2
Anteroposterior diameter of the inferior facet of C2 (cm)	1.3	4.5	1	1.7
Transverse diameter of the inferior facet of C2 (cm)	1.0	2.5	0.8	1.8
Height of the odontoid process (cm)	1.3	2.5	1	2.3
Height of the C2 anteriorly (cm)	3.0	16	4.9	8
Transverse diameter of the odontoid process (cm)	0.8	3.3	1.3	1.4
Length of the spinous process of C2 (cm)	1.2	13.3	4.2	8
Breadth of the spinous process of C2 (cm)	1.1	4	1.5	2.5
Anteroposterior diameter of the spinal canal at C2 (cm)	1.7	1.8	1.2	2
Transverse diameter of the spinal canal at C2 (cm)	2.1	2.5	1.3	2.2

entire vertebral column and the thoracic spine is more or less horizontally oriented. The head of the tiger, deer, and horse protrudes anteriorly in such a fashion that it is in the maximally flexed position at the occipitoatlantal joint articulation [Figure 2]. On the other hand, the cervicothoracic junction is aligned in the maximally extended position. This 'asymmetric' placement of the vertebrae in quadrupeds ensures an energy-saving balance of the head when the animal is in the resting position.^[4] When in the resting position, the movements permitted at the occipitoatlantal articulation are primarily of extension (flexion being gravity-assisted passive movement);

accordingly, the posterior cervical neck musculature is markedly strong in these animals. The occipital crest is remarkably thick, providing a site for muscular attachment. The occipital crest is most remarkably thick in the tiger, as seen in Figure 4. In humans, the entire spine assumes a general vertical orientation and its curvatures are much less pronounced when compared with the quadrupeds studied. The vertical stance of the human being places the head directly over the neck in line of the weight bearing of the rest of the spine.^[4] The muscles of the nape of the neck and the occipital crest in humans are significantly small in dimension. The atlantoaxial bone and joint complex of the tiger

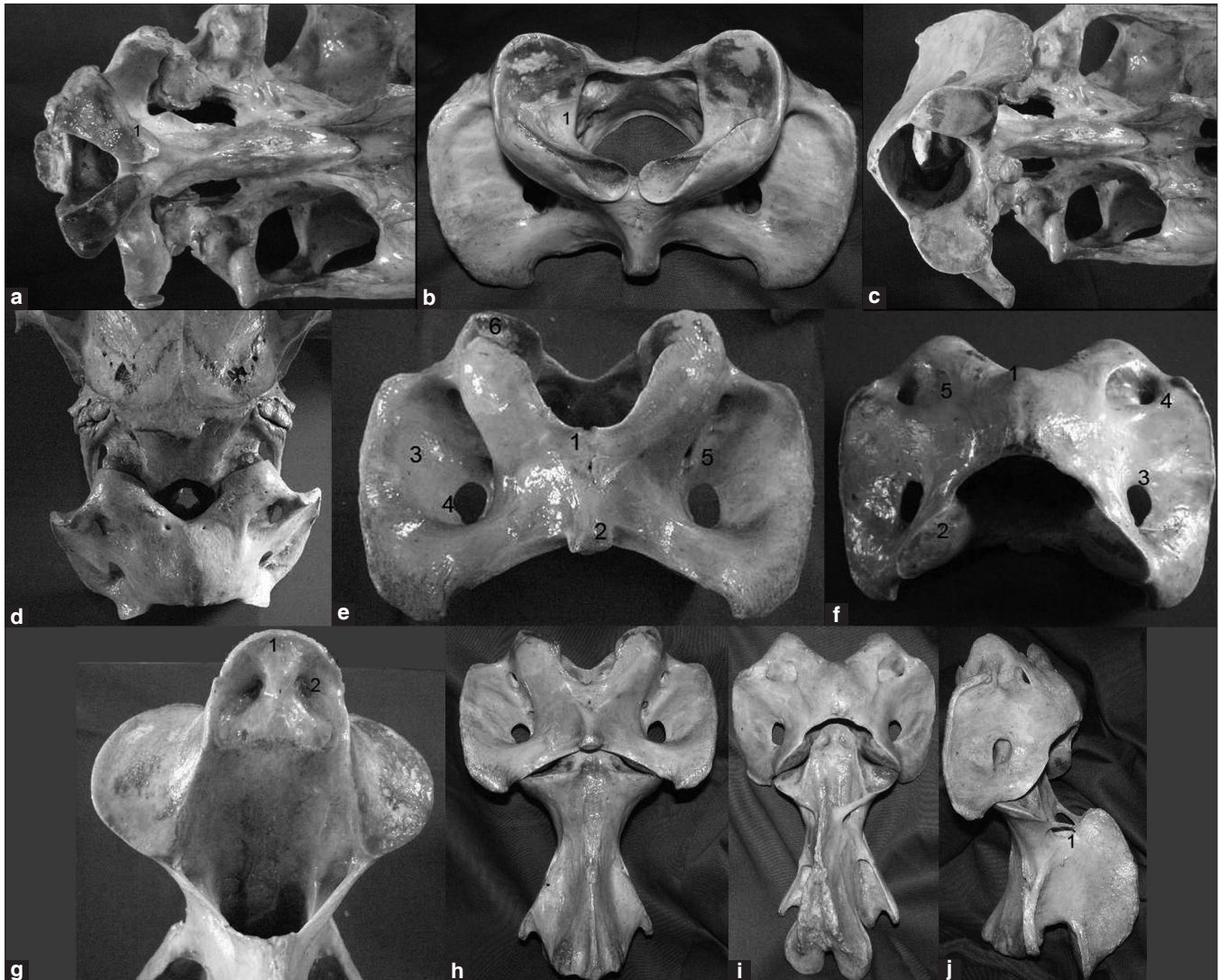


Figure 2: Images of the craniovertebral junction bones of a horse. (a) Inferior view of the posterior aspect of the skull showing the large occipital condyles (1). (b) Superior (anterior) surface of the atlas, as seen from the superior and anterior perspective, showing the deep 'cup-shaped' articular surface (1) for the articulation with occipital condyles. (c) Inferior surface showing the atlas articulated with the occipital bone. Note the acute flexed position of the head in relationship with the atlas. (d) Posterior view showing the occipitoatlantal articulation. (e) Ventral view of the C1 vertebra showing the ventral arch (1), ventral tubercle (2), transverse process (3), transverse foramen (4), atlantal fossa (5), and superior articular facets (6). (f) Dorsal view of the C1 vertebra showing the dorsal arch (1), the inferior articular facets (2), transverse foramen (3), alar foramen (4), and lateral vertebral foramen (5). (g) Superior view of the axis vertebra of the horse showing the C-shaped configuration of the odontoid process (1) and the deep impressions for the longitudinal ligament (2). The superior articular facets of the axis are seen in relationship with the odontoid process. (h) Anterior view of the C1-C2 articulation. The atlantoaxial joints are relatively flat when compared with the deep concavity of the superior facets of the atlas in relationship with the occipital bone. (i) Posterior view of the C1-C2 articulation. (j) Lateral view of the C1-C2 bones. The notch for the C2 spinal nerve is converted into the lateral vertebral foramen (1) following ossification of the ligament.

have much more remarkable resemblance to human beings than the bones of herbivorous animals such as horse and deer.

Platybasia

There is platybasia in all the three animals studied. The clivus and the anterior skull base are in the same horizontal plane. The maxilla and the upper jaw protrude anteriorly from the cranial base. The brain size is relatively small and the olfactory nerves well developed and long, reaching to a length of about a foot in the horse. The cerebellum is proportionately large in animals as compared with the cerebral hemispheres. In humans, the angulation of the anterior skull base in relationship with the clivus is probably related to the relatively large size of the cerebral hemispheres.

Occipitoatlantal articulation

The superior articular surface of the atlas (referred to as anterior articular facet in quadrupeds) and the occipital condyles are much larger, thicker, and stronger in all the three animals studied as compared with the corresponding human bones. The large occipital condyles of these animals sit deep into the cup-shaped anterior (superior) articular facets of the atlas [Figures 2–4] and form a joint that appears like a ‘ginglymus or a hinge joint’, providing an opportunity for extra stability and enhanced mobility as compared with the human occipitoatlantal joint. The superior facet of the atlas is much deeper in all the three animals as compared with the human superior facet, which is almost flat. The range of movements at the occipitoatlantal articulation is chiefly of extension and flexion, with a small

amount of lateral oblique movements.^[3] The total range of motion at the occipitoatlantal articulation varies between species. It is 90–105° in the quadrupedal mammals and only 11–13° in humans.^[5] The cervical part of the vertebral column is most mobile in horses; the mouth may be brought around to reach the flank on full lateral flexion of the neck and ventrally to reach the pasture on ventral flexion.^[6]

Atlas

The atlas bone has ring-shaped anterior and posterior arches and has wide lateral platelike projections or wings of the transverse processes in all the three animals studied [Figures 2–4]. The transverse process in the human atlas is reduced to only the vertebral artery canal. The ventral (anterior) and dorsal (posterior) arches of the atlas are much thicker in the tiger, horse, and deer as compared with the humans.^[7] The *dorsal arch* presents a median tubercle. It is perforated on either side near its cranial margin by the *lateral vertebral foramen* [Figure 2]. In these animals, the term *lateral vertebral foramen* is used instead of the term *intervertebral foramen* in the case of the atlas and axis as this foramen does not lie between the two vertebrae as the term ‘inter’ implies and rather lies on the dorsal arch of the atlas.^[3] The *ventral arch* is thicker, narrower, and less curved than the dorsal arch. On the ventral surface is the ventral tubercle, which is more prominent in the horse and deer as compared with humans and tiger.

Although the *transverse processes* are large in the horse and deer as compared with humans, they are proportionately smaller in size as compared with those of the tiger. The ventral surfaces of

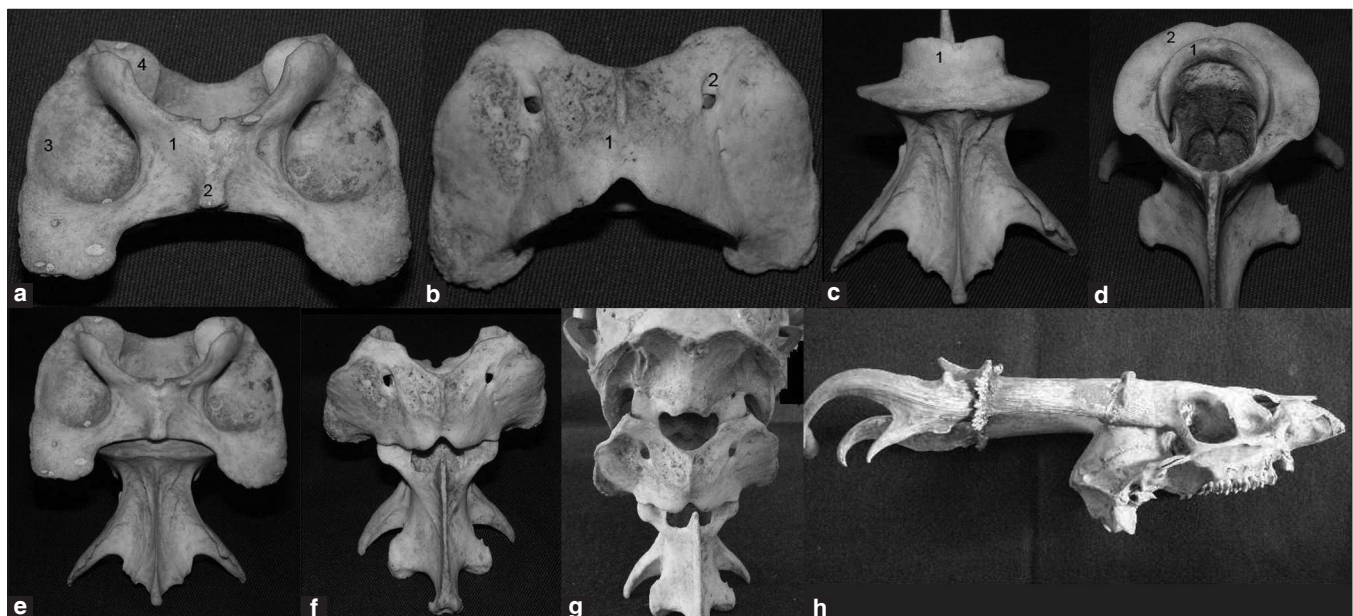


Figure 3: Images of the craniovertebral junction bones of a deer. (a) Ventral view of the C1 vertebra showing the ventral arch (1), ventral tubercle (2), transverse process (3), and superior articular facets (4). (b) Dorsal view of the C1 vertebra showing the dorsal arch (1) and the alar foramen (2). (c) Anterior view of the axis vertebra. The articular surface of the C-shaped odontoid process (1) can be seen in continuity with the superior articular facets forming a saddle-shaped joint. (d) Superior view of the axis vertebra of the deer showing the C-shaped odontoid process (1) and the confluent superior articular surfaces (2). The saddle-shaped articular surface can be vividly seen. (e) Anterior view of the C1–C2 articulation. (f) Posterior view of the C1–C2 articulation. (g) Posterior view of the craniovertebral junction. (h) Lateral view of the head of the deer. Note the location of the occipital condyles and the prominence of the occipital crest

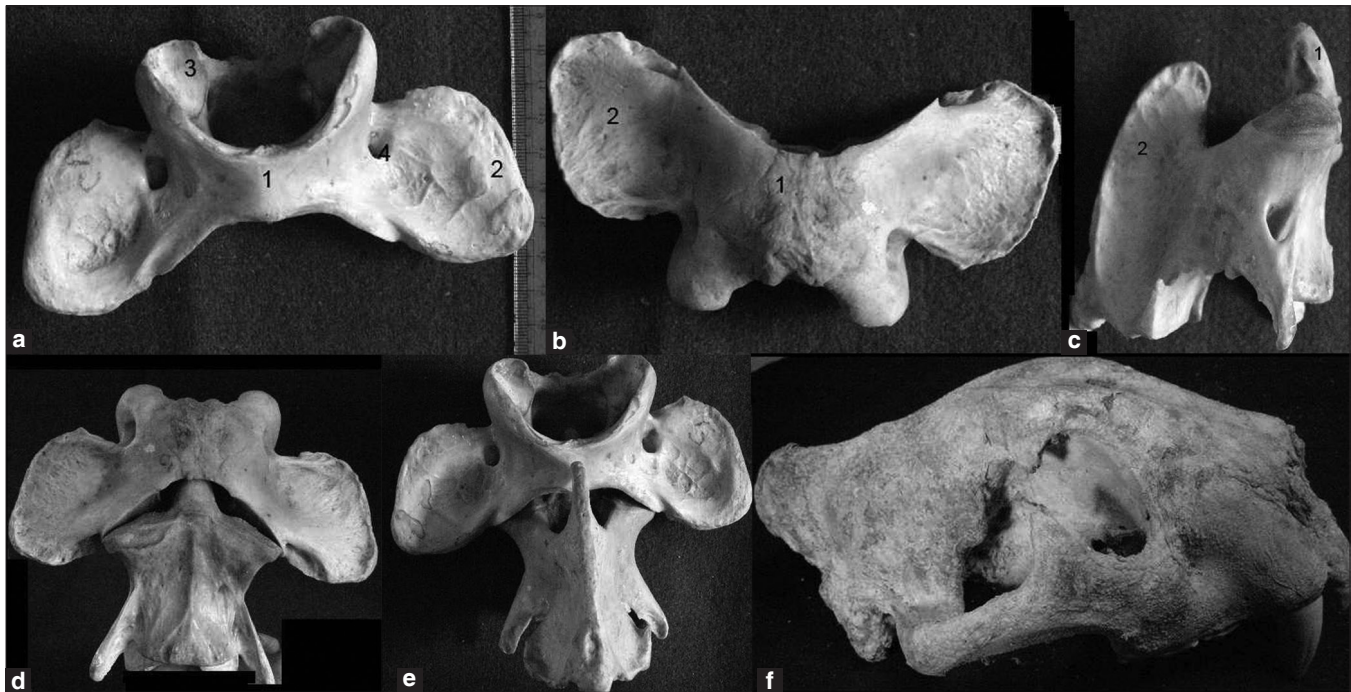


Figure 4: Images of the bones of a tiger. (a) Ventral view of the C1 vertebra showing the ventral arch (1), transverse process (2), superior articular facets (3), and alar foramen (4). Note the wings of the transverse process and the depth of the superior facets. (b) Dorsal view of the C1 vertebra showing the dorsal arch (1) and the transverse process (2). (c) Lateral view of the axis vertebra showing the denslike odontoid process (1) and the characteristic spinous process (2). Note the shape of the odontoid process and the articular surface of the facet that resemble the human C2 vertebra. (d) Anterior view of the C1–C2 articulation. (e) Posterior view of the C1–C2 articulation. (f) Lateral view of the skull of the tiger showing the large occipital crest

the transverse process of the atlas in the horse and deer have a greater depth than those of a tiger, in which they are shallower but wider. Between the ventral aspect of the transverse process and the lateral mass is a depression called the *atlantal fossa*. In horses, each wing is perforated by two foramina: the cranial one is the *alar foramen*, which connects with the lateral vertebral foramen by a short groove; and the caudal one is the *transverse foramen*^[3] [Figure 2]. In tigers, there is a lateral vertebral foramen for the first cervical nerve close to the cranial border of the dorsal arch. The alar foramen is replaced by a notch in the cranial border of the wing that transmits the ventral branch of the first cervical nerve. The base of the wing is perforated by the transverse foramen. While the human transverse process is horizontally oriented (transverse), it is vertically aligned in the animals studied.

The articular surface of the superior facet of the atlas accounts for roughly 75% of the entire ring of the atlas as compared with less than 40% in the atlas of humans. The joint surfaces are separated by a wide notch dorsally and a narrow one ventrally. The atlantodental joint is remarkably prominent in the horse and deer, providing articulation to the large and C-shaped odontoid process in these herbivorous animals [Figures 2 and 3]. The inferior articular surfaces (referred to as posterior articular surface in quadrupeds) of the lateral mass of the atlas are confluent anteriorly with the joint surface on the posterior arch of the atlas to form a saddle-shaped articular surface.

Axis

In the horse and deer, the axis is the longest of all vertebrae. It measures 16 cm in the horse and 4.9 cm in the deer in its vertical length.

The odontoid process of the tiger simulates the odontoid process of a human being. The odontoid process is denslike in human and tiger bones, whereas it is a C-shaped, relatively thin and flat ring that has a wide area of joint formation with the posterior surface of the anterior arch of the atlas [Figures 2–4]. This wide area of the atlantodental joint is seen uniformly in herbivorous animals as against the denslike odontoid process in carnivorous animals. The odontoid process of humans simulates more closely with that of carnivorous animals. The anterior surface of the odontoid process forms a well-defined joint with the posterior surface of the anterior arch of the atlas. The joints of the horse and deer are much larger as compared with those of humans and tiger. The rotatory movements of the neck at the craniocervical junction are superior in the horse and deer as compared with those of the tiger and humans. The limitations of the rotatory movements at the craniocervical junction and the placement of eyeballs in a more anterior perspective of the head in the tiger and humans as compared with those in the horse and deer are adaptations that suit their lifestyle and preying, hunting, and survival needs. The dorsal surface of the odontoid process has two deep impressions on either side of the midline in a horse and deer for the attachment of the

thick and fan-shaped longitudinal ligament [Figure 2]. This ligament extends from the rough concave dorsal surface of the dens, widens cranially, and is attached to the transverse rough area on the inner surface of the ventral arch of the atlas. These impressions are not prominent in the odontoid process of the tiger and humans. The atlantoaxial joints are relatively similar in their inclination and depth in human beings and in all the three animals studied.

In the horse, the *lamina or the arch of the axis* has a notch on each side of its cranial border that is converted into a lateral vertebral foramen (intervertebral foramen) by a ligament that ossifies later [Figure 2]. A groove extends ventrally and caudally from this foramen and houses the ventral branch of the second cervical spinal nerve. In the deer and tiger, the cranial border has a deep notch that is not converted into a foramen. In humans, there is no such notch or groove. The *inferior articular processes* of the three animals are vertically oriented as compared with their more horizontal orientation in humans. The *transverse process* in the deer and horse is small and single and projects caudally. It has an obliquely oriented foramen for the vertebral artery. The transverse process and the vertebral artery foramen in the axis of the tiger are similar to those in humans.

The *spinous processes of the axis* of all the three animals studied are large, strong, and bifid [Figures 1–4]. The axis in the tiger is characterized by its length and its enormous spinous process, which overhangs both the dorsal arch of the atlas and the laminae of the C3 vertebra. The cranial extent of the spinous process matches that of the dens^[6] [Figure 4]. The C2 spinous process of humans is short, stubby, and bifid and is smaller than that of the other three animals. The lateral surfaces are concave and rough for muscular attachments.

Vertebral artery

The vertebral artery has a peculiar relationship with the transverse process of the horse. After exiting from the transverse foramen of the axis, it crosses the capsule of the atlantoaxial joint and enters the transverse foramen of the atlas. After coursing through the atlantal fossa, it anastomoses with the occipital artery. It then runs dorsally through the alar foramen and enters the vertebral canal through the lateral vertebral foramen (intervertebral foramen).^[3]

In the tiger, the vertebral artery, after exiting from the transverse process of the axis, courses over the dorsal arch of the atlas and enters the transverse foramen, which is present in the base of the wing of the transverse process. It then runs an intraosseous course in the wing for about 2.5 cm. It then exits on the ventral aspect, loops posteriorly, and enters the lateral vertebral foramen to pursue its intracranial course.^[6]

C1 spinal nerve

The first cervical nerve emerges through the lateral vertebral

foramen of the atlas and supplies several large muscles of the nape of the neck in all the three animals studied. This is unlike the situation in humans, where the C1 nerve root is 'rudimentary' in nature and function. In the horse and deer, the dorsal branch of the nerve passes dorsolaterally and supplies the dorsal neck musculature. In the horse, the ventral branch descends through the alar foramen of the atlas and passes anteriorly into the neck.^[3] In the tiger, the C1 nerve exits from the lateral vertebral foramen and its ventral branch exits through the notch in the cranial border of the atlas along the course of the vertebral artery.^[6]

C2 spinal nerve

The second cervical nerve is larger than the first one in all the three animals, as in humans. It emerges from the spinal canal through the lateral vertebral foramen on the cranial border of the lamina of the axis. This nerve also supplies a number of muscles and skin over the neck. Their function is also significantly in excess to that in humans.

CONCLUSIONS

The craniocervical junction bones form a pillar of stability and mobility. The basic architecture and design have remarkable similarities in all the animals studied. The variations in morphometry have a relationship with the quadruped stance, acute flexion position of the neck in the neutral position, and hunting and survival needs of the individual animal.

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