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MORPHOLOGICAL STUDY ON THE CEREBRUM OF BACTRIAN CAMEL (*Camelus bactrianus*) WITH PARTICULAR REFERENCE TO SULCI

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ABSTRACT

The macroscopic anatomy of the cerebrum of the bactrian camel (*Camelus bactrianus*) is detailed herein for the first time. Many features vary significantly from most previously described ungulate species including its large size, sulci pattern of the cerebral hemispheres and well developed sular cortex. In this study, six brains of adult bactrian camels were examined and the mean values of the cerebrum length were about 11.23 cm; width 8.67 cm; height 5.77cm; weight of the brain 518.3 g and the sulci of the cerebrum, in general, were similar to that of the Chinese Qin-tibetan yak and Chinese water buffalo. The bactrian camel had the large temporal lobes, the well-developed olfactory bulbs and the prominence of the sulci and gyri. The results are beneficial for further research on the comparative neuroanatomy and developmental neurology.

Keywards: Bactrian camel, cerebrum, gyri, morphology, sulci.

Bactrian camels (*Camelus bactrianus*) are special precious and valuable domestic animals which mainly live in the arid and semi-arid areas of the northwest part of China and provide plentiful hair, milk and leather products. Cui-Sheng and Xie (1996, 1998b) and Cui-Sheng *et al* (1998a) investigated the cranial cervical ganglion, sympathetic ganglion, accessory nerve and vagus nerve in the head and cranial neck region of the bactrian camel. However, there is as yet no detailed reports describing the brain of the bactrian camels. Those of the horse donkey and ox have been reported by Getty (1975) and Xie (1987). The detailed investigation of Nokitenko *et al* (1970) constituted the comparison of brains of 13 species of Artiodactyla and concluded that the wisent possessed the most massive brain. Arroyo *et al* (1977) compared the morphology of the brain of the cat and dog in particular reference to the sulci and gyri. Hunan Research Group (1984) profoundly described the brain of the Chinese water buffalo. Smuts and Bezuidenhout (1987) in its monograph expounded in dromedary (*Camelus dromedarius*). Louw (1989) had described the development of the sulci and gyri of the bovine cerebral hemispheres. However, many other unusual and pertinent characteristics of the bactrian camel brain currently lack description. The present report concerns the anatomical topography of the bactrian camel. Comparisons with domesticated and wild ungulate species as well as other mammalian forms are also included.

Materials and Methods

Six specimen of the brain of adult bactrian camels were collected from the Minqin county Gansu China after slaughtering these animals by exsanguination in the local slaughterhouse and procedures described by Xie (1987) and Miller (1980) were followed.

Perfusion procedure: Each specimen of the head of bactrian camels was perfused immediately prior to the introduction of the fixative in the field after 5 to 15 min of death. Both internal carotid arteries were isolated by blunt dissection. Cannula (inside diameter 0.5 cm) coupled by surgical tubing to a pressure driven perfusion device were inserted into each vessel. Pressure was maintained at a constant 130 mm/Hg for both the initial rinse solution consisting of 0.5 L of 0.85% sodium chloride, 0.1% sodium nitrate and 0.1% sodium heparin and the fixative which consisted of 3 L of 0.1 M phosphate buffered 10% formalin (pH 7.4).

Brain extraction: The brains were removed from the cranium one week after death of the animals. The head was completely skinned and sawed in two directions. The first saw cut transected the anterior skull from the lateral canthus of the bony

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orbits served as landmarks. The second saw cut was along the dorsal midline from the rostral part of the remainder of the skull to the occipital condyles. When the inner table of the calvarium was reached the saw was withdrawn and sufficient lateral pressure was applied to split the skull along the midline exposing the brain. Removal of the brain was accomplished by holding the skull upside down and allowing the brain to gently pull away from the cranial cavity by its own weight. An attempt was made to remove the brain with the cranial nerves intact by transecting them in rostrocaudal succession as the brain gradually dropped from the cranial vault, however, the extremely tenacious meninges made this a difficult task. Upon removal each brain was loosely wrapped in gauze stripping and placed into a container of cold formalin solution similar to the perfused fixative.

Result

When viewed from the dorsal surface (Fig 1) the bactrian camel brain forms an elongated ovoid mass bunted at the rostral and caudal poles. A slight lateral compression near the rostral pole and prominent temporal lobes were observed. Both hemispheres appeared reasonably symmetrical. In general, the topography conformed to a pattern observed in several species of large ungulates particularly the horse and Chinese water buffalo. Measurements obtained from the bactrian camels are summarised in table-1. Unfortunately total body weight as well as other body dimensions could not be determined at the time of death. Table-2 is a partial exposition of similar data obtained from several artiodactyls (Nikitenko *et al, 1970).* Jon and Jack (1975) reproduced here for comparative purposes. It could not be ascertained from translation whether these values were derived from fresh brains or from brains preserved by a fixing agent. Neither the total number of brains measured nor the landmarks used in the measurements were reported. These authors presented their values as median scores whereas ours were means. In a normal distribution mean and median scores coincide and it was not believed that large discrepancies are to be found here.

A mean brain weight of 518.3 g was obtained by averaging three volumetric displacements of each of the six bactrian camel brains. This weight is less than that of a horse (650 g; Getty, 1975) or the Chinese water buffalo (526 g; Hunan Research Group, 1984) but greater than that of any species presented in table -2 including the American plains buffalo (485 g), wisent (448 g) and great horned cattle (420.7 g) (Nikitenko *et al,* 1970). Despite the fact that both bactrian camels and American plains buffalo brains are larger relative to the other species shown in table-2. Certain differences between them are apparent. The wisent forebrain is wider than long indicating the possibility of enlarged temporal poles in this species.

The cortex of cerebrum was thrown into numerous folds, the cerebral gyri, which were separated by sulci or fissures of varying depth. The general pattern of the gyri and sulci was similar in normal brains the same species but the details were very variable and were never alike on the two hemispheres of the same brain. In the bactrian camel the arrangement is complicated by the existence of numerous short accessory sulci or fissures which cut into the gyri at right angles and tend to confuse the observer. The principal sulci and fissures of the convex surface are shown in Fig 1, 2 and 3.

The cerebrum of the bactrian camel was convex from side to side and rostrocaudally and more or less conformed to the shape of the cranial cavity. Half way between the frontal and occipital pole was a raised point referred to as the sagittal section of marginal pole (Fig 1). The two cerebral hemispheres were incompletely separated from each other being connected through the corpus callosum. The space between the two hemispheres, the longitudinal fissure, was occupied by a sickle-shaped thickening of the dura mater- the falx cerebri (Fig 3). Caudally the cerebrum was separated from the cerebellum by an irregular transverse groove occupied by a crescentic fold of dura mater- the cerebelli tentorium. The pallium was thrown into a series of folds (gyri convoluted) separated by sulci or fissures.

Sulci of the dorsal cerebrum: The principal sulci visible in dorsal view of the cerebrum were suprasylvian sulcus, marginal sulcus, ectomarginal sulcus, endomarginal sulcus, coronal sulcus, crucial sulcus and anasal sulcus.

Suprasylvian sulcus: This distinct sulcus was a large and deep which divided the convex surface roughly into dorsal and lateral portions. It was rostral to the tentorial surface and caudally divided into 3 parts in undulating manner and extended as anterior limb, middle limb and posterior limb. Anterior limb of the suprasylvian sulcus extended from the level of the crucial sulcus. It ran in an undulating manner in the middle one-third part of the hemisphere. The posterior limb of the suprasylvian lay roughly parallelled to the marginal sulcus. It was limited caudally by oblique sulcus and ended on the tentorial surface. All of the limb have the sublimb in dorsal or ventral surface of the hemisphere. It was usually continued rostromedially with the anasal sulcus and in front with presylvian sulcus.

Marginal sulcus: This was the innermost or medial most sulcus seen on the dorsal surface. It ran roughly parallel to the longitudinal fissure along with the dorsal margin. It began a little in front of the middle of the border or unusually began from anasal sulcus and turned around the occipital pole to end on its tentorial aspect. Casually it has a short distance confluenting to the ectomarginal sulcus in the middle segment.

Ectomarginal sulcus: This sulcus located about midway between the marginal sulcus and the suprasylvian sulcus arose caudally to the sagittal pole. It broke and irregularly ran in a flexuous manner in the middle of the hemisphere. Along with its way there were many short sublimbs crossed dorsally to marginal sulcus and ventrally to suprasylvian.

Endomarginal sulcus: This sulcus arose from caudomedian to the sagittal pole and ran in a flexuous manner in the caudal half of the hemisphere. In other cases this sulcus was enveloped by marginal gyrus or part of it. In some species or double hemisphere of one cerebrum presented difference status.

Coronal sulcus: This sulcus lay dorsally to approximately the third of cerebral hemisphere and lay up medially to rostral crucial gyrus and ectosylvian gyrus. It extended below rostrally to presylvian and caudally to decussate to anasal sulcus and continued to suprasylvian sulcus. The middle segment of sulcus usually connected crucial sulcus.

Crucial sulcus: This sulcus arose rostral to the mid-portion of the coronal sulcus or decussated with coronal sulcus and divided transversely to median cortex of rostral hemisphere. It was located rostrally to precrucial gyrus and caudally to postcrucial gyrus.

Anasal sulcus: This sulcus began a little behind the middle of the calloso-marginal sulcus passed obliquely dorsally and rostrally to the dorso-medial border. It ended caudally to approximately the third of dorso-rostral hemisphere and usually joined the suprasylvian sulcus.

Sulci of the lateral cerebrum (Fig2)*:* The sulci of the lateral cerebrum lay between suprasylvian sulcus and lateral rhinal sulcus mainly included sylvian fissure, ectosylvian sulcus, diagonal sulcus and orbital sulcus. The principal sulci were visible in a lateral cerebrum view as described below:

Sylvian fissure: This sulcus was located on the dorso-lateral surface of the hemisphere. It extended from lateral fossa and divided dorsally into three limbs. Anterior limb of sylvian fissure was that which passed rostrodorsally. The limb was longer than the middle limb and origining segment paralleled proximately to the lateral rhinal sulcus. It usually gave off ventrally to the insula and ran flexuously to rostral dorsal lateral surface to sublimb at the terminal. The middle limb (ascending limb) of sylvian fissure was that one ran obliquely to dorsal lateral surface and turned rostrally in the middle of the limb or gave rise to sublimb to the dorsolateral surface. The third, posterior limb of sylvian fissure was directed caudodorsally to the insula and the terminal segment ran flexuously and caudolaterally to occipital pole. The position and the length of the anterior limb and posterior limb were variable and the position of ascending limb was diverse often.

Ectosylvian sulcus: This sulcus lay lateroventrally to the suprasylvian sulcus of the lateral hemisphere and was parallel to it. It was a deep sulcus crossed to the lateral hemisphere. Its shape appeared to be variable in that of limb extended in lateral and caudal directions. It can be considered to have an anterior, middle and posterior limb. The anterior limb of ectosylvian sulcus arose from the middle limb and extended rostrally upward to the anterior limb of suprasylvian. Compared to the anterior limb the middle limb was usually short but had more branches and extended ventrally to the middle limb of the suprasylvian sulcus. The posterior limb was usually not connected to the middle limb and arose from the terminal ectosylvian gyrus extended caudo-dorsally to the middle part ectomargial gyrus. In some cases, the posterior limb crossed the posterior limb of suprasylvian sulcus.

Presylvian sulcus: It was on the anterior part of the hemisphere, passed forward and ventrolaterally almost to the frontal pole and inclined caudally to end at dorsolateral of the rhinal sulcus. This sulcus connected rostrally to coronal sulcus or separated by orbital gyrus.

Diagonal sulcus: It lay ventrally to presylvian sulcus and extended caudally from coronal sulcus and craniocaudally downwards in direction. The rostral segment was connected to the coronal sulcus or closed to it. The posterior segment was connected to the lateral rhinal sulcus. It was the part of rostral composition gyrus that occur between the presylvian sulcus to diagonal sulcus.

Obitals sulcus: This sulcus lay between the dorsal olfactory bulb and caudally to presylvian sulcus. It was a short sulcus for a distance of about 2.5 cm that was located dorsolaterally to diagonal sulcus and ran oblique ventrally to lateral rhinal sulcus.

Lateral rhinal sulcus: This was the most ventral sulcus marking off the olfactory part of the brain

from the rest of the hemisphere. The sulcus ascended on the lateral surface of the hemisphere as the continuation of the fossa lateral in front of the pyriform lobe. After crossing the lateral olfactory stria it divided into three limbs. One limb passed dorsally one ran obliquely forward and dorsally and the third directed dorsally and backward. It contained the middle cerebral artery.

Sulci of medial surface of hemisphere (Fig 3): The medial surface of cerebrum was flat and had the more salient identifiable sulci which composed the rostral and caudal portion of the dural corpus callosum. It mainly included the calloso-marginal sulcus, callosal sulcus, entogenual and entolplenial sulcus and ectogenual sulcus. The principal sulci visible in a medial surface view were as described below:

Callosomarginal sulcus: This sulcus approximately parallelled to dorsomedial border of the hemisphere and lengthwise was about two-third to hemisphere. It began in anasal sulcus or in front of a short distance and formed a C-shaped curve and its posterior part extended on the corpora quadrigemina. The middle segment of this sulcus gave off fine sublimb on the marginal gyri. It separated the marginal gyri above from the fornicate gyrus.

Callosal sulcus: This was a fine superficial sulcus abutted on the dorsal of the corpus callosum. It began at the genu, followed the dorsal contour of the corpus callosum and curved around the splenium and separated the corpus callosum from the fornicate gyrus.

Entogenual and entosplenial sulcus: This sulcus was a longitudinal and superficial sulcus lay between callosomarginal sulcus and callosal sulcus. The rostral segment of this sulcus that was entogenual sulcus arose from rostral to the corpus callosum or hereabout. In some cases the middle segment had the sublimb dorsally to anasal limb or the callosomarginal gave off intermittent sublimb above it also. The middle and posterior segment that was entosplenial sulcus paralleled to the callosal sulcus and ended caudoventrally to the splenium.

Ectogenual sulcus: This was a variable sulcus and was rostrally to the genu of callosal sulcus. The middle segment of this sulcus gave off 2 or 3 limbs towards to cingulal gyrus. The middle and posterior segment paralleled to the callosal sulcus and ended above the middle rostral callosal sulcus.

Discussion

The cerebrum of the bactrian camel is similar in many macroscopic features to that of closely related artiodactyls such as the American plains buffalo the Chinese water buffalo and horse. However, it differs significantly from most others within the order. Considerable variation in the pattern and disposition of sulci is observed between the different specimens. The endomarginal sulcus of the bactrian camel resembles to Chinese water buffalo (Anonymous, 1984) and seem to differ in appearance from Chinese Qin-tibetan yak (Zhang, 1989). The sylvian fissure of the bactrian camel appears short and narrow is similar to that of the water buffalo and horse that of the yak and ox are very deep and extend almost to the middle of the lateral hemisphere. The crucial sulcus of the bactrian camel is similar to the horse and more salient identifiable than that of the yak, ox and water buffalo that of the giant panda (Anonymous, 1986) inclines rostroventrally to longitudinal cerebrum as formed 20 degree angle.

According to Le (1965) the cerebral sulci tend to appear along the boundary lines separating cortical areas which differ in structure (and also in function). He also proposed a mechanical factor in the developmental cortical tissue in sulci formation. Ariens (1965) while describing the development of the cerebral cortex in mammals considered that the blood vessels do not play any role to the limbs of the cerebral arteries in the occurrence of these sulcal pattern variations. Further he believed that the variable patterns relate to the heterometric expansion of a certain cortical area in the course of the early development which is dependent upon the nutrition, sex, size and other factors. In addition, the growth of the gyri and sulci may have some influence on the normal contours of the cerebral hemisphere. Louw (1989) has examined the development of the sulci and gyri of the bovine cerebral hemispheres. He indicated that the cerebral hemisphere was smooth in bovine embryos and foetuses up until 58 days. Then an indentation appears which marks the position of the sylvian fissure. The lateral rhinal sulcus appears at 68 day. At 90 day the following grooves were visible: the suprasylvian sulcus, the entogenual sulcus, entosplenial sulcus the ectogenual sulcus and the callosomarginal sulcus. At this age all the gyri associated with these sulci developed although the gyri developed only after the grooves were formed. At 110 day, the ectosylvian sulcus, the marginal sulcus and the presylvian sulcus are visible once again with their associated gyri appearing a short time thereafter. At 130 day, the following grooves were visible: the coronal sulcus, the crucial sulcus, the anasal sulcus and the endomarginal sulcus. The cerebrum of the foetus at this stage has well developed gyri. At 160 day, the orbital sulcus, the

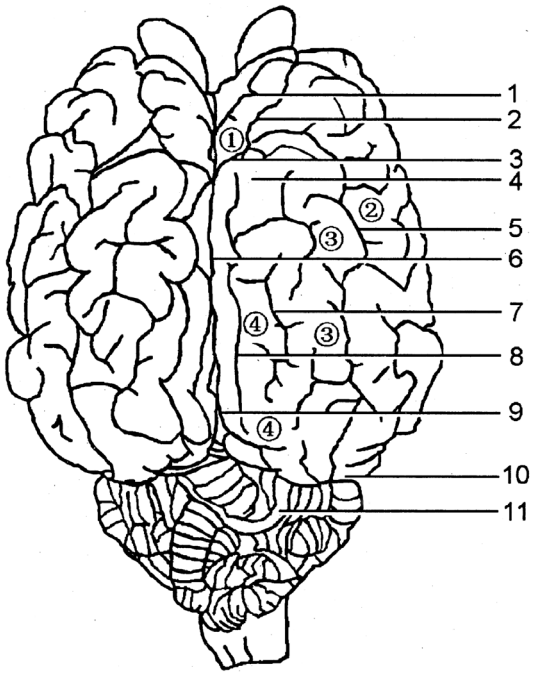

Fig. 1. Dorsal view of the brain of bactrian camel. 1, Crucial sulcus; 2, coronal sulcus; 3, anasal sulcus; 4, marginal pole; 5, suprasylvian sulcus; 6, longitudinal fissure; 7, ectomarginal sulcus; 8, marginal sulcus; 9, endomarginal sulcus; 10, occipital pole; 11, cerebellum; ①, crucial gyrus; ②, ectosylvian gyrus; ③, ectosylvian gyrus; ④, ectomarginal gyrus.

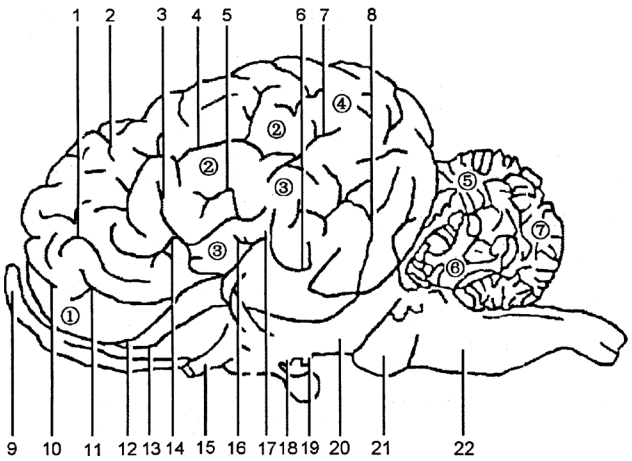

Fig 2. Lateral view of bactrian camel brain. 1, presylvian sulcus; 2, anasal sulcus; 3,anterior limb of ectosylvian sulcus; 4, middle limb of suprasylvian sulcus; 5, middle limb of ectosylvian sulcus; 6, posterior limb of sylvian fissure; 7, posterior limb of ectosylvian sulcus; 8, occipitotemporal sulcus; 9, olfactory bulb; 10, orbital sulcus; 11, diagonal sulcus; 12, rhinal sulcus; 13, lateral rhinal sulcus; 14, anterior limb of sylvian fissure; 15, optic nerve; 16, middle li mb of sylvian; 17, insula; 18, mammilary body; 19, oculomotor nerve; 20, cerebral peduncle; 21, pons; 22, medulla; ①, orbital gyrus; ②, ectosylvian gyrus; ③, sylvian gyrus; ④, ectomargial gyrus; ⑤, anterior lobe of the cerebellum; ⑥, vermis; ⑦, posterior lobe of the cererbellum.

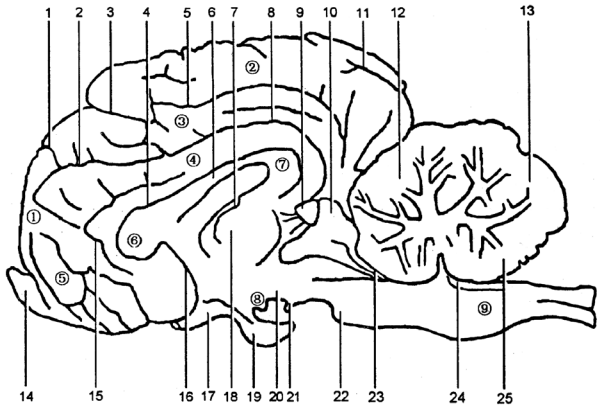

Fig. 3. Medial surface of right cerebrum and lateral surface of brain stem. 1, crucial sulcus; 2, entogenual sulcus; 3, anasal sulcus; 4, callosal sulcus; 5 callosomarginal sulcus; 6 corpus callosum; 7, stria medullaris thalami; 7, entosplenial sulcus; 8, pineal body; 9, tectum; 10, entomarginal fissure; 11, anterior lobe of the cerebellum; 12, posterior lobe of the cerebellum; 13, plfactory bulb; 14, ectogenual sulcus; 15, ectogenual sulcus; 16, anterior commissure; 17, optic chiasm; 18, thalamus; 19, pituitary; 20, tegmentum; 21, oculomotor nerve; 22, pons ; 23, rostral medullary velum; 24, caudal medullary velum; 25, nodulus; ①, postcrucial gyrus; ②, marginal gyrus; ③, dorsal cingulate gyrus; ④, ventralcingulate gyrus; ⑤, orbital gyrus; ⑥, genu of corpus callosum; ⑦, splenium of corpus callosum; ⑧, mammilary body; ⑨, medulla.

Table 1. Morphometric characteristics of the bactrian camel (in cm.)

Structure	Mean	S.D.
Length of forebrain:		
Right frontal to occipital pole	11.16	0.5029
Left frontal to occipital pole	11.23	0.5057
Width of forebrain:		
Right anterior hemisphere[1]	3.87	0.5021
Right posterior hemisphere[2]	4.76	0.2810
Left anterior hemisphere[1]	3.84	0.2581
Left posterior hemisphere[2]	4.87	0.1488
Height of forebrain		
Right anterior hemisphere[1]	5.30	0.6403
Right posterior hemisphere[2]	6.56	0.2170
Left anterior hemisphere[1]	4.81	0.1093
Left posterior hemisphere[2]	6.41	0.5614
Length of olfactory bulb		
Right	3.26	0.2978
Left	3.32	0.0981
Width of olfactory bulb		
Right	1.23	0.1023
Left	1.31	0.1152

[1]Genu of corpus callosum used as landmark
[2]Splenium of corpus callosum used as land mark

Table 2. Some morphometric characteristics of artiodactyls brains (in cm.)[1]

Structure	Pig	Domestic Sheep	Bighorn Sheep	Reindeer	European Elk	Great Horned Cattle	European Wisent	American Plains Buffalo[2]	Bactrian Camel[3]
Length of forebrain	8.54	8.50	8.40	9.30	10.50	11.6	12.28	11.43	11.23
Width of forebrain	8.20	5.82	6.98	6.40	7.95	?	13.24	9.33	8.67
Height of forebrain	3.95	4.13	7.44	9.20	5.60	6.97	7.86	6.41	5.77
Length of olfactory bulb	2.35	1.67	1.65	2.90	3.20	2.66	3.12	3.89	3.26
Total brain weight (g)	105.70	109	135	261	391	421	448	485	518.3

[1] Partially reproduced from Nikitenko *et al* (1970), pp 30-35.

[2] Data from Jon W. Harper and Jack K. Maser, (1975).

[3] Data from table 1.

ectomarginal sulcus and the suprasplenial sulcus were developed. The final groove to form was the medial rhinal sulcus. Then the brain looked like that of the adult bovine. We have shown how certain elements of the bactrian camel's visual apparatus are well developed that differ or resemble significantly from other mammalian's brain. These observations suggest the bactrian camel's cerebrum possess some homologues from other Artiodactyla.

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References

Anonymous (1984). The Anatomy of The Chinese Water Buffalo. Huynan Research Group (1984) Hunan Scientific and Technology. Press Changsha. pp 251-273 (in Chinese).

Anonymous (1986). Anatomy of The Giant Panda Sciences. Beijing Zoo, Press Beijing China, pp 373-374.

Ariens KCU, Huber GC and Crosby EC (1965). The development of the cortex in mammals. Hafner Publishing Co New York, 3rd ed. pp 1519-1550.

Arroyo GJ, Villanova TJ and Cobos CP (1977). Comparative study of the morphology of the brain of the cat and dog Anales de la facultad de Veterinaria de Leon 21:13-25.

Cui Sheng and Xie ZM (1996). The gross anatomy of the parasympathetic ganglia of the bactrian camel. Indian Veterinary Journal 73:951-957.

Cui Sheng and Xie ZM (1998b). Gross anatomy of the accessory nerve and vagus nerve of the head and cranial neck region in the bactrian camel. Veterinary Journal 155:317-322.

Cui Sheng, Jianlin Wang and Xie ZM (1998a). The gross anatomy of the cranial cervical ganglion and its branches in the bactrian camel. Veterinary Research Communications 22:1-5.

Getty R (1975). Sisson and Grossman's Anatomy of The Domestic Animals. 5th edn. WB Saunders, Philadelphia. pp 788-813.

Le GC (1965). The tissues of the body : In- An Introduction of The Study of Anatomy. 5th edn. Oxford University Press London. pp 332-413.

Louw GF (1989). The development of the sulci and gyri of the bovine cerebral hemisphere Anatomia Histologia Embryologia 18(3):246-264.

Miller ME, Howard EE and Alexander DVM (1980). Miller/s Guide to The Dissection of The Dog. 2nd Edn. WB Saunders Company. Philadelphia, pp 278-300.

Nikitenko MK, YT Volod'ko, LF Zvezdina and AA Leshko (1970). Golovnoi mozg parnokopytnykh (the brain artiodactyla) (Isdatel'stvo Baukai Teknika Minsk) (Translated from original copy)

Smuts MS and Bezuidenhout A (1987). Anatomy of the Dromedary. Oxford: Clarendon Press, Oxford. pp 182-188.

Xie ZM (1987). On The Spot Anatomy of The Donkey and Horse. 2nd Edn Agricultural Press, Beijing. pp 359-388 (in Chinese).

Zhang RY (1989). The Chinese Yak Science and Technique. Press Gansu China. pp 96-102.