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Origin and distribution of the brachial plexus in the Spix's yellow-toothed cavy (*Galea spixii* Wagler, 1831) (Rodentia, Caviidae)

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ABSTRACT: Due to the absence of literature on the brachial plexus in the Spix's yellow-toothed cavy, this study was conducted to examine the origin and neural distribution of this rodent's brachial plexus. Ten adult animals obtained from previous experiments were thawed, fixed in 10% formalin solution for 72 h and then dissected. Cotton blocks soaked in 2% hydrogen peroxide were placed on the ventral roots of the plexus. Photographs of the most representative specimens were taken and schematic sketches were prepared to illustrate the results. The Spix's yellow-toothed cavy's brachial plexus primarily originated from the ventral roots of the sixth (C_6), seventh (C_7) and eighth (C_8) cervical nerves and from the first two thoracic nerves (T_1, T_2), and less frequently from C_6–T_1 or C_6–T_3. The peripheral nerve trunks of the Spix's yellow-toothed cavy's brachial plexus are the following: suprascapularis (C_6–C_7), axillaris (C_6–C_7), subscapulares (C_6–C_7), cranial pectoral (C_6–C_7), musculocutaneous (C_7–C_8), radialis (C_7–T_2), medianus (C_7–T_2), ulnaris (C_7–T_2), pectorales caudales (C_7–C_8), thoracicus longus (C_7–C_8), thoracicus lateralis (C_7–T_2) and thoracodorsalis (C_7–T_2).

Keywords: anatomy; brachial plexus; nervous system; rodent; *Galea spixii*

List of abbreviations

C_6 = ventral root of C_6; C_7 = ventral root of C_7; C_8 = ventral root of C_8; T_1 = ventral root of T_1; T_2 = ventral root of T_2; T_3 = ventral root of T_3

The Spix's yellow-toothed cavy is a rodent of the Caviidae family that is found in open areas, in savannas and in the semi-arid Caatinga region, in both primary and disturbed habitats, ranging from eastern Bolivia to north-eastern Brazil (Eisenberg and Redford 1999). The cavy's body is of uniform colour, dark grey on the dorsal surface and white on its belly. It has a large head and eyes, small and rounded ears, four fingers in the thoracic member and three in pelvic members (Oliveira et al. 2010; Oliveira et al. 2012a; Oliveira et al. 2013; Oliveira et al. 2014). Rodents are nocturnal animals that live in groups and feed on leaves, branches and fruits of creepers, roots, tubercles and the bark of young trees (Mendes 1987). Currently this species is listed as being of Least Concern because of its wide distribution, presumably large population, occurrence in a number of protected areas and tolerance to habitat modification (IUCN 2008).

The brachial plexus is a cervicothoracic network of ventral nerve roots that form the peripheral nerves innervating the thoracic limb and lateral thoracic wall. As a rule, the plexus in domestic animals is formed by connections established between the ventral branches of the last three cervical spinal nerves and by the first two thoracic ones, with occasionally some contribution from the fifth cervical and/or thoracic nerves (Getty 1986).

There are no reports on the topography of the brachial plexus and its nerve derivatives and their distribution on the thoracic limb and the lateral thorax in the Spix's yellow-toothed cavy. The literature on the Spix's yellow-toothed cavy is restricted to studies on vascularisation (Oliveira et al. 2011;

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Oliveira et al. 2012a; Oliveira et al. 2013), placentation (Oliveira et al. 2012b; Vale et al. 2013) and reproduction (Santos et al. 2012), whereas studies on the nervous system are limited to the lumbosacral plexus (Oliveira et al. 2010; Oliveira et al. 2014).

The study of the morphology of species found in the wild is assuming growing importance, especially of those species with zootechnical potential or biological value, as is the case with *Galea spixii*, a rodent of great importance, since their meat is used as a source of animal protein for poor people or even more broadly owing to cultural habits in the north-eastern part of Brazil. In addition, studies on the brachial plexus contribute to the optimisation of clinical, anaesthetic and surgical procedures on thoracic members and provide important comparative anatomical data.

MATERIAL AND METHODS

Animals. The ten adult Spix's yellow-toothed cavies (five males and five females) used in this study were specimens frozen at (–10 °C) from previous experiments. This study was approved by the Committee for Institutional Ethics (CEUA/UFERSA No. 15/2014, Process 23091.000653/2014-26) and by SISBIO (Authorization and Information System in Biodiversity No. 35231-1). The animals were kept frozen (–10 °C) for three days in the Center for the Multiplication of Wild Animals of the Federal Rural and Semi-Arid University (CEMAS/UFERSA), a scientific breeding division established by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA, No. 1478912).

The animals were thawed, placed in a 10% formalin solution for 72 h and then the skin, muscles, sternum and adjacent forelimbs were dissected carefully. Bilateral incisions were made near to and parallel with the sternum. The forelimbs were carefully dissected and reflected laterally. The ribs were disarticulated, the sternum removed and the contents of the thoracic cavity removed; then, the muscles close to the intervertebral foramina were dissected to allow visualisation of the thoracic nerves. Small cotton blocks moistened with 2% hydrogen peroxide were put in place to facilitate the dissection of the nerves.

Dissection was followed by sketches of the different arrangements of the brachial plexus for analysis and documentation, and photographs were taken to illustrate the results. The nomenclature was based on the International Committee on Veterinary Gross Anatomical Nomenclature (2005).

RESULTS

The dissections showed that in one animal the brachial plexus was formed by roots coming from (C_6–T_1) as shown in Figure 1 and Table 1. In nine animals (90%) the plexus was formed by branches from (C_6–T_2) (Figure 2). However, a contribution of the third thoracic nerve (C_6–T_3) on the left antimere was only observed in one out of the ten animals analysed (Figure 3).

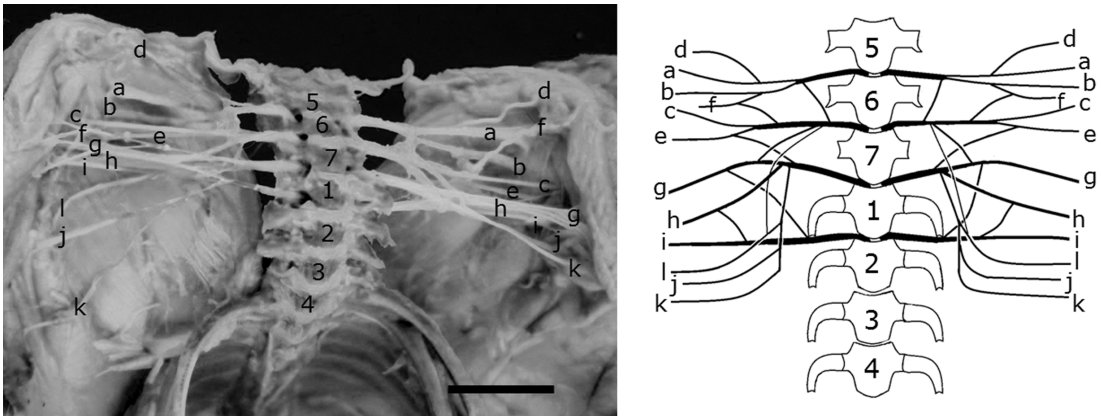

Figure 1. Photograph of the brachial plexus formed by ventral roots of C_6–T_1 on the left, followed by a sketch to the right. The nerves that compose the plexus are the following: suprascapular (a), subscapular (b), axillary (c), cranial pectoral (d), musculocutaneous (e), caudal pectoral (f), radial (g), median (h), ulnar (i), thoracodorsal (j), lateral thoracic (k) and long thoracic nerve; bar = 1 cm

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Table 1. Origin of the brachial plexus in the Spix's yellow-toothed cavy (*Galea spixii*) distributed on the right (RA) and left (LA) antimere

Origin	Frequency (%)	
	RA	LA
C_6, C_7, C_8, T_1	10	10
C_6, C_7, C_8, T_1, T_2	90	80
C_6, C_7, C_8, T_1, T_2, T_3	–	10
Total	100	100

The main nerves of the brachial plexus of the Spix's yellow-toothed cavy were suprascapular, axillary, subscapular, cranial pectoral, musculocutaneous, radial, median, ulnar, caudal pectoral, long thoracic, lateral thoracic and thoracodorsal nerves. They innervated the muscles of the forelimb and lateral thorax (Table 2).

The suprascapular nerve usually originated from the ventral roots of the sixth and seventh cervical nerves (C_6–C_7) and innervated the supraspinatus and infraspinatus muscles, near the articulation to the shoulder.

The axillary, subscapular and cranial pectoral nerves had a common origin from the roots of C_6 and C_7. The axillary nerve innervate the subscapularis, teres major, teres minor and deltoideus muscles. The subscapular nerve solely innervated subscapular muscles. The cranial pectoral nerves innervated the superficial pectoral muscle.

The musculocutaneous nerve usually had its origin in branches from C_7 and C_8 and innervated the biceps brachii, brachialis and coracobrachialis muscles.

The radial nerve usually arose from the ventral roots of C_8–T_2, and innervated the brachialis, brachioradialis, flexor digiti II, flexor digiti III, triceps brachii and tensor fasciae antebrachii muscles. In one specimen, the radial nerve received a contribution from the third thoracic nerve of the left antimere.

The median nerve originated from the ventral roots of C_7–T_2, and followed the olecranon cranially before innervating the flexor carpi radialis, pronator, flexor digiti III, and flexor digiti IV muscles. In one specimen, the median nerve received a contribution from the third thoracic nerve of the left antimere.

The ulnar nerve usually originated from C_7–T_2, and provided branches to the skin (cutaneous caudal nerve of the forearm), anconeus, flexor digitalis, flexor carpi ulnaris, flexor digiti V muscles, and the cutaneous palmar surface. In one case, the ulnar nerve had a contribution from T_3 on the left antimere nerve.

Table 2. Origin of nerves from the brachial plexus of the Spix's yellow-toothed cavy (*Galea spixii*) analysed from the right (RA) and left (LA) antimeres and their distribution by the muscle complex on the thoracic member and thorax

Nerve	Origin	Frequency (%)		Muscles
		RA	LA	
Suprascapular	C_6	30	50	supraspinatus and infraspinatus
	C_6, C_7	70	50	
Axillary	C_6, C_7	100	100	subscapularis, teres major, teres minor and deltoideus
Subscapular	C_6, C_7	100	100	subscapular
Cranial pectoral	C_6, C_7	100	100	superficial pectoral
Musculocutaneous	C_6, C_7	30	30	biceps brachii, brachialis and coracobrachialis
	C_7	10	10	
	C_7, C_8	60	60	
Radial	C_7, C_8	10	10	brachialis, extensor carpi radialis longus, triceps brachii, tensor fasciae antebrachii, flexor digiti II and flexor digiti III
	C_7–T_1	10	10	
	C_7–T_2	10	10	
	C_8, T_1	10	10	
	C_8–T_2	60	50	
	C_8–T_3	0	10	
Median	C_7–T_1	10	10	flexor carpi radialis, pronator, flexor digiti III, flexor digiti IV
	C_7–T_2	60	60	
	C_8, T_1	10	10	
	C_8–T_2	20	10	
	C_8–T_3	0	10	
Ulnar	C_7–T_2	40	40	skin, anconeus muscle, flexor carpi ulnaris and interossei, flexor digiti V and digital hand cutaneous region.
	C_8, T_1	20	20	
	C_8–T_2	40	30	
	C_8–T_3	0	10	
Caudales pectoral	C_7, C_8	50	50	deep pectoral
	C_7–T_2	30	20	
	C_7–T_3	0	10	
	C_8	10	10	
	C_8, T_1	10	10	
Long thoracic	C_6–C_8	10	0	thoracic belly of ventral serrate
	C_7–C_8	80	80	
	C_7–T_1	0	10	
	C_7–T_2	0	10	
	C_8–T_2	10	0	
Thoracodorsal	C_8, T_1	20	20	latissimus dorsi
	C_8–T_2	80	70	
	C_8–T_3	0	10	
Lateral thoracic	C_8, T_1	20	20	cutaneous trunci
	C_8–T_2	80	70	
	C_8–T_3	0	10	

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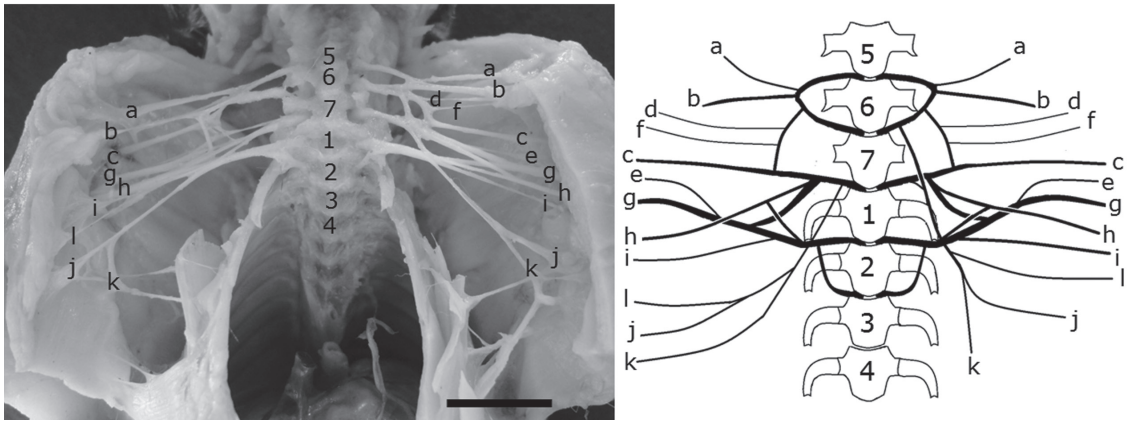

Figure 2. Photograph of the brachial plexus formed by ventral roots of C_6–T_2 on the left, followed by a sketch at the right. The nerves that compose the plexus are the following: suprascapular (a), subscapular (b), axillary (c), cranial pectoral (d), musculocutaneous (e), caudal pectoral (f), radial (g), median (h), ulnar (i), thoracodorsal (j), lateral thoracic (k) and long thoracic nerve; bar = 1 cm

The caudal pectoral nerve usually originated from C_7 and C_8, with contributions from T_1, T_2, and in some cases from T_3, and innervated the pectoralis profundus muscle.

The long thoracic nerve usually originated from C_7 and C_8 and traversed caudally to innervate the thoracic belly of the ventral serrate muscle. The lateral thoracic and the thoracodorsal nerves had a common origin from C_8–T_2, with a small contribution of T_3 on the left antimere (10%). These nerves innervated the cutaneous trunci muscle and the latissimus dorsi muscle, respectively.

DISCUSSION

The Spix's yellow-toothed cavy's brachial plexus frequently originates between C_6 and T_2, and thus differs from what has been described for other rodents such as the coypu (Guimaraes et al. 2013) and chinchilla (Gamba et al. 2007). These authors reported that the plexus of these species is formed from C_6–T_1, a pattern found less frequently in the Spix's yellow-toothed cavy. However, Santana et al. (2003) reported that the brachial plexus of the rock cavy is predominantly formed from the roots of

Table 3. Origin of the brachial plexus nerves in different mammalian species

Nerves	Species						
	Hydrochaeris hidrochaeris	*Chinchilla lanigera*	*Agouti paca*	*Myocastor coypus*	*Tayassu tajacu*	*Mazama gouazoubira*	*Cerdocyon thous*
Suprascapular	C_4–C_7	C_6	C_5–C_7	C_5–C_6	C_6–C_7	C_6–C_7	C_6–C_7
Axillary	C_5–C_8	C_6–C_7	C_6–C_7	C_6–C_7	C_6–C_7	C_6–C_7	C_7–C_8
Subscapular	C_5–C_7	C_6–C_7	C_6	C_6	C_6–C_7	C_6–C_7	C_6–C_7
Cranial pectoral	–	C_7	C_5–C_8	C_6	C_7	C_8–T_1	–
Musculocutaneous	C_6–T_1	C_6–C_7	C_6–C_8	C_7–C_8	C_7–C_8	C_6–C_8	C_6–C_7
Radial	C_6–T_1	C_7–T_1	C_7–T_1	C_7–T_1	C_8–T_2	C_7–C_8	C_7–T_1
Median	C_6–T_1	C_7–T_1	C_8–T_1	C_8–T_1	C_7–T_2	C_7–T_1	C_8–T_1
Ulnar	C_6–T_1	C_7–T_1	C_8–T_1	C_8–T_1	C_8–T_2	C_8–T_1	C_8–T_1
Caudal pectoral	–	C_8–T_1	C_8–T_1	C_6	C_7–C_8	C_8–T_1	–
Long thoracic	C_6–C_8	C_7–C_8	C_7–C_8	–	C_7–C_8	C_7–C_8	–
Thoracodorsal	C_6–T_1	C_8	C_8–T_2	C_8	C_6–C_8	C_7–C_8	C_8–T_1
Lateral thoracic	C_7–T_1	C_8–T_1	C_8–T_2	–	C_8–T_2	C_8–T_1	C_8–T_1
Reference	Fioretto et al. 2003	Gamba et al. 2007	Scavone et al. 2008	Guimaraes et al. 2013	Moura et al. 2007	Vieira et al. 2013	Pinheiro et al. 2014

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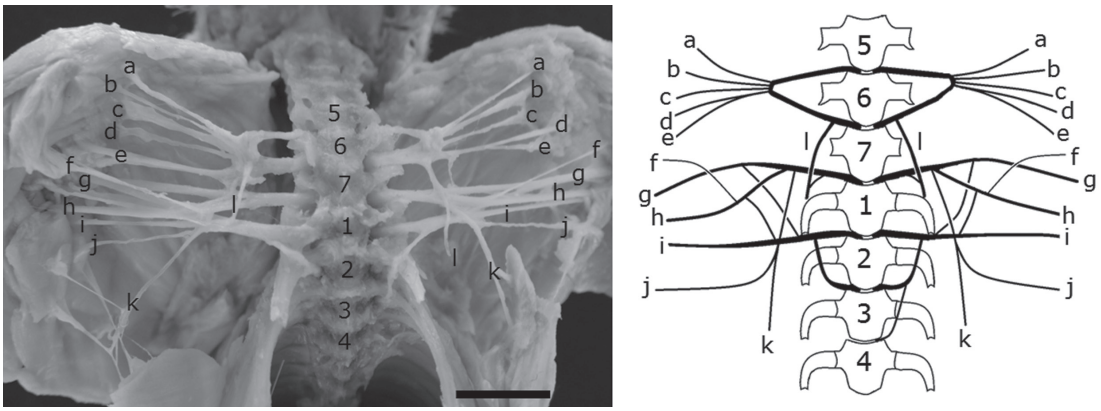

Figure 3. Photograph of the brachial plexus formed by ventral roots of C_6–T_3 on the left, followed by a sketch at the right. The nerves that compose the plexus are the following: suprascapular (a), subscapular (b), axillary (c), cranial pectoral (d), musculocutaneous (e), caudal pectoral (f), radial (g), median (h), ulnar (i), thoracodorsal (j), lateral thoracic (k) and long thoracic nerve; bar = 1 cm

C_6–T_2. They also observed that C_5 may participate or that T_2 may be lacking, a description verified in the Spix's yellow-toothed cavy.

In the Spix's yellow-toothed cavy, the suprascapular, axillary, subscapular and cranial pectoral nerves had a common origin, frequently from C_6 and C_7. The suprascapular nerves innervate the supraspinatus, and infraspinatus muscles (Table 3).

Aydin (2011) reported that the axillary nerve in the red squirrel originates from C_5–C_6, whereas in the paca (Scavone et al. 2008), coypu (Guimaraes et al. 2013), chinchilla (Gamba et al. 2007), and rat (Greene 1963), it is formed from C_6 and C_7, similarly to the Spix's yellow-toothed cavy. According to Guimaraes et al. (2013), in the coypu, branches towards the deltoid teres major, teres minor and subscapularis muscles are observed, as is the case in the Spix's yellow-toothed cavy. The authors also reported that the nerve branches towards the fascia and skin of the forearm region.

The subscapular nerve of the Spix's yellow-toothed cavy originates from the ventral roots of C_6 and C_7, and only innervates the subscapularis muscle, as in the paca (Scavone et al. 2008). On the other hand, in the coypu (Guimaraes et al. 2013) the subscapular nerve originates from C_6 and innervates the subscapularis and the teres major muscles.

In most cases, the musculocutaneous nerve in the Spix's yellow-toothed cavy originates from C_7 and C_8, from C_6 and C_7 or only from C_7. It branches towards the biceps brachii, brachialis and coracobrachialis musculus, similar to the paca (Scavone et al. 2008), and capybara (Fioretto et al. 2003). Aydin and Karan (2012) described that the musculocutaneous nerve in the mole-rat branches towards the cutaneus antebrachi muscle, which was not found in the Spix's yellow-toothed cavy.

The radial nerve in the Spix's yellow-toothed cavy frequently originates from C_8–T_2, as described for the collared-peccary (Moura et al. 2007). Guimaraes et al. (2013) reported that the radial nerve in the coypu is formed from the ventral roots of C_7–T_1 and innervates the tensor fasciae antebrachii, teres major, ulnaris lateralis, anconeus, extensor carpi radialis, extensor digitalis communis, extensor digitalis lateralis and triceps brachii muscles. The above described differs from the situation in the Spix's yellow-toothed cavy since the nerve does not branch towards the ulnaris lateralis and anconeus muscles.

The median nerve of the Spix's yellow-toothed cavy originates from the ventral roots of the C_7–T_2, similar to reports for the collared-peccary (Moura et al. 2007). Gamba et al. (2007) reported that in the chinchilla the median nerve innervates the flexor carpi radialis, pronator, flexor digiti IV, and flexor digiti V muscles. It should be underscored that the Spix's yellow-toothed cavy lacks the digiti I and in this case the median nerve not only branches to the muscles mentioned above, but also towards the flexor digiti III and digiti IV muscles.

The Spix's yellow-toothed cavy's ulnar nerve is formed by ventral roots from C_8–T_2 or C_7–T_2, branching towards the skin and anconeus, flexor carpi ulnaris, interossei, flexor digiti V muscles, and the finger palmar cutaneous region. This differs

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from the chinchilla (Gamba et al. 2007) since in this species the authors did not find any innervation of the triceps brachii and anconeus muscles of the rodent.

The cranial pectoral nerve in the Spix's yellow-toothed cavy originates from C_6 and C_7 and innervates the pectorales superficiales muscle. In contrast, in rats (Greene 1963), the cranial pectoral nerve originates from C_5 and C_6.

The caudal pectoral nerve in the Spix's yellow-toothed cavy frequently originates from C_7 and C_8, and innervates the pectoralis profundus muscle, similar to results on the collared-peccary (Moura et al. 2007). According to Fioretto et al. (2003) this nerve is absent in the capybara and the pectoralis profundus muscle is innervated by the lateral thoracic nerve.

The long thoracic nerve in the Spix's yellow-toothed cavy frequently originated in C_7–C_8, and innervated the serratus ventralis thoracis muscle; the lateral thoracic and thoracodorsal nerves originated in C_8–T_2 and innervated the cutaneus trunci and the latissimus dorsi muscles, respectively, very similar to what has been described for the chinchilla (Gamba et al. 2007).

Scavone et al. (2008) reported that the lateral thoracic nerve in the paca is formed by roots of C_8–T_2 and is distributed towards the cutaneus trunci muscle, similar to results in the Spix's yellow-toothed cavy.

The thoracodorsal nerve of the Spix's yellow-toothed cavy originated from C_8–T_2, and innervated the latissimus dorsi muscle. It should be emphasised that the radial, median, ulnar, caudal pectoral, long thoracic, thoracodorsal and lateral thoracic nerves contributed towards the third thoracic ventral branch on the left antimere in one specimen. To date, such a branch has yet to be described in any other mammals.

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