

Peripheral nerves of the brachial plexus with their distribution to the muscles of the pectoral limb in the captive African Striped Ground Squirrel (*Xerus erythropus*)

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ABSTRACT: This research provides a detailed description of the gross morphology of the brachial plexus with its peripheral nerve distribution to the muscles of the pectoral limb in the African Striped Ground Squirrel (ASGS). Six (6) adult ASGSs of both sexes were used for this study. The squirrels were euthanised using ketamine hydrochloride at a dose of 60 - 80 mg/kg intramuscularly. They were perfused intracardially with 10 % formalin and fixed in the same solution for three days. The muscles were dissected along the intermuscular septae, and the nerves supplying them were identified and photographed. The vertebral column was opened by laminectomy to expose the cervical and thoracic nerve roots. The last four cervical nerves and the first two thoracic nerves arose from the cervical and thoracic segments, respectively, of the spinal cord of the ASGS by means of dorsal and ventral roots. The cervical and thoracic nerves are divided into dorsal and ventral rami just after exiting the intervertebral foramen. The ventral rami of the last four cervical nerves (C5, C6, C7, and C8) and the first two thoracic nerves (T1 and T2) are interconnected to form the brachial plexus. The peripheral nerves of the brachial plexus, including the subscapular nerve, suprascapular nerve, pectoral nerve, axillary nerve, radial nerve, musculocutaneous nerve, ulnar nerve, median nerve and thoracodorsal nerve, supplied the subscapularis, supraspinatus, pectoralis, teres major, triceps brachii, coracobrachialis, flexor carpi ulnaris, flexor carpi radialis and latissimus dorsi, respectively. The peripheral branches of the brachial plexus supply innervation to the muscles of the pectoral limb. The increased number of spinal nerves that constituted the brachial plexus of the ASGS from this study points to increased versatility of actions of the pectoral limb of the ASGS in climbing, wide jump between tree branches and digging.

Keywords: Cervical, plexus, spinal, thoracic.

INTRODUCTION

The Captive African Striped Ground Squirrel (ASGS) is a diurnal rodent which belongs to the family Sciuridae, genus *Xerus*, species *Xerus erythropus* (Thorington and Hoffmann, 2005). They are moderately large, ranging from 22 to 29 centimetres in length, with a tail that is 19 to 26 centimetres, nearly as long as the body; their adults weigh between 0.5 to 1 kilogram. They have a sandy-brown to dark brown fur and whitish underparts, which have a lateral stripe of pure white fur extending from the shoulders to the hip (Herron and Waterman, 2004). The squirrel is found across Africa, south of the Sahara and savannah countries, usually around cultivated lands (Thorington *et al.*, 2012). It is well distributed in Nigeria, particularly in the North-eastern and South-eastern parts of the country (Ibe *et al.*, 2020). Six subspecies are currently recognised, two of which are in Nigeria: *Xerus erythropus erythropus* and *Xerus erythropus chadensis* (Herron and Waterman, 2004). This rodent is an adaptable species, and no particular threats have been identified. Thus, the International Union for Conservation of Nature has rated its conservation status as being of least concern (Grubb *et al.*, 2008).

The brachial plexus is a large somatic nerve plexus, formed by the ventral branches of C6, C7, C8 and T1, which gives origin to the peripheral nerves that supply the thoracic limb in the dog (Dyce *et al.*, 2010; Fletcher, 2013). The ventral branch of C5 also contributes to the plexus, and the T2 contribution is lacking in the *Myocastor coypus* (Mari, 2017), *Microtus guentheri* (Iftar and Yasin, 2021) and the African giant rat (Maidawa, 2019). When C5 and T2 enter into formation of the brachial plexus, they are very small in comparison to other ventral branches forming the plexus, as can be seen in porcupine (Ayidin, 2003) and *Sphiggurus villosus* (Thais, 2024).

There is a paucity of detailed information on the morphology and distribution of the spinal nerves of the ASGS, a rodent with potential for teaching comparative gross anatomy. The objectives of this study were to identify and describe the arrangement and distribution of the peripheral nerves of the brachial plexus to the muscles of the pectoral limb in African striped ground squirrels. This research differs from other rodents because the brachial plexus here was formed by C5, C6, C7, C8, T1 and T2.

MATERIALS AND METHODS

Acquisition of experimental animals

Six apparently healthy, adult ASGS of both sexes were used for this study without taking sex differences into consideration. The ASGSs were caught alive in the wild around Samaru village in Zaria, Nigeria, by hunters using metal cage traps. The ASGSs were housed in customised laboratory cages in the Department of Veterinary

Anatomy, Faculty of Veterinary Medicine, Ahmadu Bello University, Zaria and fed with sweet potatoes, carrots, water melon, groundnuts, mangoes and water ad libitum. They were allowed to acclimatise for three (3) weeks before the commencement of the study. Ethical permission for this study was approved by the Committee on Animal Use and Care, Ahmadu Bello University, Zaria, Nigeria (Approval Number obtained is ABUCAUC/2023/079).

Experimental procedure

The squirrels were restrained and deeply anaesthetised with injection of ketamine hydrochloride intramuscularly at a dosage of 60 - 80 mg/kg, respectively. They were immediately weighed individually with a sensitive balance (Mettler p1210, Mettler Instrument Ag., Switzerland; Sensitivity 0.001 g), then perfused intracardially (Gage *et al.*, 2012) with 10% neutral-buffered formalin (NBF), and post-fixed in the same solution for three (3) days.

As much as possible, the skin was removed without affecting much of the cutaneous muscle. The muscles of the head, neck and thorax regions were dissected along the intermuscular septae separating them, and the nerves supplying them were identified and photographed using a Cannon digital camera 5X optical zoom lens 2.0 – 5.0 mm, 12.1 mega pixels (Apple Cannon, Made in China). Careful and gentle dissection of the dorsal epaxial and ventral hypaxial musculature from the superficial to deep muscles was done using a scalpel blade and Ruskin's rongeur until the vertebral arches and spinous processes were exposed dorsally, and the bodies of the vertebrae were exposed ventrally (Ayidin, 2010; Ko *et al.*, 2004). The Nomenclature used in identification was adopted according to the Nomina Anatomica Veterinaria (NAV, 2017).

RESULTS

Morphology of the brachial plexus of the ASGS

The ventral rami of the last four cervical nerves (C5, C6, C7, and C8) and the first two thoracic nerves (T1 and T2) are interconnected to form the brachial plexus (Figures 1 and 2). The roots of the brachial plexus were noted to pass ventral to the scalenus muscles into the axillary space. These roots were observed to unite together to form three trunks. The cranial trunk was formed by the union of the ventral branches of C5 and C6, the middle trunk was formed by the ventral branch of C7 alone, and the caudal trunk was formed by the union of the ventral branches of C8, T1 and T2 (Figure 2). The trunks were also noted to divide into cranial and caudal parts, which combined variously to form cords. The lateral cord in this study was formed by the cranial division of the cranial trunk. The



Figure 1. A photograph showing the lateral view of the cervicothoracic nerve roots and related structures; black arrows, cervical nerves 1 - 8; blue arrows, thoracic nerves 1 & 2; a, head; b, trapezius cervicis; c, occipitoscapularis; d, subscapularis; e, third rib; f, fourth rib; g, spinal cord.



Figure 2. A photograph showing dorsal view of ventral branches of the brachial plexus with related structures; white arrows, cervical nerve C; red arrows, thoracic nerve T; last four cervical nerves C5 – C8; red arrows, first two thoracic nerves T1 - T2; brachial plexus, cervical nerves C5- C8 and first two thoracic nerves T1 - T2; cranial trunk, C5 and C6; middle trunk, C7; caudal trunk, C8, T1 and T2; a, splenius; b, trapezius cervicis; c, subscapularis; d, spinous process of thoracic vertebrae.

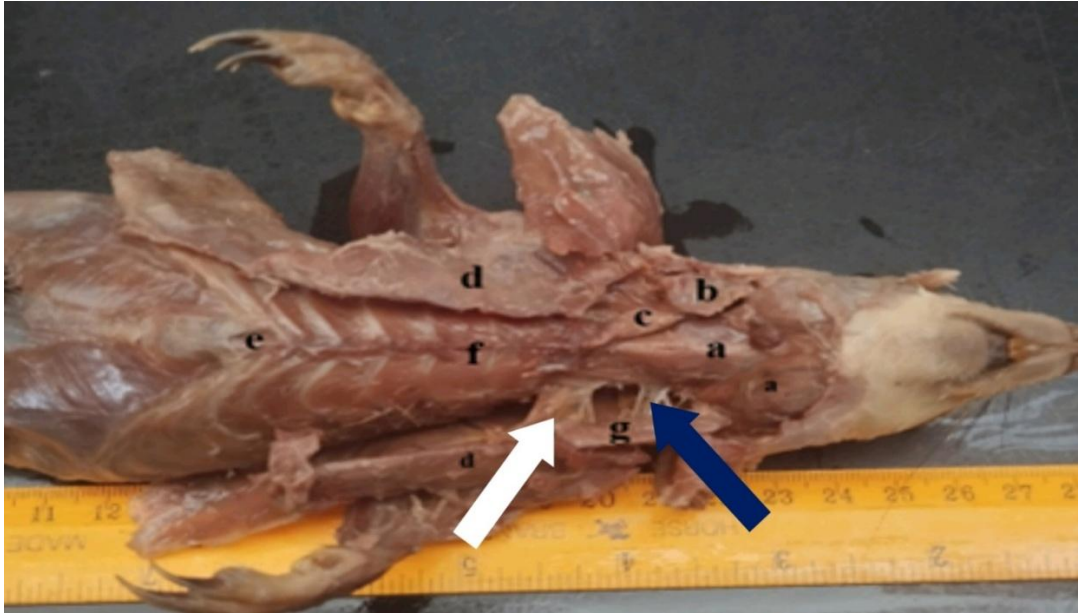


Figure 3. A photograph showing ventral view of the ASGS; blue arrow, cervical plexus; white arrow, brachial plexus a, sternocephalicus; b, brachiocephalicus; c, sternomastoideus; d, pectorales; e, xiphoid cartilage; f, rectus thoracis; g, clavicle.

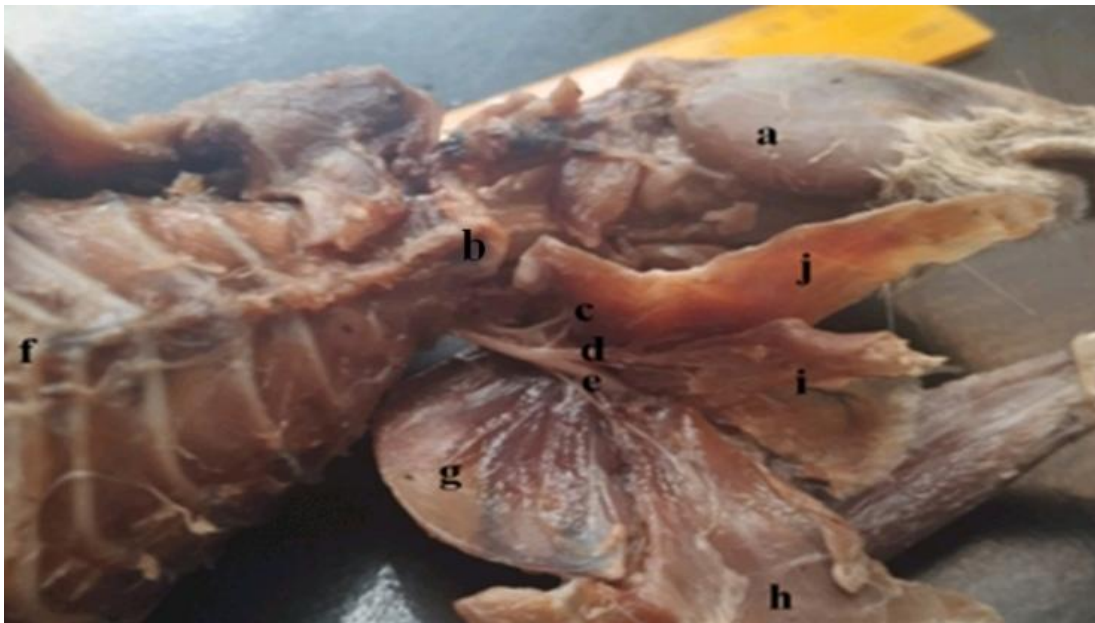


Figure 4. A photograph showing medial view of the forelimb of the ASGS. Peripheral nerves of the brachial plexus and related structures; a, masseter; b, manubrium sterni; c, pectoral nerve; d, axillary nerve; e, thoracodorsal nerve; f, xiphoid cartilage; g, subscapularis; h, latissimus dorsi; i, pectoralis profundus; j, pectoralis superficialis.

medial cord was formed by the combination of the cranial division of the middle trunk and the cranial division of the caudal trunk, and the caudal cord was formed by the combination of three caudal divisions of the three trunks.

The cords gave rise to terminal or peripheral branches to some of the extrinsic and intrinsic muscles of the forelimb of the ASGS (Figures 3 and 4).



Figure 5. A photograph showing medial view of the forelimb of the ASGS. The Peripheral nerves of brachial plexus and related structures; a, suprascapular nerve; b, ventral branch of fourth cervical nerve; c, occipitoscapularis; d, rhomboideus; e, subscapularis; f, subscapular nerve; g, trunk of brachial plexus; h, thoracodorsal nerve; i, pectoral nerve; j, pectoralis superficialis; k, pectoralis profundus; l, latissimus dorsi.

Peripheral nerves of the brachial plexus to the thoracic limb of the ASGS

The suprascapular nerve was noted to arise from the cranial trunk in the cranial part of the brachial plexus and passed ventrolaterally and disappeared in the interstice between the supraspinatus and the subscapularis muscles (Figure 5).

The subscapular nerves, about four branches, were observed to be distributed to the parts of the subscapularis muscle. One branch arose from just caudal to the suprascapular nerve from the cranial trunk of the brachial plexus. The two branches arose from the middle trunk of the brachial plexus, formed by the ventral branch of C7. The fourth branch of the subscapular nerve arose from the axillary nerve and passed between the subscapularis and teres major muscles (Figure 5).

The cranial and caudal pectoral nerves, which were distributed to the superficial and deep pectoral and cutaneous trunci muscles of the ASGS, arose from the middle and caudal trunks of the brachial plexus. The caudal trunk was formed by the union of C8, T1 and T2 ventral branches (Figure 2).

The axillary nerve arose from the middle trunk of the brachial plexus and passed to the interstice between the subscapularis and the teres major cranially and ran behind the shoulder joint along with the caudal circumflex humeral artery and vein to supply the muscles on the lateral aspect of the shoulder, including the deltoideus (Figure 4).

The thoracodorsal nerve was observed to arise from the

caudal trunk of the brachial plexus and passed caudally in company of the thoracodorsal artery and vein to supply the latissimus dorsi muscle (Figure 5).

The radial nerve was noted to be the largest of the branches that emanated from the brachial plexus to the forelimb. The nerve arose from the caudal trunk of the brachial plexus along with the musculocutaneous, median and ulnar nerves. It passed caudally to enter the interstice between the long and medial heads of the triceps brachii and distributed branches to all heads of the triceps brachii muscles, including the lateral head and the anconeus (Figure 6). The nerve passes between the brachialis and lateral head of the triceps brachii, emerging below the lateral head as the lateral cutaneous antebrachial nerve.

The musculocutaneous nerve in the ASGS arose from the caudal trunk of the brachial plexus together with the radial, median and ulnar nerves. The nerve separated from the group and passed to the deep part of the coracobrachialis muscle and detached the proximal muscular branch to the biceps brachii muscle, and continued distally deep to the coracobrachialis and biceps brachii (Figure 6).

The median nerve arose together with the ulnar and musculocutaneous nerve from the caudal trunk of the brachial plexus and passed together on the medial aspect of the arm with the ulnar nerve after the separation of the musculocutaneous nerve near the proximal third of the arm. The median nerve is separated from the ulnar at the elbow joint, crossing the joint cranial to the medial epicondyle of the humerus and into the forearm deep to

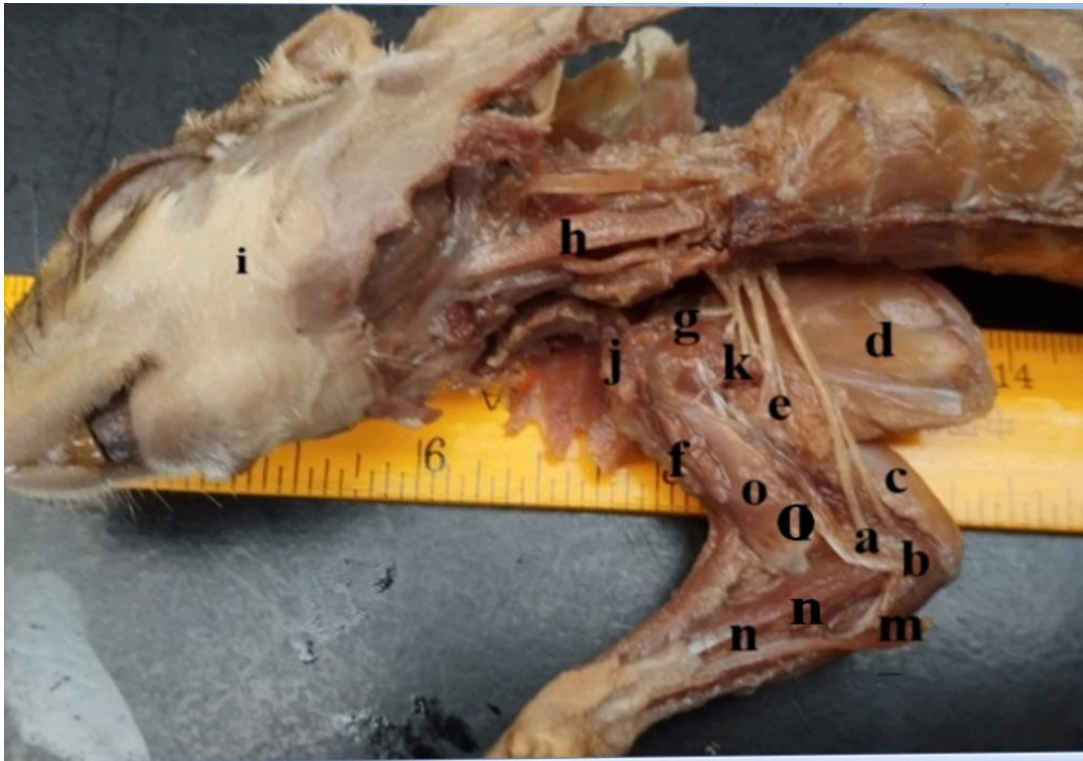


Figure 6. A photograph showing medial view of the forelimb of the ASGS. Peripheral nerves of the brachial plexus and related structures; a, median nerve; b, ulnar nerve; c, triceps brachii; d, subscapularis; e, radial nerve; f, biceps brachii; g, suprascapular nerve; h, sternocephalicus; i, head; j, deltoideus; k, musculocutaneous nerve; m, flexor carpi ulnaris; n, flexor carpi radialis; o, coracobrachialis.

the pronator teres, passing through and sending branches to the flexor muscles of the antebrachium, including the pronator teres, flexor carpi radialis, flexor digitorum superficialis and flexor digitorum profundus (Figure 6). The nerve passed distally into the forepaw to supply the palmar aspect together with the ulnar nerve.

The ulnar nerve arose in close association with the median, musculocutaneous and radial nerves from the caudal trunk of the brachial plexus but passed together with median nerve along the medial aspect of the arm and diverged at the elbow joint with the ulnar nerve, passing caudal to medial epicondyle of the humerus and passed into antebrachium deep to the flexor carpi ulnaris muscle (Figure 6).

DISCUSSION

The brachial plexus of the ASGS was noted to be formed mainly by the ventral branches of C5, C6, C7, C8, T1 and T2. This result is similar to what was observed in *Sphiggurus villosus* (Thais *et al.*, 2024), porcupine (Ayidin, 2003) and white New Zealand rabbit (Mohiuddin *et al.*,

2011; Mussa *et al.*, 2016). The brachial plexus of some rodents like *Myocaster coypu* (Mari, 2017), *Microtus guentheri* (Ifar and Yasin, 2021), wistar rats (Uzun *et al.*, 2001; Ozbag *et al.*, 2009), chinchilla (*Chinchilla lanigera*) (Cevik-Demirkan *et al.*, 2007), mole-rat (*Spalax leucodon*) (Ayidin and Karan, 2012) and primates such as Owl monkey (*Aotus trivirgatus*) (Mizuno, 1966), Capuchin monkey (*Cebus capucinus*) (Mizuno, 1969), the rhesus monkey (*Macaca mulata*) (Lu *et al.*, 2013; Santos-Souza *et al.*, 2016), common marmoset (Emura *et al.*, 2017), the giant anteater (*Myrmecophaga tridactyla*) (Souza *et al.*, 2013) and African giant rat (Maidawa, 2019) to be formed by the ventral branches of C5, C6, C7, C8 and T1. The brachial plexus of some rodents, like the red squirrel (*Sciurus vulgaris*), was noted by Ayidin (2011) to be formed by ventral branches of C5, C6, C7 and C8 without any contribution from the ventral branch of T1. The brachial plexus derived its fibres from the ventral branches of C6, C7, C8 and T1 in the Caracal (Arkadiusz *et al.*, 2024), goat, sheep and pig and T2 in the ox and horse (Magilton, 1966; Ghoshal, 1975). This is similar to reports of occasional small contribution of nerve fibres from the C4 root to the brachial plexus of Wistar rats (Ozbag *et al.*,

2009), primates such as lemurs and the old-world monkey (Miller, 1934), rhesus monkey (Lu *et al.*, 2013; Santos-Souza *et al.*, 2016) and common marmoset (Emura *et al.*, 2017).

In the ASGS, the roots of the brachial plexus formed three trunks, viz., a cranial trunk formed by the union of C5 and C6, a middle trunk formed by C7 and a caudal trunk formed by the union of C8, T1 and T2 roots. This is similar to what was reported in the monotreme and new and old-world monkeys by Miller (1934), chacma baboon (Booth *et al.*, 1997), bonobo (*Pan paniscus*), rhesus monkey (Santos-Souza *et al.*, 2016) and common marmoset (Emura *et al.*, 2017). This differs from what was reported in the African giant rat, in which a cranial trunk formed by the union of C5 and C6, a middle trunk formed by C7 and a caudal trunk formed by the union of C8 and T1 roots (Maidawa, 2021).

The suprascapular nerve was observed in this study to originate from the cranial trunk of the brachial plexus of the ASGS which agrees with the findings reported in some non human primates such as chacma baboon (Booth *et al.*, 1997), bonobo (Kikuchi *et al.*, 2011), gorilla and chimpanzee (Martinez Pereira and Zancan, 2005), rhesus monkey (Lu *et al.*, 2013; Santos-Souza *et al.*, 2016), common marmoset (Emura *et al.*, 2017), as well as in porcupine (Ayidin, 2004), red squirrel (Ayidin, 2011), rats (Martinez-Pereira and Zancan, 2015), rabbit (Mohiuddin, 2011; Reichert *et al.*, 2014; Mussa *et al.*, 2016), giant anteater (Souza *et al.*, 2013) and guinea pigs (Martinez-Pereira and Zancan, 2015).

The subscapular nerve was noted in this study to arise from the cranial and middle trunks and supply four branches to the divisions of the subscapularis and teres major muscles of the ASGS. This is similar to the observation made in the rhesus monkey (Santos-Souza *et al.*, 2016) and common marmoset (Emura *et al.*, 2017).

The cranial and caudal pectoral nerves of the ASGS originated from the middle and caudal trunks of the brachial plexus, respectively. This is similar to what was observed in the chinchilla (Cevik- Dermirkan *et al.*, 2007). In the rat, the cranial pectoral nerve originated from C5 and C6, while the caudal pectoral nerve arose from C7 (Martinez-Pereira and Zancan, 2015). Mussa *et al.*, (2016) observed that the cranial pectoral nerve originated from the cranial trunk of the brachial plexus and the caudal pectoral nerve from the caudal trunk. The cranial and caudal pectoral nerves in the porcupine originated from the caudal trunk of the brachial plexus as four branches: two branches to the pectoralis descendens, one to the descendens and transversus and one together with the lateral thoracic nerve and the caudal pectoral nerve to the cranial part of the pectoralis transversus and the ascendens muscles (Ayidin, 2004). The cranial and caudal pectoral nerves of the red squirrel were reported to originate respectively from the cranial and caudal trunks of the brachial plexus (Ayidin, 2011).

The axillary nerve from the brachial plexus of the ASGS was observed in this study to arise from the cranial and middle trunks of the brachial plexus. This is similar to the pig (Martinez-Pereira and Zancan, 2015) and chacma baboon (Booth *et al.*, 1997). In the rhesus monkey, the axillary contained fibres from C5 and C6, similar to the situation of the musculocutaneous nerve in this animal (Lu *et al.*, 2013). Santos-Souza *et al.* (2016) reported the origin of the axillary nerve from C7 with contributions from C6 and C8 in the rhesus monkey. In the common marmoset, Emura *et al.* (2017) reported that the axillary nerve emerged from the common trunk of the dorsal branches from the upper and middle trunks and formed a common trunk with the caudal most subscapular nerve in all the specimens studied. Martinez-Pereira and Zancan (2015) reported the origin of the nerve from C5-C8 in the primates, C7-C8 in the guinea pig and dog and from C6-C7 in the rat, chinchilla and cat.

The thoracodorsal nerve arose from the caudal trunk of the brachial plexus of the ASGS. In the chinchilla, it was formed by the ventral branch of C8 (Cevik-Demirkan *et al.*, 2007). Booth *et al.* (1997) reported that in the chacma baboon, the thoracodorsal nerve arose from a common trunk with the radial nerve from almost all roots of the brachial plexus or may more often appear as a branch of the radial nerve. Emura *et al.* (2017) observed that the thoracodorsal nerve either branched from the dorsal branch of the lower or caudal trunk or from the radial nerve in the common marmoset. In bonobos, the thoracodorsal nerve ramifies from the posterior cord (Kikuchi *et al.*, 2011). Martinez-Pereira and Zancan (2015) reported that the thoracodorsal nerve originated from C6-C7 in the rat and guinea pig, C7 in the rabbit and cat and from C8 in the chinchilla.

The radial nerve was noted to be the largest peripheral branch of the brachial plexus of the ASGS. It arose from the caudal cord of the plexus along with the musculocutaneous, median and ulnar nerves. This is similar to the observation made in the owl monkey (Mizuno, 1966), capuchin monkey (Mizuno, 1969), bonobo (Kikuchi *et al.*, 2011) and chacma baboon (Booth *et al.*, 1997). In the giant anteater, the radial nerve received contributions from both cranial and caudal trunks of the brachial plexus (Souza *et al.*, 2013). Santos-Souza *et al.* (2016) observed that the radial nerve originated from the union of roots C7 and C8 of the brachial plexus of the rhesus monkey.

The musculocutaneous nerve was noted in this study to arise from the caudal cord of the brachial plexus of the ASGS along with the radial, median and ulnar nerves. This is similar to what was reported in the porcupine (Ayidin, 2004) and, rabbit (Mussa *et al.*, 2016). In the giant anteater, the musculocutaneous nerve arose from the cranial trunk of the brachial plexus (Souza *et al.*, 2013). In the macaca mulatta, the nerve arose mostly from C6 and C7 but also from C5, C6 and C7 in a few cases (Santos-

Sousa *et al.*, 2016; Lu *et al.*, 2013).

The median nerve in the ASGS was observed to arise together with the ulnar, radial and musculocutaneous nerves from the caudal cord of the brachial plexus. This is similar to the observation reported in the rabbit (Mussa *et al.*, 2016) and porcupine (Ayidin, 2004). Cevik –Demirkan *et al.* (2007) observed the origin of the median nerve as principally from C7, C8 and T1 in the chinchilla. Reichert *et al.* (2014) observed the origin of the median nerve in the rabbit from C7, C8 and T1. The median nerve was formed mostly by C6-T1 in macaca mulatta, and in a few cases, T2 was included in the formation of the nerve (Santos-Sousa *et al.*, 2016).

The ulnar nerve arose from the caudal cord of the brachial plexus of the ASGS along with the median, radial and musculocutaneous nerves and passed along the medial aspect of the arm together with the median nerve in close relationship with the brachial artery and vein. This observation is similar to what was reported in the porcupine (Ayidin, 2004), rabbit (Reichert *et al.*, 2014; Mussa *et al.*, 2016). The ulnar and median nerves of the ASGS are separated from each other at the elbow joint. In the chinchilla, the ulnar nerve arose from T1 and T2 (Cevik-Demirkan *et al.*, 2007).

Conclusion

The brachial plexus was formed by C5, C6, C7, C8, T1 and T2. The peripheral branches of the brachial plexus supply innervation to the muscles of the pectoral limb. The increased number of spinal nerves that constituted the brachial plexus of the ASGS from this study (6 spinal nerves) points to increased versatility of actions of the pectoral limb of the ASGS in climbing, wide jump between tree branches and digging.

CONFLICT OF INTEREST

There is no conflict of interest regarding this article.

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