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Research Article

Anatomical study of the brain of the African ostrich

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Abstract: The anatomical characteristics of the African ostrich brain were investigated in this study. The average weight, length, and width of the total brain are 26.34 g, 59.26 mm, and 42.30 mm, respectively. The cerebellum appears relatively well developed and obviously protrudes dorsally. The posterior superior part of the cerebellar vermis almost forms an angle of 130°. The ostrich brain has many more transverse fissures of the cerebellar vermis than do the brains of domestic fowls. Therefore, the surface area of the African ostrich's cerebellum is larger. The formation of the cerebrum is an obtuse triangle. Its surface is smooth, without any gyrus or sulcus. The gray matter is very thin. There is an arcuated telencephalic vallecula on the dorsal surface, and the sagittal eminence is elliptic. The olfactory bulbs are quite small. The hypophysis is spherical. The whole brain represents only 0.015% of the total body weight, and it is 17 times lighter than the brain of domestic fowls. Statistical analysis showed that the ratio of brain weight to body weight is significantly smaller ($P < 0.01$) in the African ostrich than in the 3 domestic fowls investigated. The present study suggests that the brain of the African ostrich is underdeveloped.

Key words: African ostrich, brain, anatomy

Introduction

The African ostrich (*Struthio camelus*) belongs to the class Aves, order Struthioniformes, family Struthionidae, genus *Struthio*. It is the only extant species of 2-toe birds in the world, and its frame is the largest of all extant birds. The male African ostrich can reach 2.75 m in height. The body length ranges from 1.8 m to 2.0 m, and the body weight can reach 200 kg. They mainly live in dry African regions and the extremely hot Arabian Desert, in harsh climates with food shortages (1). In the past, the ostriches that people saw were generally just in zoos for visitors. However, in the last 2 decades, people have begun to pay more attention to ostriches because of their great economic value. The ostrich breeding industry is growing rapidly in many places, including the USA, Australia, New Zealand, Israel, Canada, Europe, and China (2). The percentage of lean meat with high nutritional value and flavor can reach 62.5% in an ostrich. The percentages of both fat and cholesterol are lower in ostrich meat than in pork, beef, or chicken (1,3,4). Its skin is the most valuable top-grade leather, more expensive than that of crocodile. Therefore, people raise ostriches for commercial

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reasons worldwide. There are many reports about the bioecology and breeding of ostriches (5,6), and others about ostrich morphology (7-11). However, there has been no report about the central nervous system of the ostrich. Therefore, this research provides reliable morphological data for the feeding management, physiological functions, and disease prevention of the ostrich.

Materials and methods

Six adult African ostriches (3 males and 3 females), weighing 158-184 kg, were used in this study. After being deeply anesthetized with 20% urethane (1 g/kg body weight), all of the ostriches were perfused with 3000 mL of 0.85% normal saline (including 0.075% sodium citrate) through the carotid artery. At the same time, the right auricle was opened. After the solution coming from the heart became clear, the posterior segment of the neck was cut and perfused with 2000 mL of 4% paraformaldehyde phosphate-buffered solution (4 °C, pH 7.4, 0.1 mol/L) through the carotid artery for 1 h. Then the skull was immediately removed and opened so as to remove the entire brain; data from every part of the brain were gathered with a sliding caliper. Then statistical analysis was done and pictures were taken. *Nomina Anatomica Avium* was used for the anatomical nomenclature (12). The present study referred to and made a comparison with the brain morphology of the adult Oriental white stork, the Pekin duck, and the gray goose (13). The means and standard deviations of each item were calculated. The significance of the differences between the ratio of brain weight to body weight of the African ostrich and of the other 3 domestic fowls was analyzed with the Wilcoxon rank sum test. The statistical significance was considered at $P < 0.01$. The internal structure of the African ostrich brain will be described in detail in another paper.

Results

Shape of the whole brain

After application of a biodemography method, documents about the external morphology of the African ostrich brain were compiled in the Table together with the correlated data of the other birds.

All data items are the average value of figures from 6 birds. Statistical analysis showed that the ratio of brain weight to body weight is significantly smaller ($P < 0.01$) in the African ostrich than in the 3 domestic fowls investigated.

Table. Comparison of the brains of the African ostrich with the brains of other birds.

Items	African ostrich (mean ± S.E.)	Oriental white stork (mean ± S.E.)	Pekin duck (mean ± S.E.)	Gray goose (mean ± S.E.)
Total brain weight/g	26.34 ± 0.073	14.23 ± 0.01	6.53 ± 0.011	12.57 ± 0.016
Total brain length/ mm	59.26 ± 0.020	44.10 ± 0.019	36.83 ± 0.015	46.17 ± 0.015
Total brain width/ mm	42.30 ± 0.025	36.10 ± 0.026	26.13 ± 0.014	35.13 ± 0.013
Midbrain width/ mm	32.10 ± 0.018	26.50 ± 0.011	20.50 ± 0.009	22.17 ± 0.012
Optic lobe length/ mm	14.18 ± 0.02	14.50 ± 0.006	9.57 ± 0.014	10.60 ± 0.008
Optic lobe width/ mm	12.23 ± 0.011	9.10 ± 0.008	6.03 ± 0.016	6.53 ± 0.012
Optic tract width/ mm	8.20 ± 0.007	8.37 ± 0.008	3.20 ± 0.010	4.16 ± 0.010
Medulla length/ mm	18.66 ± 0.015	10.57 ± 0.015	10.23 ± 0.007	11.93 ± 0.012
Medulla width/ mm	16.60 ± 0.009	14.63 ± 0.014	11.50 ± 0.009	12.16 ± 0.007
Cerebrum length/ mm	35.35 ± 0.009	23.80 ± 0.009	23.67 ± 0.012	28.63 ± 0.008
Cerebellum length/ mm	24.36 ± 0.015	23.50 ± 0.007	8.80 ± 0.009	12.70 ± 0.007
Cerebellum width/ mm	18.42 ± 0.010	15.20 ± 0.010	9.93 ± 0.011	13.03 ± 0.020
Hypophysis length/mm	6.38 ± 0.009	5.63 ± 0.013	3.23 ± 0.012	6.20 ± 0.009
Hypophysis width/ mm	6.30 ± 0.015	3.03 ± 0.015	1.83 ± 0.011	2.56 ± 0.009

The dorsal view

Two cerebral hemispheres are at the anterior part of the brain, and the cerebellum and medulla are at the posterior part. There are 2 small olfactory bulbs in the intermediate of the head end of the cerebrum. A cerebral longitudinal fissure is between the 2 cerebral hemispheres and there is a transverse sulcus between the cerebrum and cerebellum. The cerebrum composes 59.65% of the brain's total length. The formation of the cerebrum is an obtuse triangle. The cerebral surface is smooth, and there is no gyrus or sulcus on it. However, on the dorsal surface of the cerebrum, there is a cambered supersulcus bending posterior-medially, a so-called telencephalic vallecula. There is a small rod-shaped, bottom-up tuber, known as the conarium (pineal body), at the juncture of the transverse sulcus and the 2 cerebral hemispheres. The cerebellum is located behind the transverse sulcus. An apparent vermis is at the center of the cerebellum with some transverse fissures, and there is a cerebellar auricle on each side of the vermis (Figure 1).

The ventral view

At the foremost head of the brain of the African ostrich, there is an underdeveloped olfactory bulb on each side of the cerebral hemisphere. There is no olfactory tract like those found in Mammalia. The orbital faces of the cerebral hemisphere are located in the anterior part of the brain. The optic chiasm occurs at the center rear of the 2 cerebral hemispheres. The optic tract of the ostrich is comparatively developed and its average width is 8.20 mm. The nerve fibers of the optic tract slope laterally because they intersect and link with the optic lobe of the midbrain. The optic lobe is a stylolitic eminence at the ventral part of the midbrain. The parts behind the optic chiasm all belong to the brainstem structure. There is a very superficial longitudinal sulcus, the ventral midmost fissure, at the ventral brain stem. The front portion of the brain stem is the hypothalamus, with a small global hypophysis on it. The midbrain peduncle, the pons, and the medulla oblongata are located consecutively at the back. There is no apparent demarcation between the midbrain and the pons and the medulla oblongata. An oculomotor root erupts from the ventral midbrain peduncle adjoining the median line, and a trochlear nerve root erupts from the lateral part. The pons and the medulla oblongata become narrow and thin toward the rear and erupt at the fifth to twelfth cerebral nerve roots from the ventral, together with the bilateral parts (Figure 2).

The lateral view

The underdeveloped olfactory bulb is at the foremost head of the brain of the African ostrich. The cerebral hemisphere is close to being globular. Its

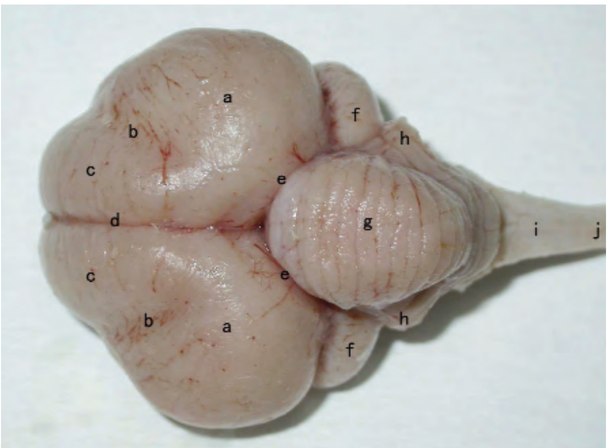

Figure 1. The dorsal view of the African ostrich brain. a, cerebral hemisphere; b, telencephalic vallecula; c, sagittal prominence; d, longitudinal fissure; e, transverse fissure; f, optic lobe; g, cerebellum; h, cerebellum auricle; i, medulla oblongata; j, spinal cord.

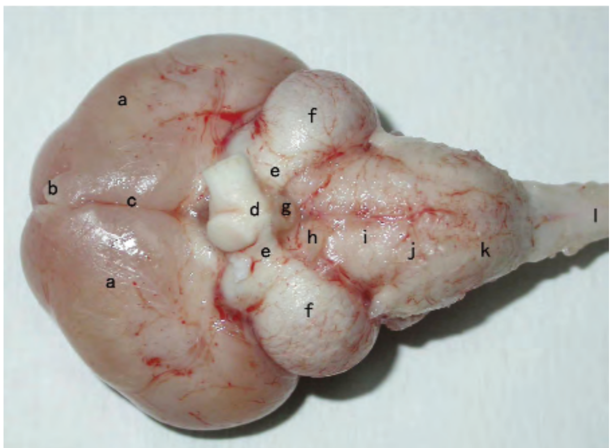

Figure 2. The ventral view of the African ostrich brain. a, cerebral hemisphere; b, olfactory bulb; c, longitudinal fissure; d, optic chiasma; e, optic tract; f, optic lobe; g, hypophysis; h, diencephalon; i, midbrain; j, pons; k, medulla oblongata; l, spinal cord.

anterolateral surface forms a concavity known as the orbital face that adapts to the orbital fossa of the cerebrum. The orbital face and occipital pole occupy the greater part of the lateral of the brain. The posterior ventral part of the cerebral hemispheres connects with the optic lobe of the midbrain, and the dorsal part adjoins the cerebellum. The cerebellum appears as a lozenge from the lateral view. Its length exceeds its height and it slopes onward to plug into the hollow area formed by the 2 cerebral hemispheres. The cerebellum auricles located at the ventrolateral surface of the cerebellar vermis extend posterolaterally and cover the choroid plexus of the fourth ventricle. The optic tract is located at the anterior part of the optic lobe. The pons and medulla oblongata are located at the back of the optic lobe and the ventral surface of the cerebellum (Figure 3).

The anatomical characteristics of each part of the brain

1) Cerebrum: The cerebrum of the ostrich appears as an obtuse triangle from the dorsal view, but that of the Oriental white stork is a trapezoid, and the Pekin duck's and grey goose's cerebra appear as tapers. The middle of the head of the ostrich's cerebral hemisphere is a relative cusp, linking to the undeveloped olfactory bulb. The posterior part of the cerebral hemisphere is wide, connecting with the optic lobe of the midbrain. The left and right lateral parts of the cerebrum expand laterally, as a hemicycle. The surface of the cerebrum is smooth, with no gyrus or sulcus. On the dorsal surface, 2 sagittal eminences in the shape of an ellipse diverge from the telencephalic vallecula and run parallel to each other. They protrude markedly on the surface. The medial surface is smooth and straight. Its anterior part is the cerebral cortex, and there are distinct fibers at the posterior part that centralize ventrally from the occipital pole. The fibers, known as the septo-midbrain bundle, slope from the back toward the ventral anterior; together they extend toward the precommissural anterior and reach the diencephalon. The cerebral cortex of the ostrich is similar to that of the Pekin duck and other domestic fowls. The gray matter is underdeveloped with a very thin stratum griseum covering the dorsal and lateral surfaces of the cerebral hemisphere. The striatum is developed and takes up most of the area of the cerebral hemisphere. It is the thickest and most important part of the brain.

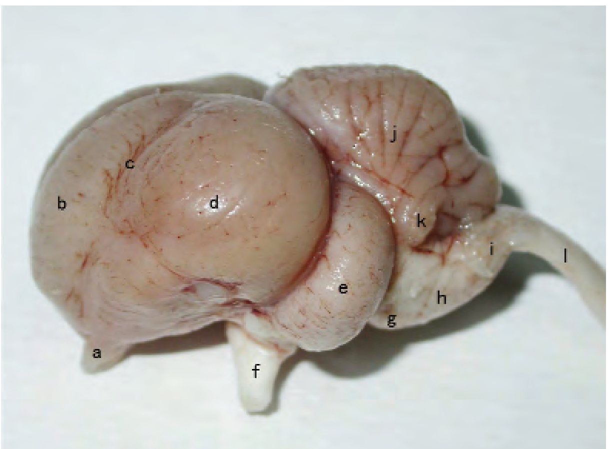

Figure 3. The lateral view of the African ostrich brain. a, olfactory bulb; b, sagittal prominence; c, telencephalic vallecula; d, cerebral hemisphere; e, optic lobe; f, optic chiasm; g, midbrain; h, pons; i, medulla oblongata; j, cerebellum; k, cerebellum auricle; l, spinal cord.

2) Cerebellum: The cerebellum of the African ostrich is relatively developed. The average width of the cerebellar vermis is 18.42 mm, the average length is 24.36 mm, and the average height is 15.85 mm. The length is 1.53 times larger than the height. The top of the cerebellum is relatively smooth and straight, but the posterior border is steep. Therefore, the parietal margin and the posterior border almost form a 130° angle. There are 18-19 strips of either superficial or deep transverse sulcus distributed on the cerebellar vermis, dividing the vermis into lobules. The cerebellar auricles extend to the lateral posterior. The bilateral of the bottom of the cerebellum links with the cerebellar peduncles, which have 3 pairs and are not easy to distinguish in shape. The superficial layer of the cerebellum is gray matter and it covers the interior white matter.

3) Diencephalon: Located at the ventral of the cerebral hemispheres of the African ostrich, the diencephalon occupies the anterior of the brain stem and its post-limit is between the posterior commissure, or the location of the pineal body, and the midbrain. Its links bilaterally with the optic lobe of the midbrain. In the diencephalon, there are 2 cycloid eminences, i.e. the thalami, which can be divided into

the epithalamus, ventral thalamus, dorsal thalamus, and hypothalamus. The hypothalamus, which protrudes slightly ventrally, is seated at the backside of the optic chiasma, and links with the hypophysis by means of the infundibular stalk. The hypophysis is an important endocrine organ. The hypophysis of the African ostrich is developed and appears almost globular (6.38 mm × 6.30 mm), but the hypophyses of domestic fowls are relatively slender, flat ellipses.

4) Brain stem: The brain stem of the African ostrich, including the midbrain, pons, and medulla oblongata, is similar to those of the other domestic fowls.

The scope of the midbrain is small. The limit of its anterior extremity is between the posterior commissure and the diencephalon. The posterior extremity links with the pons and the medulla oblongata directly, with no apparent limit, and it only can be divided by the emanative location of the trigeminal nerve root. The dorsal surface of the front half of the midbrain is covered by the occipital pole of the cerebral hemisphere, and the back half is covered by the cerebellum. The optic lobe is located at the bilateral of the midbrain and it converges at the ventral median line, receiving the fibers of the optic chiasma. The optic lobe is a pair of oval eminences. They protrude on the ventral and lateral surfaces of the midbrain, which are equal to the anterior colliculi of Mammalia. The footwall of the mesocephalic central region is the cerebellar peduncle. The oculomotor root is at the ventral median of the midbrain and the trochlea nerve root is at the lateral.

The pons and medulla oblongata are located at the ventral surface of the cerebellum. They are the 2 posterior parts of the brain stem that extend from the trigeminal nerve root to the occipital bone foramen. There is a longitudinal supersulcus at its ventral center, the fissura mediana ventralis. A symmetrical transversal vascular sulcus erupts to the left and right from the supersulcus, dividing this segment into 2 parts. The anterior part is the pons, with the trigeminal nerve root at its lateral. The abducent nerve root at the central bilateral adjoins the transverse sulcus. The posterior part of the transverse sulcus is the medulla oblongata, the ventral of the original part of which forms the lowest spot of the brain stem. There is a hypoglossal nerve root on both sides of the median line, and the seventh to eleventh pairs of the cerebral nerve roots are at the lateral surface. The pons, together with the medulla oblongata, forms the base wall of the fourth ventricle. There is a relatively wide sulcus at the center with a pair of white longitudinal medial bundles at its bilateral. The lateral walls of the fourth ventricle are 2 longitudinal eminences known as the restiform body, which forms the postpeduncle and extends upward into the cerebellum.

Discussion

The magnitude and shape of the cerebella are significantly different according to disparate animal categories, and the degree of the cerebellum's development is relevant to the degree of the complexity of body kinematics (14). The physiological functions of the cerebellum include motor control and physical gesturing, maintenance of the balance of the organism, regulation of muscle tension, and so on (15). The cerebella of avian species are more developed than those of crawling animals. There are complicated pleats in the superficial gray matter of the cerebellum, which is why it has a larger surface area. The cerebellum executes monitoring, regulating, and correcting by means of a connection with the locomotor system of the brain stem and cerebrum. It receives extraorgan information endlessly, at all times, to determine the current condition of every part of the body, such as location, speed of movement, and tension of the muscles (16,17). The cerebellum of the African ostrich protrudes visibly upward and its length is approximately 1.5 times larger than its height. The posterior superior part of the cerebellar vermis almost forms an angle of 130° and the number of transverse sulci of the cerebellar vermis is much larger than that of the domestic fowls. It diverges into more sublobules, which demonstrates that the cerebellar area of the ostrich is accordingly larger and its physiological function is inevitably more complicated. Some experiments show that injuring the cerebellum will severely impact the accuracy of voluntary movement and cause dyskinesia, including the change of muscular tension, disequilibrium, hypomotility or involuntary movement, and so on (16). After resecting the cerebellum, the muscles of the cervical area and legs cramp, and the head shakes and twitches irregularly (18). African ostriches come from wild deserts with harsh climates and sparse food. Their legs are 1327 mm long, muscular and sturdy, so that ostriches can run very fast, with speeds of up to 80-90 km/h (7). The physiological functions and life habit of fast running are caused by the ostrich's unique living environment. Legs that can kick backward and tread forward are also used as a weapon to defend against and fight enemies. These complicated physiological functions are closely related to the characteristics of the ostrich's cerebellar morphology.

The nervous system is the most complicated and important synthetic organ system of animals. Its general functions are linked to the enhancement of its characteristic centralization that makes the nervous system form a central part and peripheric part, the central part being more important. The nervous system plays a leading role in controlling vital movements of the animal organism. It not only adjusts the dynamic balance of every organ system and makes the organism adapt proactively to the surrounding environment, but it is also an information reservoir and the foundation for mental activities (19). The Table above shows that in African ostriches of weight 158-184 kg, the brain weighs 26.34 g, representing only 0.015% of the body weight. However, the brain of an Oriental white stork of 5.4 kg weighs 14.23 g, thus accounting for 0.264% of the body weight. In a Pekin duck of 2.5 kg, the brain weighs 6.53 g, accounting for 0.261% of the total body weight. The total weight of a gray goose is 5.0 kg while the brain weighs 12.57 g, or 0.251% of the total body weight. The above data demonstrate that the encephalic ratio of the African ostrich is the lowest among the 4 examined birds, 17 times lower than the others. The nervous system of the organism shows integrated unity in conformation and function. The magnitude of brain weight or volume is an important yardstick for measuring the development level of animal brains and intellectual ability. The brain of the African ostrich is underdeveloped and there is only a very thin layer of gray matter covering the dorsal and lateral surfaces of the cerebral hemisphere. It depends on the striatum for receiving massive sensory nerve fibers, and the striatum becomes the center of complicated instinctual activity and learning. The olfactory bulbs of the African ostrich are very small. With the underdeveloped olfaction, the olfactory stimulus has little effect on the brain.

The underdeveloped brain may lead to the low intelligence of ostrich. The authors have encountered 3 ostriches that died from eating plastic bags and other items by mistake. Carpolite accumulation in the stomach is a common illness among ostriches (20). Ostriches have allotriophagy by nature, and daily observation shows that both adult and young birds always peck a great quantity of carpolite and other things. The weight of the carpolites accumulated in the glandular stomach and muscular stomach can reach up to 3 kg by the time of dissection. Because the specific gravity of sandstone is high, it will block the gastrointestinal tract and directly affect the normal physiological functions of the ostrich, even leading to death (21). As mentioned above, it is obvious that the morphological characteristics of the African ostrich brain are coincident with its physiological functions.

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