Arterial Patterns of the Face in Perissodactyla

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ABSTRACT
Considerable consistency in the arterial pattern of the head has been observed in species of Artiodactyla, but few studies have examined the order Perissodactyla. Here, we describe arteries supplying the intermandibular, mental, masseteric, buccal, labial, and nasal regions in eight perissodactylans, including representing of all families comprising this order. Observations were made on a total of 45 preparations of head arteries, obtained by injection of arteries with acetone-dissolved stained vinyl superchloride or stained latex LBS3060. In the Equidae species alone it was found that the facial artery descends from the linguofacial trunk. In tapirs and rhinos the facial artery branches off directly from the main arteries of the head. In tapirs alone it was found that the inferior alveolar artery gives off the buccal and sublingual arteries, and then extends into the mental artery. In the rhino a specific feature of the arterial pattern of the head was the exit of the occipital artery from the superficial temporal artery. In all equines studied, the transverse facial artery gave off a larger blood vessel to the masseter muscle and ran along the facial crest, while in tapirs and rhinos the transverse facial artery fanned out branches in the masseteric fossa. The variations observed can be considered in future studies on the origin of Perissodactyla. In this context, we note that the most similar patterns of exit and course of the facial, mental, transverse facial and infraorbital arteries exist in tapirs and rhinos (Ceratomorpha suborder), at least among the perissodactylans studied here. Anat Rec, 300:1529–1534, 2017. © 2017 Wiley Periodicals, Inc.

Key words: perissodactyla; facial arterial supply; arterial pattern of the head

INTRODUCTION

Descriptive and comparative analyses of the arteries of the head not only broaden our knowledge on animal anatomy, but they also provide valuable information useful in veterinary practice for clinical purposes (Dias et al., 2012). Apart from their value to basic science, veterinary practice and teaching, results of these analyses supply general biological information. Certain characteristics of the vascular system in animals are also applicable in taxonomy (Shoshani and McKenna, 1998) and play an important role in the discussion of classification and phylogenesis of both contemporary and extinct species (Rougier et al., 1992; Kielan-Jaworowska, 1996). A considerable consistency between selected traits of the arterial pattern of the head and the position in taxonomy has been observed in species of Rodentia (Bugge, 1971) and in Artiodactyla (Godynicki, 1972a). Blood vessels of the head have also been investigated by physiologists studying mechanisms of certain processes connected with the blood flow or regulation of blood

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TABLE 1. Species of examined animals, short taxonomy and numbers of preparations

Family	Species	n = 45 (male, female)
Equidae	*Equus asinus*-donkey	3 (1,2)
	Equus burchellii-plains zebra	6 (1,5)
	Equus grevyi-Grevy's zebra	9 (3,6)
	Equus przewalskii-Przewalski's wild horse	3 (2,1)
	Equus caballus-horse	8 + 3[a] (4,7)
	Equus hemionus-Asiatic wild ass	4 (1,3)
Tapiridae	*Tapirus terrestris*-South American tapir	7 (2,5)
Rhinocerotidae	*Ceratotherium simum*-white rhinoceros	2 (0,2)

[a]Preparations obtained using latex.

pressure in the central nervous system and thermoregulation of the brain (Lluch et al., 1985).

The facial artery has been carefully described in the dog, rabbit (Irifune, 1980, 1986), cat (Nakamura, 1987) and domestic mammals (Nickel and Schwarz, 1963). The patterns of facial artery and transverse facial artery in numerous ruminants and different variants of the exit of facial artery from arterial mainstream have been described by Zdun et al. (2014). The facial artery was not found in small ruminant species, as well as mouflon, goat and springbok (Godynicki, 1972a; Frąckowiak, 2003; Zdun et al., 2014). In Equidae the linguofacial trunk *(truncus linguofacialis)* was observed (Nickel and Schwarz, 1963; Frąckowiak, 2003).

A general pattern of the arteries of the head as described in the tapir (Frąckowiak and Godynicki, 1991). The arteries of brain base were described in Equidae and Tapiridae (Frąckowiak and Giejdasz, 1998), whereas no such information is available concerning the vascularization of the head in rhinos. So far, textbook presentations of arteries of the head in Perissodactyla species have been given only for the horse (Nickel and Schwarz, 1963; Dyce et al., 2010).

Clinical aspects and already mentioned lack of information about head vascularization in Perissodactyla have been an incentive for undertaking studies on this vascular region within this clade, and may be valuable in resolving questions on the origin of the order (Archibald and Rose, 2005).

The aim of this study was to compare the exit, pattern, connections and branching of the facial artery *(a. facialis)*, submental artery *(a. submentalis)*, mental artery (*a. mentalis*), transverse facial artery *(a. transversa faciei)*, buccal artery *(a. buccalis)* and infraorbital artery *(a. infraorbitalis)* in selected species from the families: Equidae, Tapiridae and Rhinocerotidae. Based on the consistency observed among odd-toed ungulates, we hypothesize that arteries supplying selected facial regions in species of Perissodactyla will likewise have patterns consistent within the order.

MATERIALS AND METHODS

The study was conducted on eight species of Perissodactyla, including 6 belonging to Equidae, and one species each from Tapiridae and Rhinocerotidae. Analyses were performed on a total of 45 preparations of head arteries from animals of both sexes, from the collection of the Division of Animal Anatomy, Poznan University of Life Sciences. Most of the studied animals were adults. Only one South American tapir was aged 5 months and two foals of the domestic horse were aged one week. The animal material was collected from national zoological gardens, abattoirs and studs. Corrosion casts (n = 42) were prepared by injecting arteries with acetone-dissolved stained vinyl superchloride, which was introduced to common carotid arteries using a syringe at 60–80 kPa (Godynicki, 1970). After complete polymerization of the plastic filling the vessels, preparations were subjected to enzymatic maceration (tap water with detergent) for 40 days at 38°C. In this way corrosion casts of arteries on osseous material were prepared. Latex preparations of arteries of the head from three horses were prepared by injecting stained latex LBS3060 to the common carotid arteries using a medical syringe. Next the preparations were fixed in 10% formalin and then prepared manually. Based on these preparations the exit, connections and patterns of arteries supplying the intermandibular *(regio intermandibularis)*, mental (*regio mentalis*), masseteric (*regio masseterica*), buccal (*regio bucalis*), superior and inferior labial (*regio labialis superior et inferior*), and lateral and dorsal nasal (*regio lateralis et dorsalis nasi*) regions were analyzed. Graphic and photographic documentation was prepared. Nomenclature of arteries was adopted following Nomina Anatomica Veterinaria (2012) and Illustrated Anatomical Nomenclature of the Heart and the Arteries of Head and Neck in the Domestic Mammals (Simoens et al., 1978–). Taxonomy of mammals followed Mammal Species of the World (Wilson and Reeder, 2005).

RESULTS

A list of analyzed animal species and the number of preparations are given in Table 1. There was no difference between sexes in the course of the arteries. Arterial patterns in the analyzed Perissodactyla species were as follows:

- The facial artery exited:
  1. From the linguofacial trunk, while on the lateral mandibular region its branches vascularized the labial and nasal regions in species from Equidae,
  2. Directly from external carotid artery *(a. carotis externa)*, while in the lateral mandibular region its branches extended only to the inferior labial region in species from Tapiridae and Rhinocerotidae families.
- The submental artery, which supplied the intermandibular region was a branch of:
  1. The sublingual artery (a. sublingualis) in Equidae species
  2. The inferior alveolar artery (*a. alveolaris inferior*) in representatives of the Tapiridae

3. The facial artery in representatives from Rhinocerotidae in all examined animals the mental artery was an extension of the inferior alveolar artery, which was a branch of the maxillary artery.

- The transverse facial artery in all analyzed animals exited from the superficial temporal artery *(a. temporalis superficialis)* together with the rostral auricular artery *(a. auricularis rostralis)* and:
  1. Gave off the larger blood vessel to the masseter muscle, and next ran parallel to the facial crest in species from Equidae,
  2. The masseteric branch *(ramus massetericus)*, and next gave off numerous branches to the masseter muscle in representatives of Tapiridae,
  3. The masseteric branch and the occipital artery *(a. occipitalis)*, and next gave off numerous branches to the masseter muscle in representatives of Rhinocerotidae.
- The buccal artery was a branch of:
  1. The maxillary artery *(a. maxillaris)* in representatives of horse and rhino,
  2. The inferior alveolar artery in representatives of the Tapiridae.
- The infraorbital artery was the maxillary artery branch and:
  1. Was connected to the lateral nasal artery *(a. lateralis nasi)* through the anastomotic branch with the infraorbital artery *(ramus anastomoticus cum a. infraorbitali)* in species of Equidae.
  2. Gave off numerous branches to the lateral and dorsal nasal regions, as well as the angular artery of the eye *(a. angularis oculi)*, and became into the superior labial artery *(a. labialis superior)* in species representing the families Tapiridae and Rhinocerotidae.

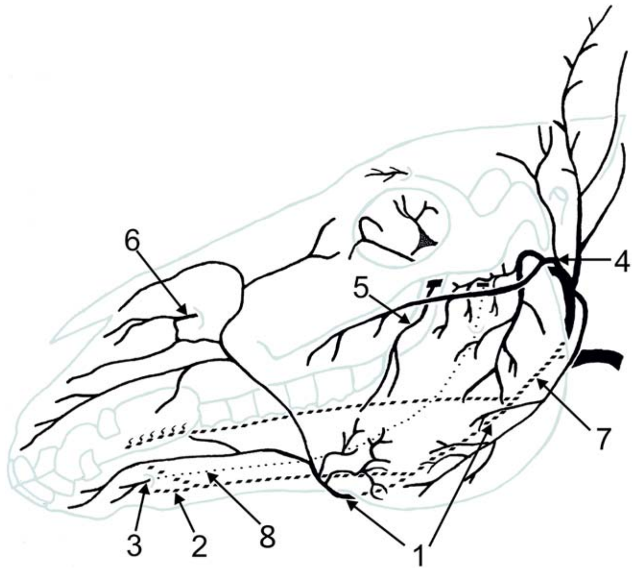

Fig. 1. Arterial blood supply of the face in Equines. 1. A. facialis 2. A. submentalis 3. A. mentalis 4. A. transversa faciei 5. A. buccalis 6. A. infraorbitalis 7. Truncus linguofacialis 8. A. alveolaris inferior.

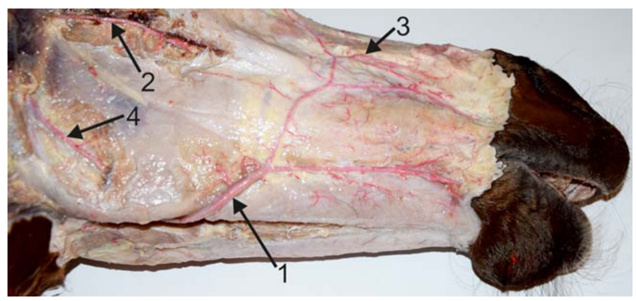

Fig. 2. Latex preparations of arteries of the head from horses (foal). 1. A. facialis 2. A. transversa faciei 3. A. infraorbitalis 4. Ramus massetericus.

Equines

In vascular preparations of arteries of the head from all the examined representatives of Equidae an universal pattern was observed for the exit and course of the facial artery, submental artery, mental artery, transverse facial artery, buccal artery and infraorbital artery (Figs. 1 and 2).

In all the examined species from this family (donkey, plains zebra, Grevy's zebra, Przewalski's wild horse, horse and Asiatic wild ass) the facial artery exited from the external carotid artery via a common trunk with the lingual artery *(a. lingualis)*, forming the linguofacial trunk. The facial artery branched off the sublingual artery, which gave off the submental artery. These arteries supplied the intermandibular region. The facial artery penetrated through a notch for the facial vessels and, on the lateral surface of the mandible, gave off small branches to the masseter muscle and the inferior labial artery (a. labialis inferior), while from the latter—to the angular artery of the mouth (a. angularis oris).

Rostrally, on the lateral surface of the maxillary, the facial artery splits into the superior labial artery, lateral nasal artery, dorsal nasal artery *(a. dorsalis nasi)* and the angular artery of the eye. The lateral nasal artery gave off an anastomotic branch with the infraorbital artery.

The mental region was supplied by the mental artery, which was an extension of the inferior alveolar artery.

The transverse facial artery, together with the rostral auricular artery, exited from the superficial temporal artery, which was a branch of the external carotid artery. The transverse facial artery ran rostrally along the facial crest. A larger blood vessel branched off to the masseter muscle from its initial part.

The buccal artery was a branch of the maxillary artery, coursed to the lateral surface of the mandible between the maxillary tuber and the anterior ramus of the mandible, and extended to the buccal region.

The infraorbital artery was the maxillary artery branch, penetrated to the infraorbital canal, which it exited through the infraorbital foramen and reached the lateral nasal region *(regio lateralis nasi)*.

Tapirs

In tapirs (Figs. 3 and 4) the facial artery branched off directly from the external carotid artery and did not gave off branches to the intermandibular region. It penetrated through a notch for facial vessels and projected to the lateral surface of the mandible, where it gave off small branches to the masseter muscle, and it was

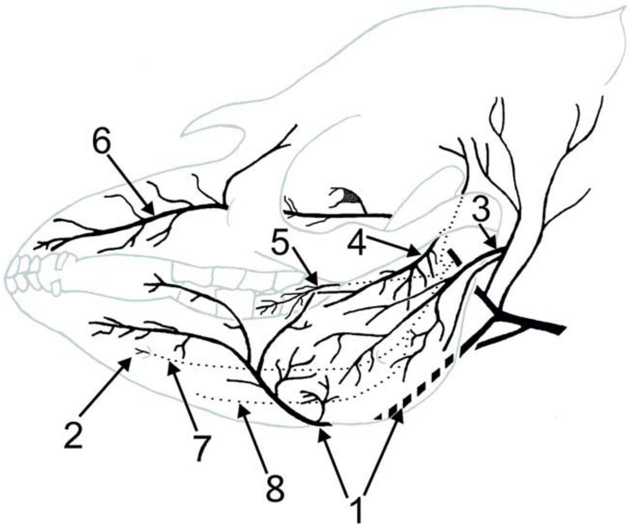

Fig. 3. Arterial blood supply of the face in Tapirs. 1. A. facialis 2. A. mentalis 3. A. transversa faciei 4. A. masseterica 5. A. buccalis 6. A. infraorbitalis 7. A. alveolaris inferior 8. A. submentalis.

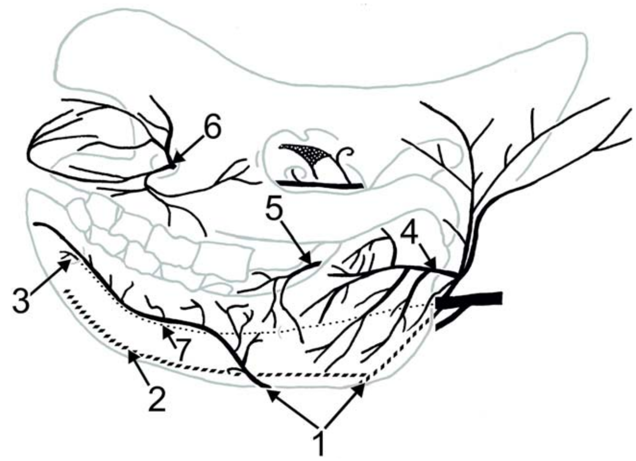

Fig. 5. Arterial blood supply of the face in Rhinos. 1. A. facialis 2. A. submentalis 3. A. mentalis 4. A. transversa faciei 5. A. buccalis 6. A. infraorbitalis 7. A. alveolaris inferior.

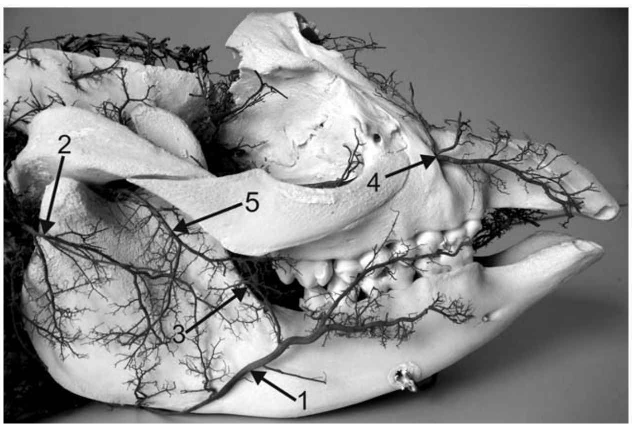

Fig. 4. Arterial blood supply of the face in Tapirs-corrosion casts. 1. A. facialis 2. A. transversa faciei 3. A. buccalis 4. A. infraorbitalis 5. A. masseterica.

transformed into the inferior labial artery, branching off the angular artery of the mouth. Only in tapirs the submental artery originated from the inferior alveolar artery.

The mental artery, similar to the other taxa studied, projected through the mental foramen to the lateral surface of the mandible and was an extension of the inferior alveolar artery.

The transverse facial artery, together with the rostral auricular artery and the masseteric branch, branched off from the superficial temporal artery, which was a branch of the external carotid artery. The transverse facial artery sent out numerous branches to the masseter muscle, and split in the masseteric fossa. In tapirs an additional vessel supplying the masseter muscle was the masseteric artery (*a. masseterica*), a branch of the caudal deep temporal artery *(a. temporalis profunda caudalis)*, which penetrated through the mandibular notch *(incisura mandibulae)* on the lateral surface of the mandible. The caudal deep temporal artery exited from the inferior alveolar artery.

The buccal artery, which penetrated on the lateral surface of the mandible between the maxillary tuber and the ramus of the mandible and extended to the buccal region, was a branch of the inferior alveolar artery.

The superior labial artery and arteries supplying the lateral and dorsal nasal regions were bifurcations of the infraorbital artery, which was an extension of the maxillary artery.

Rhinos

In rhinos (Figs. 5 and 6) the facial artery branched off directly from the external carotid artery. On the medial surface of the mandible the facial artery gave off the submental artery. After penetrating through the notch for facial vessels, the facial artery projected to the lateral surface of the mandible, where it gave off small branches to the masseter muscle and it was transformed into the inferior labial artery, sending out the angular artery of the mouth.

The mental artery, which was an extension of the inferior alveolar artery, penetrated through the mental foramen on the lateral surface of the mandible.

The transverse facial artery together with the rostral auricular artery, the masseteric branch and the occipital artery branched off from the superficial temporal artery. The transverse facial artery gave off numerous branches to the masseter muscle, where they fanned out in the masseteric fossa.

The buccal artery was a branch of the maxillary artery. It projected on the lateral surface of the mandible between the maxillary tuber and the ramus of the mandible and it extended to the buccal region.

The superior labial artery and arteries, supplying the lateral and dorsal nasal regions, were bifurcations of the infraorbital artery. The infraorbital artery was an extension of the maxillary artery, which branched off directly from the external carotid artery.

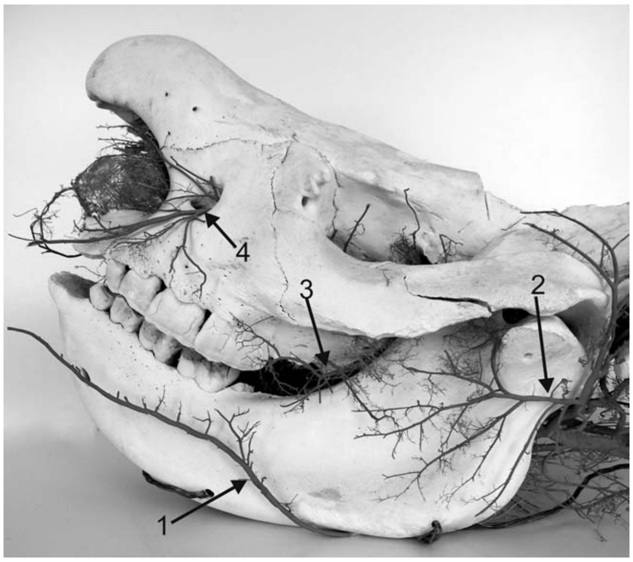

Fig. 6. Arterial blood supply of the face in Rhinos- corrosion casts. 1. A. facialis 2. A. transversa faciei 3. A. buccalis 4. A. infraorbitalis.

DISCUSSION

The facial region in species of Perissodactyla studied here were supplied by the facial artery, submental artery, mental artery, transverse facial artery, buccal artery and infraorbital artery. The exit, course and division of these arteries lacked a universal pattern for the entire clade. In species of Equidae the examined arteries branched off and ran in a pattern similar to that previously described in the horse (Nickel and Schwarz, 1963; Colles and Cook, 1983) and in donkey (Ahmed et al., 1985). Based on this study it was stated that in Equidae the facial artery together with the lingual artery bifurcated from the external carotid artery through the common linguofacial trunk. The presence of the linguofacial trunk in animals of Artiodactyla was shown in domestic cattle (Nickel and Schwarz, 1963), in numerous representatives of Bovidae (impala, Cape hartebeest, White bearded wildebeest, blackbuck, dik-dik, American Bison, European Bison, banteng, cattle, zebu, nilgai, Common eland, nyala, sitatunga, Greater kudu, Roan Antelope, Ellipsen waterbuck) (Godynicki, 1972a; Frąckowiak, 1986; Frąckowiak, 2003; Zdun et al., 2014) and *Cervidae* (Spotted deer, European red deer, wapiti, Dybowski sika deer, Fallow deer, Pere David's deer, Reeves's or Chinese Muntjac, moose, Roe deer) (Godynicki, 1971, 1972a,b; Frąckowiak, 1977; Frąckowiak, 2003; Zdun et al., 2014) as well as musk deer from Moschidae (Frąckowiak, 2003; Zdun et al., 2014).

A common feature for the arterial pattern of the head in tapirs and rhinos, was a separate exit of the lingual artery and the facial artery from external carotid artery. This feature distinguishes rhinos and tapirs (*Ceratomorpha*) from Equidae (*Hippomorpha*). The direct stem of the lingual artery and the facial artery from the main arteries of the head was present only in some species of Artiodactyla: in the reindeer, which is a unique exception among species of Cervidae (Akajewskij, 1929; Godynicki, 1972a, Frąckowiak, 2003; Zdun et al., 2014), as well as the giraffe from Giraffidae (Godynicki, 1972a; Frąckowiak and Godynicki, 1979; Frąckowiak, 2003; Zdun et al., 2014) and boar, pig and hippopotamus from Suiformes (Godynicki, 1972a). Separate exit of the lingual artery and the facial artery from the external carotid artery was also described in Carnivora (Frąckowiak, 2003).

Moreover, the analysis showed that the vascularization of the superior labial region, as well as the lateral and dorsal nasal regions, was similar in the tapir and the rhino, while it differed significantly compared to species of Equidae. The superior labial artery in the tapir and the rhino branched off from the infraorbital artery, whereas in Equidae it was an extension of the facial artery.

The course of the facial artery and the transverse facial artery in the tapir was consistent with its earlier description (Frąckowiak and Godynicki, 1991, Frąckowiak, 2003). Our analyses confirmed that the superior labial artery in the tapir was a vessel originating from the infraorbital artery. Branches of the infraorbital artery in that species also participated in the vascularization of the lateral and dorsal nasal regions. A similar vascularization pattern for these facial regions was also observed in the rhino. In Equidae these regions were supplied by branches of the facial artery.

In tapirs the submental artery, in contrast to the other analyzed Perissodactyla, branched off from the inferior alveolar artery, which was also confirmed in other publications (Frąckowiak and Godynicki, 1991). The submental artery in all examined species of Equidae, similarly as in the pattern described in the horse (Nickel and Schwarz, 1963), branched off from the sublingual artery, being a bifurcation of the facial artery. In twenty percent of the cases, the submental artery of the donkey was a branch of the sublingual artery, as in the horse; whereas in 80% cases it was a branch of the facial artery (Ahmed et al., 1985). In the rhino the sublingual artery was a direct branch of the facial artery.

In representatives of all examined families of Perissodactyla the transverse facial artery exited from the superficial temporal artery together with the rostral auricular artery. In the rhino an additional bifurcation of the superficial temporal artery was the occipital artery, which extended into the caudal auricular artery. In Equidae (Nickel and Schwarz, 1963) and tapirs (Frąckowiak and Godynicki, 1991) the occipital artery branched off directly from the external carotid artery. The transverse facial artery in Equidae gave off the larger blood vessel to the masseter muscle, and then extended along the facial crest, while in tapirs and rhinos the transverse facial artery bifurcated in the masseteric fossa. In Equidae the masseteric branch was an artery supplying additionally the masseteric muscle and constituting a strong branch of the external carotid artery (Frąckowiak, 2003).

The course of the facial artery and transverse facial artery, shown in this study in white rhino and tapir, was similar to that described earlier in tapir (Frąckowiak and Godynicki, 1991; Frąckowiak, 2003). The facial artery in the rhino on the lateral surface of the mandible extended only to the inferior labial region. The transverse facial artery in the rhino, similar to tapirs, bifurcated in the masseteric fossa. A feature distinguishing the transverse facial artery in the rhino from that in the tapir and in Equidae was its common exit, together with the occipital artery, from the superficial temporal artery. In the other Perissodactyla the transverse facial artery was the first branch of the superficial temporal artery.

The mental artery, supplying blood to the mental region in all the examined animals, was an extension of the inferior alveolar artery.

In turn, the exit of the buccal artery and submental artery from the inferior alveolar artery, reported in the tapir, was a unique exception in animals not only within the investigated clade. The research hypothesis was not fully positively verified. Variation was shown in the exit of the facial artery from the arterial mainstream of the head in the analyzed species, and as a consequence the pattern of blood supply for the lateral and dorsal nasal regions also differed. Considerable similarities for this artery were found in the tapir and rhino, while its branching off and course differed in species of Equidae. In turn, the transverse facial artery and the infraorbital artery in all examined Perissodactyla showed a similar branching off pattern and course.

Similarities in the arterial patterns in tapirs from Tapiridae and rhinoceros from Rhinocerotidae, both representing Ceratomorpha, appear to confirm the close phylogenetic relationship asserted in previous work (Price and Bininda-Emonds, 2009; Steiner and Ryder, 2011). The arterial pattern of Equidae from Hippomorpha was similar, which supports their close relationship as well. On the other hand, greater differences in the division and course of arteries of the head among species of *Ceratomorpha* and *Hippomorpha* suggest the need for further consideration on the unity within these clades (Price and Bininda-Emonds, 2009; Steiner and Ryder, 2011).

CONCLUSIONS

1. In the Perissodactyla order, there is no universal pattern of exit, course and branching of arteries supplying selected facial regions.
2. Based on the most common patterns of exit and course of the facial, mental, transverse facial and infraorbital arteries, it may be stated that tapirs and rhinos (Ceratomorpha suborder) are the most similar to one another, at least among the perissodactylans studied here.
3. Only one family, Equidae, presented with a common pattern for the exit, course and branches as well as the supply of the selected facial regions by the facial, submental, mental, transverse facial, buccal and infraorbital arteries.
4. Pattern of the arteries of the head in Perissodactyla showed accordance with position of these species in the taxonomy, and hence with their phylogenetic development.

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