

# Systematization of the brain base arteries in ostrich (*Struthio camelus*)

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## Abstract

Thirty ostrich (*Struthio camelus*) brains were used, injected with latex, to describe the arteries of the brain base. The largest occurrences of the arteries were: The cerebral carotid artery (100%), the intercarotid anastomosis (100%). The caudal branch of the cerebral carotid artery was, on the right (R), developed (53.3%) and vestigial (46.7%); on the left (L), developed (66.7%) and vestigial (33.3%). The ventral tectal mesencephalic artery on the R (53.3%), on the L (66.7%), direct branch of the cerebral carotid artery on the R (43.3%), on the L (30%) and, direct branch of the basilar artery (3.3%) in both antimeres. The basilar artery was a single vessel (80%), double in (13.3%) and “in island” formation (6.7%). The caudal ventral cerebellar artery was single (96.7%), double (3.3%) on the R and, single (93.3%), double (6.7%) on the L. The dorsal spinal artery was a collateral branch of the caudal ventral cerebellar artery on the R (96.7%), on the L (93.3%). The ventral spinal artery was double (90%) and single (10%). The rostral branch of the cerebral carotid artery (100%). The caudal cerebral artery, on the R, was double (90%) and single (10%); on the L, was double (53.3%) and single (46.7%). The middle cerebral artery was a single vessel (100%). The cerebroethmoidal artery was single (100%). The rostral cerebral artery was single (90%), double (10%) on the R and single (96.7%), double (3.3%) on the L. The cerebral arterial circle was rostrally open (100%) and, caudally, open (80%) and closed (20%).

**Keywords:** cerebral arteries, brain vascularization, ostrich.

## 1 Introduction

Research into how the central nervous system operates has intensified during the last few years. Therefore, the increase in information about cerebral vascularization is found to be necessary to this research, and, for that reason, innumerable works of basic contents are being developed to give support to these needs. There are few studies about encephalic irrigation on wild and exotic species, the first classic work being done by De Vriese (1905) who established important considerations about the phylogenesis and ontogenesis of the encephalic artery patterns. The present work will broach the description of the brain base arteries of the ostrich (*Struthio camelus*), a bird belonging to the family *Struthionidae*, originally from Africa. In spite of the irrigation of the brain basis of other birds having already been a source of study by some researchers, the pattern, variations, distributions and the behavior of the arteries which are responsible for blood irrigation of the ostrich brain basis is still unknown. Hence, due to the non-existence of such data with reference to the *Struthio camelus* species, in both classic bibliography and in specialized articles, our results will be compared to the results of authors who dedicated themselves on the study of brain vascularization in other birds, including: Crowe (1979), in *N. meleagris*; Midtgard (1984), in *Larus argentatus*; Campos (1987), in *Gallus gallus* and Holliday, Cridgely, Balanoff et al. (2006), in *Phoenicopterus ruber*. This research was an attempt to describe and maps the brains base arteries, creating a standard model and its main variations in ostrich.

## 2 Material and methods

Thirty heads of *Struthio camelus* with a segment of the neck were used, 17 males and 13 females, youth and adults, originating from breeding farms within the state of Rio Grande do Sul, collected from slaughterhouse used by producers cooperatives (Cooperativa dos Criadores e Produtores de Avestruz do Rio Grande do Sul – CPARS and Cooperativa dos Criadores de Avestruz de Santa Catarina – COOPERCASC). After collecting the head's, both internal right and left carotid arteries were exposed and cannulated. The arterial system was washed with cold (15 °C) 0.9% saline solution (100 mL/animal) mixed with 2500 IU heparin (Cristália Produtos Químicos Farmacêuticos Ltda, Itapira, SP, Brazil). After washing, the arterial system was filled using 20 mL of latex (Altamira – Indústria e Comércio de Látex Altamira Ltda, São Paulo, SP, Brazil) colored in red with the specific colorant (Suvinil Corante – Basf S.A. São Bernardo do Campo, SP, Brazil). The samples remained for at least one hour under running water for latex polymerization purposes. A window was then made in the skullcap. The specimens were immersed in a 20% formaldehyde solution for seven days. The brain was removed with a spinal cord segment. Additionally, the dura-mater was also removed and the arteries dissected. The material was analyzed under magnifying glasses (LTS illuminated magnifier with a 5x magnification, Stemi SV8 Zeiss, Goettingen, Germany). The vessels were named according to Nomina Anatomica Avium (BAUMEL, KING, BREAZILE et al., 1993). In

order to illustrate the documentation, some samples were photographed. The occurrence and distribution of the vessels were expressed as the percentage of a total number of 30 brain samples examined.

### 3 Results

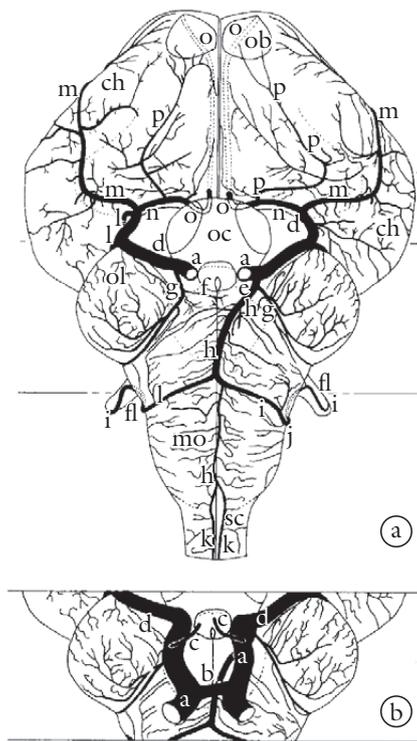
The internal carotid artery left the cervical carotid canal diverging laterally until it reached the skull base, where it divided into an external carotid artery, for the face, and a cerebral carotid artery of thick caliber. It penetrated the bone carotid canal, which passed rostro-medially through the skull base, emerging caudo-ventrally in the interior of the sella turcica. The cerebral carotid artery diverged rostro-dorso-laterally around the hypophysis to reach the tuber cinereum. On this course, it gave off two collateral branches, the intercarotid anastomosis and the internal ophthalmic artery as (Figure 1b). The cerebral carotid artery showed a predominant caliber on the right in 43.3% of the samples, on the left in 36.7%, and equivalence between the calibers in 20%, allocated very close to the median line and interlinked by an intercarotid anastomosis. The latter showed a medium caliber in 46.7% of the samples, thick in 43.3%, and a thin

caliber in 10%, interlinking the cerebral carotid arteries in an oblique way, with flow inclination to the left antimerie in 53.3% of the specimens and to the right in 46.7%.

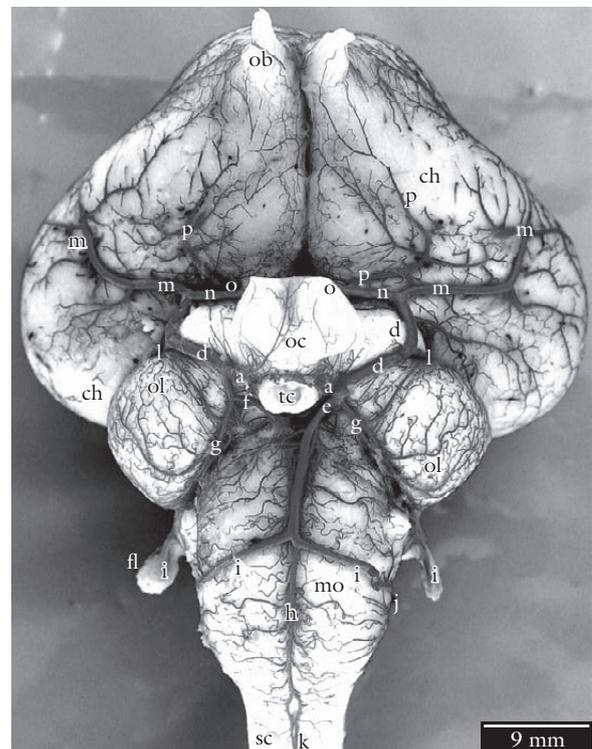
The internal ophthalmic artery, a vessel of medium caliber, branched from the cerebral carotid artery, ventro-rostrally, soon after the intercarotid anastomosis. It was rostrally projected, reaching the optic nerve leaving the cranial cavity with it towards the orbitary cavity through the optic foramen (Figure 1b).

The cerebral carotid artery at the level of the tuber cinereum divided into two terminal branches, the caudal and the rostral branch (Figures 1a and 2). The caudal branch presented in different ways in each antimerie, i.e., when in one of the antimeres the caudal branch was developed, in the opposite antimerie it became the ventral tectal mesencephalic artery, and its vestigial continuation plunged into the interpeduncular fossa. The rostral branch was a natural continuity of the cerebral carotid artery, latero-rostrally in the direction of the cerebral hemisphere.

The caudal branch of the cerebral carotid artery was developed as a single antimerie continuing caudally as the basilar artery after originate its collateral branch, the ventral tectal mesencephalic artery, leaving the cerebral arterial circle



**Figure 1.** Schematic drawing of ventral view of the Ostrich brain (Obs. 13). a) Without hypophysis, b) detail with intercarotid anastomosis: a – cerebral carotid artery; b – intercarotid anastomosis; c – internal ophthalmic artery; d – rostral branch of a; e – developed caudal branch of a; f – vestigial caudal branch of a; g – ventral tectal mesencephalic artery; h – basilar artery; i – caudal ventral cerebellar artery; j – dorsal spinal artery; k – ventral spinal artery; l – caudal cerebral artery; m – middle cerebral artery; n – cerebroethmoidal artery; o – ethmoidal artery; p – rostral cerebral artery; ob – olfactory bulb; ch – cerebral hemisphere; oc – optic chiasm; ol – optic lobe; fl – flocculus; mo – medulla oblongata; sc – spinal cord.



**Figure 2.** Picture in ventral view of Ostrich brain (Obs. 13), without hypophysis, to show the brain base vessel's, standard model; a) cerebral carotid artery; d) rostral branch of a; e) developed caudal branch of a; f) vestigial caudal branch of a; g) ventral tectal mesencephalic artery; h) basilar artery; i) caudal ventral cerebellar artery; j) dorsal spinal artery; k) ventral spinal artery; l) caudal cerebral artery; m) middle cerebral artery; n) cerebroethmoidal artery; o) ethmoidal artery; p) rostral cerebral artery; ob) olfactory bulb; ch) cerebral hemisphere; oc) optic chiasm; ol) optic lobe; tc) tuber cinereum; fl) flocculus; mo) medulla oblongata; sc) spinal cord. Bar = 9,0 mm.

caudally opened. The corresponding branch of the opposite antimere was a vestigial vessel which was projected from the ventral tectal mesencephalic artery, medially, to the interior of the interpeduncular fossa, caudally to the mammillary body (Figure 1). The caudal branch of the cerebral carotid artery revealed to be, on the right, developed in 53.3% of the specimens and vestigial in 46.7%. On the left, it was developed in 66.7% and vestigial in 33.3%.

The cerebral arterial circle presented caudally open in 80% of the brain and closed in 20%. In two of the six cases, the closing of the cerebral arterial circle occurred due to anastomosis between the caudal branches of the left and right cerebral carotid arteries, immediately caudally to the tuber cinereum (Figure 3). In other two specimens, the closing occurred due to anastomosis of the double basilar arteries almost at the same level of the origin of the caudal ventral cerebellar arteries (Figure 4). In two other brains, the basilar artery closed the circle on the third medium of its passage before the origin of the caudal ventral cerebellar arteries. The caudal branch of the cerebral carotid artery, when developed, gave off a collateral branch, the ventral tectal mesencephalic artery.

The ventral tectal mesencephalic artery projected itself caudolaterally in the interior of the fissure which separates the optic lobe from the rhombencephalon, releasing arboreous ramifications which vascularized ventrally the optic hemilobe. The ventral tectal mesencephalic artery was, in 66.7% of the samples on the left and in 53.3% on the right, a branch of the caudal branch of the cerebral carotid artery. On the other hand, in 30% on the left and in 43.3% on the right, it

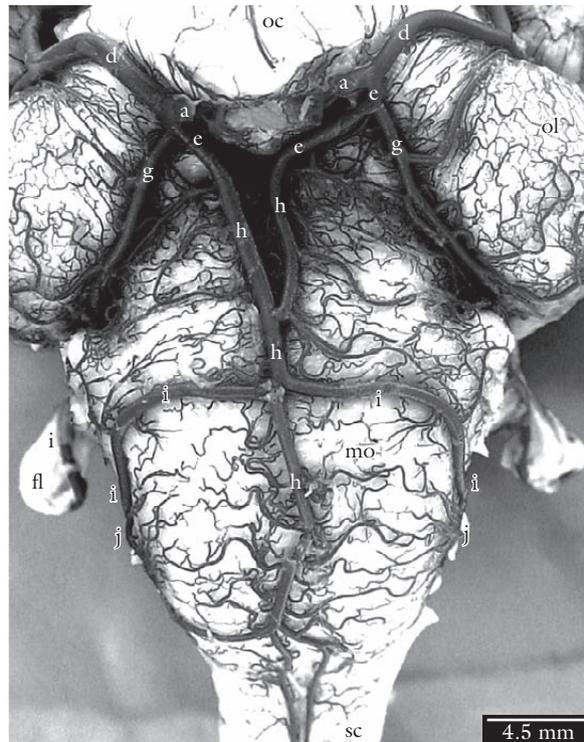
was a direct branch of the cerebral carotid artery, whereas in 3.3% both on the left and on the right, it was a direct branch of the basilar artery.

The basilar artery was a thick caliber vessel which was formed from the continuation of the developed caudal branch of the cerebral carotid artery at the level of the apparent origin of the oculomotor nerve (III), ventrally to the interpeduncular fossa. This vessel projected itself caudally, on the ventral median fissure, in a little sinuous way, where immediately after the pontine flexure it formed its two most developed collateral branches, the right and left caudal ventral cerebellar arteries. Thereafter, it continued as a vessel of thin caliber which by leaving the cranial cavity through the foramen magnum formed the ventral spinal artery of the spinal cord. The basilar artery also produced innumerable medullar branches on its course; however, it did not show rostral ventral cerebellar artery. The part of the thick caliber of the basilar artery was a single vessel in 80% of the samples, double in 13.3%, and it revealed an "island" formation in 6.7%. The portion of thin caliber was single in 90% and double in 10%.

The main collateral branches of the basilar artery were the right and left caudal ventral cerebellar arteries. They projected themselves latero-dorsally as a single vessel of thick caliber. They formed a collateral branch, on the lateral side of the medulla oblongata, the dorsal spinal artery, and immediately



**Figure 3.** Picture in ventral view of Ostrich brain's detail (Obs. 01), to show the persistence of the caudal branch of cerebral carotid artery closing the cerebral arterial circle caudally. a) cerebral carotid artery; d) rostral branch of a; e) developed caudal branch of a; g) ventral tectal mesencephalic artery; h) basilar artery; i) caudal ventral cerebellar artery; oc) optic chiasm; ol) optic lobe; tc) tuber cinereum; mo) medulla oblongata. Bar = 4,2 mm.



**Figure 4.** Picture in ventral view of Ostrich brain's detail (Obs. 08), to show the duplicity of the basilar artery, closing the cerebral arterial circle caudally. a) cerebral carotid artery; d) rostral branch of a; e) developed caudal branch of a; g) ventral tectal mesencephalic artery; h) basilar artery; i) caudal ventral cerebellar artery; j) dorsal spinal artery; oc) optic chiasm; ol) optic lobe; fl) flocculus; mo) medulla oblongata; sc) spinal cord. Bar = 4,5 mm.

after, they developed an important branch to the choroid plexus of the IV ventricle. Next, they reached the ventral base of the flocculus, surrounding it dorsally up to its base, forming a typical loop, separating themselves in all extension of the lateral surface of the cerebellar vermis, except for its rostral lobe. The right caudal ventral cerebellar artery was single in 96.7% of the samples with standard ramifications, forming loops, and presenting normal territorial distribution in 25 of the 29 pieces. No loop was detected in four of the 29 samples because of the absence of the flocculus. Nevertheless, it presented standard ramifications and territorial distribution. It was double in 3.3% of the samples because its habitual component, the dorsal spinal artery, was a collateral branch of the thin caliber portion of the basilar artery, close to the foramen magnum. The left caudal ventral cerebellar artery was a single vessel in 93.3% of the samples. Of the 28 cases with standard ramifications, in 18 it presented loop forming and normal territorial distribution, whereas in 6 it did not show loop formation due to the absence of flocculus and in 4, despite the presence of the flocculus, it did not form the typical loop detouring rostrally to it. It was double in 6.7% of the samples since its component, the dorsal spinal artery, originated from the left portion of the thin caliber of the double basilar artery, in the third medium-caudal of the medulla oblongata.

The dorsal spinal artery was a thin caliber vessel beginning as a collateral branch of the caudal ventral cerebellar artery which projected itself caudo-dorsally forming a vascular chain on the dorsal surface of the spinal cord, laterally, from successive anastomoses of the segmentary spinal arteries. The right dorsal spinal artery was a collateral branch of the caudal ventral cerebellar artery on the right in 96.7% and on the left in 93.3%. On the other hand, it was collateral branch of the thin caliber portion of the basilar artery in 3.3% on the right and 6.7% on the left.

The ventral spinal artery was the natural continuation of the thin caliber portion of the basilar artery, on the caudal direction, traveling through and bordering the ventral median fissure of the spinal cord, from the foramen magnum. It revealed to be a double vessel in 90% of the specimens originating from the bifurcation of the thin caliber portion of the basilar artery near the foramen magnum. The gradual reduction of the caliber of the thin portion caliber of the basilar artery in the direction of the ventral spinal artery was quite noticeable.

The rostral branch of the cerebral carotid artery was its natural continuation, from the caudal branch emission, at the tuber cinereum level. This thick caliber vessel projected itself latero-rostrally, as an arch, until it reached the cerebral transverse fissure between the optic lobe and the cerebral hemisphere. At this point, it gave off its first collateral branch, the caudal cerebral artery. Next, it projected itself, rostrally, forming its second collateral branch, the middle cerebral artery, continuing medially as its terminal branch, the cerebroethmoidal artery.

The caudal cerebral artery, which is normally double, was the first collateral branch of the rostral branch of the cerebral carotid artery presenting a variable caliber, ranging from medium to thick, due to the variety of options in its ramifications. In general, the first component to be formed presented a larger caliber than the second. The first vessel was usually formed from the rostral branch at the same

level of the cerebral transverse fissure, whereas the second vessel was formed from the rostral branch, near the origin of the middle cerebral artery, at the base of the cerebral hemisphere. The collateral branches of the caudal cerebral artery can be formed from both antimeres, such as in the dorsal tectal mesencephalic arteries and the occipital hemispheric branches, or from only one antimeres, such as the interhemispheric and dorsal cerebellar arteries. After passing through the cerebral transverse fissure, the single interhemispheric artery penetrated the interhemispheric fissure producing dorsal hemispheric branches for both hemispheres up to the level of the olfactory bulb. The caudal cerebral artery was double in 90% of the samples on the right and 53.3% on the left. However, it was single in 10% of the samples on the right and 46.7% on the left.

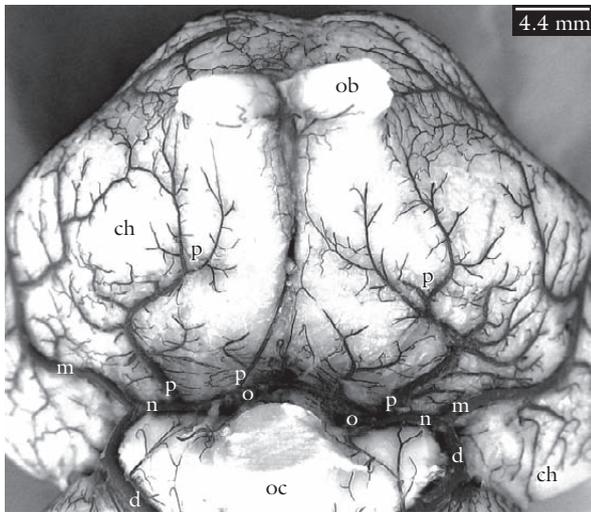
The middle cerebral artery, second collateral branch of the rostral branch of the cerebral carotid artery, appeared in all samples as a single vessel with thick caliber, which projected itself lateral and rostrally, on the ventral surface of the cerebral hemisphere, forming an arch. Its terminal branch reached the convex surface of the cerebral hemisphere, on its third lateral medium, reaching dorsally the olfactory bulb. On its course, it formed innumerable lateral hemispheric branches which ascended the convex surface of the cerebral hemisphere surpassing the vallecule and, near the interhemispheric fissure, anastomosed themselves with the dorsal hemispheric terminal branches of the interhemispheric artery. In addition to the ventral hemispheric branches, it also formed innumerable perforating branches to the nuclei of the subjacent striatum,

From the formation of the middle cerebral artery, the rostral branch of the cerebral carotid artery, already in the ventral surface of the cerebral hemisphere curved medially forming its terminal branch, the cerebroethmoidal artery. By surpassing the optic nerve dorsally and before reaching the median line, its main axis, formed the rostral cerebral artery remaining as the ethmoidal artery. The cerebroethmoidal artery was always present, as a single vessel, of medium to thick caliber, in both antimeres.

The ethmoidal artery, a single vessel of medium to thick caliber, was the natural continuation of the cerebroethmoidal artery after the formation of the rostral cerebral artery. It projected itself ventral and rostrally coursing the interhemispheric fissure leaving the cranial cavity through the olfactory foramen together with the homonym nerve running through the orbitary cavity and finally distributing itself in the nasal cavity. In all situations, the ethmoidal artery was single and standard.

The rostral cerebral artery was a well developed vessel rostrally projected from the cerebroethmoidal artery, at the level of the optic nerve, to a ventral area of the cerebral hemisphere, limited by the middle cerebral and ethmoidal arteries, until it reached rostrally the olfactory bulb. The right rostral cerebral artery was single in 90% of the situations and 96.7% on the left. On the other hand, it was double in 10% on the right and in 3.3% on the left (Figure 5). The rostral cerebral artery showed variation in its territorial extension, and when reduced, this area was substituted due to an increase of the ventral hemispheric branch of the middle cerebral artery.

The ostrich (*Struthio camelus*) cerebral arterial circle was rostrally open all the time since the right and left



**Figure 5.** Picture in ventral view of Ostrich brain (Obs. 07), to show the presence of duplicity of the right rostral cerebral artery. d) rostral branch of a; m) middle cerebral artery; n) cerebrothmoidal artery; o) ethmoidal artery; p) rostral cerebral artery; ob) olfactory bulb; ch) cerebral hemisphere; oc) optic chiasm. Bar = 4,4 mm.

cerebrothmoidal arteries, or their branches, did not show anastomosis between the vessels of the two antimeres. In 80% of the samples, the cerebral arterial circle was caudally open since the caudal branch of the cerebral carotid artery of each antimeres did not form relevant anastomosis between them. In 20% of the samples, the cerebral arterial circle was closed, and in four samples, the cerebral arterial circle closed due to anastomosis between the basilar arteries, right and left and, in two samples, due to anastomosis between the caudal branch of the cerebral carotid artery of both antimeres.

#### 4 Discussion

No citations were found about ostrich brain irrigation in the literature review, neither in the classical compendiums of anatomy. However, studies on this issue specifically but focusing on other birds were found in specialized literature. Therefore, in a descriptive systematic study, it is pertinent to make comparisons with such similar species.

The ostrich's cerebral carotid artery courses rostro-medially in the carotid canal and immediately caudally in the hypophysis. The two arteries approached and combined themselves by the transversal intercarotid anastomosis, which is also found in *Gallus gallus* (WESTPFAHL, 1961; KITO, 1962; BAUMEL, 1981; CAMPOS, 1987; CAMPOS, FERREIRA and MARRONE, 1995).

In the ostrich, the internal ophthalmic artery was branched by the cerebral carotid artery (WESTPFAHL, 1961) and coursed ventro-rostrally immediately after the intercarotid anastomosis. The internal ophthalmic artery was a vessel of a medium caliber in 60% of the situations on the left antimeres and in 43.3% on the right antimeres. It left the cranial cavity together with the optic nerve and anastomosed with the external ophthalmic artery in *Gallus gallus* (KITO, 1962; RICHARDS, 1967; SCHWARZE and SCHRODER, 1970; NICKEL, SCHUMMER and SEIFERLE, 1977;

BAUMEL, 1981; CAMPOS, 1987; CAMPOS, FERREIRA and MARRONE, 1995) in seagulls (MIDTGARD, 1984) and in guinea fowl (CROWE, 1979).

The ostrich's cerebral carotid artery divided itself beside the hypophysis into a large caliber rostral branch and into a medium caudal branch (DE VRIESE, 1905; WESTPFAHL, 1961; RICHARDS, 1967; CROWE, 1979; MIDTGARD, 1984; CAMPOS, 1987; CAMPOS, FERREIRA and MARRONE, 1995). The right and left caudal branch of the cerebral carotid artery, when developed, originated the ventral tectal mesencephalic artery as a collateral branch, and remained as a basilar artery, which is similar to the finding described by Kitoh (1962). On the opposite antimeres, in cases where the caudal branch was not developed, the ventral tectal mesencephalic artery projected itself from the cerebral carotid artery and released, medially, a vestigial vessel of thin caliber (BAUMEL, 1981; KING and MCLELLAND, 1981; MIDTGARD, 1984; CAMPOS, 1987; CAMPOS, FERREIRA and MARRONE, 1995), which moved into the interpeduncular fossa, which is the continuation of the caudal branch.

In the ostrich, in 20% of the findings, the caudal branch of the two antimeres seemed developed closing the cerebral arterial circle caudally. The same closing was reported for *Gallus gallus* by Westpfahl (1961) in 6.7% of the cases and by Campos (1987) and Campos, Ferreira and Marrone (1995) in 3.3% of brains. Kitoh (1962), Nickel, Schummer and Seiferle (1977) and Crowe (1979) also reported the presence of an anastomosis of thin caliber between the caudal branches closing the cerebral arterial circle caudally although not in the same incidence rates. Campos (1987) and Campos, Ferreira and Marrone (1995) argued that the thin caudal branch always anastomosed with the developed caudal branch of the opposite antimeres closing the cerebral arterial circle.

The caudal branch of the cerebral carotid artery in the ostrich formed the basilar artery in 46.7% of the samples on the left and in 33.3% on the right. In 20% of the samples it was found a connection from both caudal branches to form the basilar artery. According to Westpfahl (1961), the caudal branch formed the basilar artery in 60% of the situations on the left and 33.3% on the right, and only in 6.7% of the samples the author found a connection of both caudal branches to form the basilar artery.

In the ostrich, the basilar artery was detected similarly to what was found in other birds, which was an initial portion of thick caliber and a final portion after the origin of caudal ventral cerebellar arteries of thin caliber (CAMPOS, 1987). The basilar artery caudally projected itself through the ventral median fissure immediately after the pontine flexure, and it divided the two most developed collateral branches, the right and left caudal ventral cerebellar arteries; however, without evidence of the presence of the rostral ventral cerebellar artery as found by Westpfahl (1961), Kitoh (1962) and Campos (1987). After the formation of its two main branches, the basilar artery continues as a vessel of thin caliber which while leaving the cranial cavity through the foramen magnum formed the ventral spinal artery of the spinal cord (DE VRIESE, 1905; WESTPFAHL, 1961; KITO, 1962; NICKEL, SCHUMMER and SEIFERLE, 1977).

The ventral tectal mesencephalic artery of the ostrich projected itself caudolaterally into the interior of the fissure

that separates the optic lobe from the rhombencephalon projecting arborescent ramifications which vascularized ventrally the optic hemi-lobe, as observed by Richards (1967), Campos (1987), and Campos, Ferreira and Marrone (1995). In 66.7% of the samples on the left and in 53.3% on the right, the ventral tectal mesencephalic artery was a branch of the caudal branch of the cerebral carotid artery, whereas in 30% on the left and in 43.3% on the right it was a direct branch of the cerebral carotid artery. However, in 3.3% on both on the left and on the right it was a direct branch of the basilar artery. For Campos (1987) and Campos, Ferreira and Marrone (1995), the ventral tectal mesencephalic artery was in 73.3% of the samples on the left and in 70% on the right a branch of the caudal branch of the cerebral carotid artery, whereas in 26.7% on the left and 30% on the right it was direct branch of the cerebral carotid artery.

In the ostrich, the left and right caudal ventral cerebellar arteries were the main collateral branches of the basilar artery and a single vessel in 96.7% of the samples and double in 3.3% on the right. While on the left, it was single in 93.3% and double in 6.7% of the situations. According to Campos (1987), the caudal ventral cerebellar artery was also a vessel originating from the basilar artery, which was present and single in 100% of the samples found on the right. Nevertheless, on the left it was single in 96.7% of the samples and double in 3.3% being denominated accessory caudal ventral cerebellar artery (CAMPOS, 1990; CAMPOS, FERREIRA and MARRONE, 1995). According to Richards (1967), also in *Gallus gallus*, the caudal ventral cerebellar artery was the main branch of the basilar branch surrounding the flocculus in an arch opening into innumerable small branches, which supplied most parts of the cerebellum. In the ostrich, it was evidenced that the caudal ventral cerebellar artery reached the ventral base of the flocculus surrounding it dorsally up to its base forming a typical loop distributing itself in all extension of the lateral surface of the cerebellar vermis, except for the rostral lobe.

The ventral spinal artery was the natural continuation of the thin portion caliber of the basilar artery, on the caudal direction, passing through and boarding the ventral median fissure of the spinal cord such as from the foramen magnum. It seemed as a double vessel in 90% of the samples starting from the bifurcation of the thin caliber portion of the basilar artery or from its duplicity near the foramen magnum. According to Richards (1967), the ventral spinal artery is a delicate vessel, single or double, which originated from one or other caudal ventral cerebellar artery, and it was not the end of the basilar artery anymore. In the ostrich, the gradual reduction of the caliber of the thin portion caliber of the basilar artery in the direction of the ventral spinal artery was perfectly perceptible, as also reported by Westpfahl (1961), Kitoh (1962), and Richards (1967).

The rostral branch of the cerebral carotid artery was its natural continuation starting from the caudal branch formation at the level of the tuber cinereum. This vessel of thick caliber projected itself latero-rostrally in an arch until it reached the cerebral transverse fissure (KITOH, 1962; CAMPOS, 1987; CAMPOS, FERREIRA and MARRONE, 1995). This rostral branch presented itself as collateral branches, the caudal cerebral artery and the middle cerebral artery. Its terminal branch went to the cerebroethmoidal artery (CROWE, 1979; BAUMEL, 1981;

KING and MCLELLAND, 1981; CAMPOS, 1987; CAMPOS, FERREIRA and MARRONE, 1995). Nonetheless, Westpfahl (1961) found that the rostral branch went latero-rostrally through the ventral surface of the hindbrain and reached the cerebral transverse fissure, where it formed the caudal cerebral artery travelling through it between the mesencephalon and the cerebral hemisphere, but, unlike found in mammals, it was not a collateral vessel of the caudal branch of the cerebral carotid artery. Some authors also described that after the origin of the caudal cerebral artery the rostral branch formed the middle cerebral artery and continued as the ethmoidal artery (RICHARDS, 1967; NICKEL, SCHUMMER and SEIFERLE, 1977). In guinea fowl (CROWE, 1979), the rostral branch gave origin to the ventral tectal mesencephalic artery, caudally, and afterwards it directed itself rostrally emitting the caudal cerebral arteries, the middle cerebral, ethmoidal, and rostral cerebral artery, which was also found for the seagull (MIDTGARD, 1984) and in flamingo (HOLLIDAY, CRIDGELY, BALANOFF et al., 2006).

The caudal cerebral artery was, in the ostrich, the first collateral branch of the rostral branch of the cerebral carotid artery presenting a variable caliber ranging from medium to thick due to the variation options in its ramifications. It was double in 90% of the situations on the right and 53.3% on the left. In 86.7% of the samples on the right and in 76.7% on the left, the caudal cerebral artery was a branch of the rostral branch of the cerebral carotid artery at the level of the cerebral transverse fissure between the optic lobe and the cerebral hemisphere (RICHARDS, 1967). The middle cerebral artery, second collateral branch of the rostral branch of the cerebral carotid artery, was a single vessel of thick caliber, which projected lateral and rostrally on the ventral surface of the cerebral hemisphere forming an arch. According to Westpfahl (1961), Richards (1967), Nickel, SCHUMMER and SEIFERLE (1977), Campos (1987), Campos (1990) and Campos, Ferreira and Marrone (1995), the middle cerebral artery in *Gallus gallus* formed an arch which reached the olfactory bulb without leaving the ventral surface of the cerebral hemisphere. In the ostrich, the terminal branch reached the convex face of the cerebral hemisphere on its lateral medium third up to the olfactory bulb, dorsally. The middle cerebral artery also formed innumerable perforating branches to the nuclei of the striatum subjacent besides the ventral hemispheric branches (BAUMEL, 1981; KING and MCLELLAND, 1981; CAMPOS, 1987; CAMPOS, 1990; CAMPOS, FERREIRA and MARRONE, 1995). It also formed, on its course, innumerable lateral hemispheric branches which ascended to the convex surface of the cerebral hemisphere surpassing the vallicula and, near the interhemispheric fissure, they anastomosed themselves to the dorsal hemispheric terminal branches of the interhemispheric artery. This type of behavior was not observed in *Gallus gallus*. Neither was it observed in the present work (the double middle cerebral artery) as it was verified by Campos (1987), who found that the duplicity of this vessel occurred in 3.3% of the observations on the left antimer.

From the formation of the middle cerebral artery on the rostral branch of the cerebral carotid, already in the ventral surface of the cerebral hemisphere, curved medially forming its terminal branch, the cerebroethmoidal artery which,

by surpassing dorsally the optic nerve, before reaching the median line, formed the rostral cerebral artery continuing as the ethmoidal artery (CROWE, 1979; BAUMEL, 1981; KING and MCLELLAND, 1981; MIDTGARD, 1984; CAMPOS, 1987; CAMPOS, FERREIRA and MARRONE, 1995). In the ostrich, the cerebroethmoidal artery was present in all situations and projected rostrally as the rostral cerebral artery and continuing as the ethmoidal artery. According to Richards (1967) and Crowe (1979), the rostral branch of the cerebral carotid artery also emitted the rostral cerebral artery between the ethmoidal and middle cerebral arteries; however, this was a vessel of thin caliber. Campos (1987), however, found that the rostral cerebral artery, also released by the cerebroethmoidal artery, presented, on most of the specimens, situations of duplicity, and it was single and triple also. In the ostrich, the right rostral cerebral artery was single in 90% of the situations and double in 10%, whereas on the left it was single in 96.7% and double in 3.3% of the samples being on both antimeres, a well developed vessel. When the territorial extension of the rostral cerebral artery of the ostrich was compared to *Gallus gallus*, a large increase of the ostrich territorial area could be observed. It can be said that the rostral cerebral artery of the *Struthio Camelus* is a vessel of considerable expression.

The ethmoidal artery in the ostrich, which is a single vessel ranging from medium to thick caliber was the natural continuation of the cerebroethmoidal artery after the emission of the rostral cerebral artery. It projected itself rostrally and ventrally following the interhemispheric fissure leaving the cranial cavity by the foramen olfactory together with the homonym nerve passing through the orbital cavity and distributing itself in the nasal cavity. As found by Richards (1967), the ethmoidal artery was single in 100% of the situations on both antimeres. According to Kitoh (1962), the ethmoidal artery was the one which formed the rostral cerebral artery. However, Campos (1987) found that there were situations of duplicity of the ethmoidal artery in 10% of the samples on the left.

The cerebral arterial circle of the ostrich (*Struthio camelus*) always appeared rostrally open since the right and left cerebroethmoidal arteries or its branches did not present anastomosis between the vessels of the two antimeres. It was caudally closed in 20% of the situations, whereas Westpfahl (1961) found 6.7% in *Gallus gallus* and Campos (1987) and Campos, Ferreira and Marrone (1995) found 100% of caudal closing of the cerebral arterial circle. In other studies carried out with birds, the cerebral arterial circle was considered caudally opened because no anastomoses were found between the caudal branches of the cerebral carotid arteries. (KITOH, 1962; BAUMEL and GERCHMAN, 1968; KING and MCLELLAND, 1981).

## 5 Conclusion

The encephalic arterial vascularization of the ostrich is exclusively of carotid source, corresponding to class I reported by De Vriese (1905).

The rostral cerebral artery in ostrich was more developed compared to other birds as *Gallus gallus*.

The cerebral arterial circle in the ostrich (*Struthio camelus*) always appeared rostrally open. In 80% of the samples, the

cerebral arterial circle was caudally open, and in 20% of the samples the cerebral arterial circle was closed.

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