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Anatomy of the brachial plexus in the Mongolian gerbil (*Meriones unguiculatus* Milne-Edwards, 1867)

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ABSTRACT: The Mongolian squirrel is a murine rodent widely used as an experimental model and kept as a pet. With respect to the significance of the brachial plexus, we aimed to describe the origin and the nerves that constitute it, providing new information about the neuroanatomy of this species. Twenty adult animals were used, which were fixed in a 10% formaldehyde solution at the Applied Animal Morphophysiology Laboratory of the Brazilian Federal University of the Semi-Arid Region (UFERSA). The animals were medially incised with an opening of the thoracic cavity, and then bilateral dissection was carried out. Once the nerves were identified, cotton wool soaked with a 2% hydrogen peroxide solution was added for bleaching and better visualisation of structures. The gerbil brachial plexus derived from ventral roots of the fourth, fifth, sixth, seventh and eighth cervical nerves (C_4–C_8) and the first thoracic root (T_1). The suprascapular nerve was formed from the nerve roots C_4 and C_5; the subscapular and cranial pectoral nerves from C_5 and C_6; the musculocutaneous and axillary nerves from C_5, C_6 and C_7; and the caudal pectoral, radial, median, ulnar, thoracodorsal, lateral thoracic and long thoracic nerves from C_7, C_8 and T_1. This resembles what is described in other rodents, such as the rat and capybara. The gerbil has a pre-fixed plexus conformation.

Keywords: neuroanatomy; innervation; thoracic limb; expimental model; murine

List of abbreviations

C_4 = ventral root of C_4; C_5 = ventral root of C_5; 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

The gerbil, also known as the Mongolian squirrel, is a rodent belonging to the muridae family and while native to Mongolia, southern Siberia and northern China (Batsaikhan and Tsytsulina 2016), is currently found worldwide. It is physically characterised by an elongated body, long tail and short ears (Agren et al. 1989). It is predominantly diurnal in its habits; in natural conditions, the diet consists of seeds and vegetables, but it also eats fruits of desert plants, and it can migrate about 50 km in search of food when it is scarce (Batsaikhan and Tsytsulina 2016). Its coat may be white, gold, brown, grey or black in colour.

According to Schwentker (1963), initially the gerbil was taken from Mongolia to the United States in 1954 in order to be used as an experimental model, and since then it has been used in numerous studies. With respect to the nervous system, this species has been widely used in studies on vascularization of brain (Costa et al. 2017), epilepsy (Kaplan and Miezejeski 1972; Loskota et al. 1974; Loskota and Lomax 1975) and neuropathies (Thompson 1970; Akao et al. 2003; Canta et al. 2010; Smith et al. 2010), especially in cases of stroke (Kirino 1982; Kirino and Sano 1984; Ginsberg and Busto 1989; Somova et al. 2000; Casals et al. 2011).

The brachial plexus is a network of nerves consisting of sensory, motor and sympathetic fibres that innervate the thoracic limb and is usually formed by the roots C_5, C_6, C_7, C_8 and T_1; in some cases, there may be a contribution of C_4 in the pre-fixed

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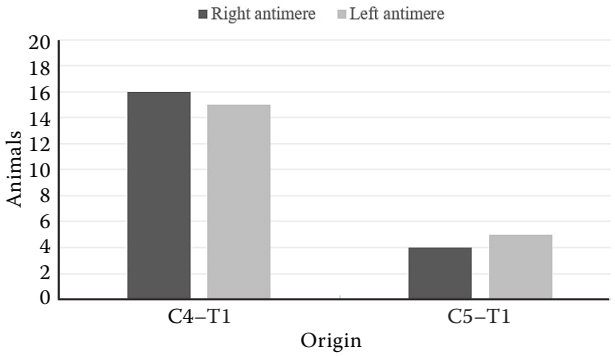

Figure 1. Types of brachial plexus found in the gerbil (*Meriones unguiculatus* Milne-Edwards, 1867)

plexus and T_2 in the post-fixed plexus (Sugiyama 1965; Hill 1972; Dyce et al. 2010).

The nerve roots C_5 and C_6 join adjacent to the lateral border of the anterior scalene muscle to form the upper trunk of the brachial plexus. The root C_7 alone constitutes the middle trunk while the roots C_8 and T_1 constitute the inferior trunk posterior to the anterior scalene muscle, which is located on the first rib (Resnick 1995; Reede and Holliday 2003).

Our aim in this study was to establish a standard model of the brachial plexus in this species and to provide information regarding the Mongolian gerbil's neuroanatomy. Such knowledge may be useful in anaesthetic, clinical and surgical procedures, as well as in future studies on nerve degeneration, nerve damage and other models of experimental neuropathies.

MATERIAL AND METHODS

Twenty adult animals of both sexes obtained from previous experiments approved by the Committee for Institutional Ethics (CEUA 04/2014, Protocol 23091.005376/2013-67) were used, and fixed in a 10% formaldehyde solution at the Applied Animal Morphophysiology Laboratory of the Brazilian Federal University of the Semi-Arid Region (UFERSA).

The animals were dissected and an incision was made near the sternum up to the axillary region. Subsequently, the thoracic limbs were removed and the muscles covering the intervertebral foramina region were dissected in order to observe the nerves that constitute the brachial plexus. Once the nerves were identified, cotton wool soaked with a 2% hydrogen peroxide solution was added for bleaching and better visualisation of the plexus elements.

The terminology was based on the International Committee on Veterinary Gross Anatomical Nomenclature (ICVGAN 2017).

RESULTS

The brachial plexus of the gerbil was characterised as a prefixed plexus often formed by ventral roots emerging from C_4–T_1 (Figures 1 and 2) and less frequently by C_5–T_1 (Figure 3). The main nerves responsible for innervating the limb and thorax muscles were suprascapular, subscapular, musculocutaneous, axillary, cranial pectoral, caudal pectoral, radial, median, ulnar, thoracodorsal and lateral thoracic and long thoracic nerves (Table 1).

DISCUSSION

The origin of the gerbil brachial plexus resembles that described by Greene (1963) in rats (*Mus nor-*

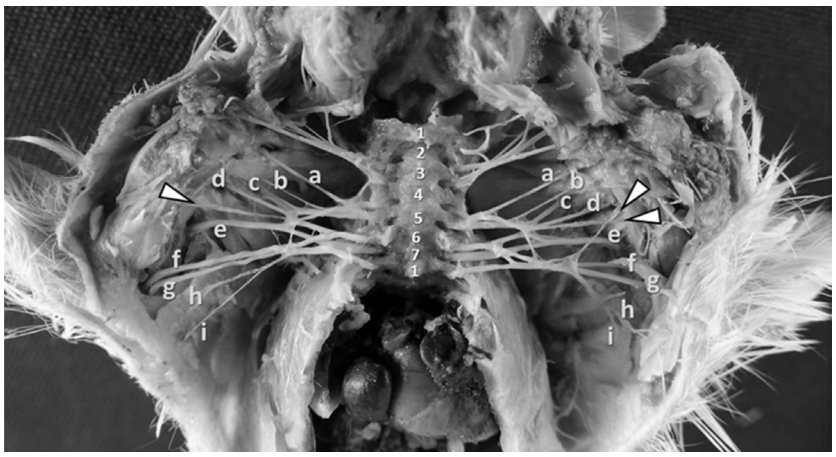

Figure 2. Brachial plexus in the gerbil (C_4–T_1); ventral view. The following nerves can be visualised: suprascapular (a); subscapular (b); axillary (c); musculocutaneous (d); radial (e); median (f); ulnar (g); thoracodorsal (h); lateral thoracic (i); long thoracic (j); pectoral nerves: cranial and caudal (arrowhead)

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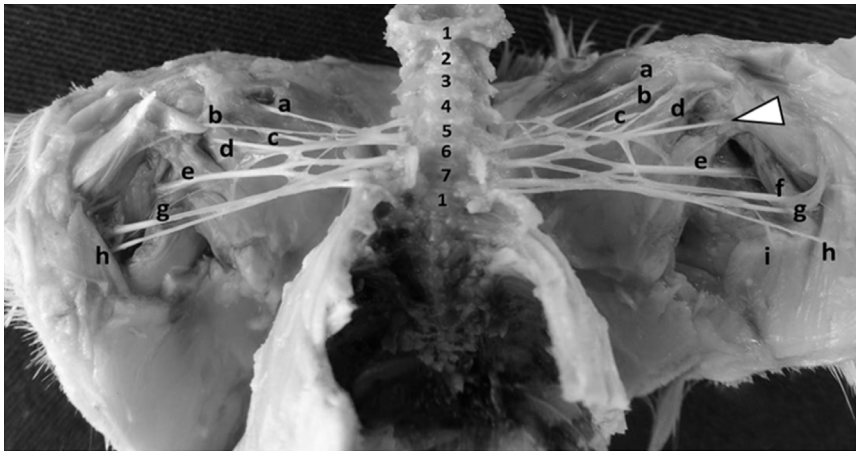

Figure 3. Brachial plexus in the gerbil (C_5–T_1); ventral view. The following nerves can be visualised: suprascapular (a); subscapular (b); axillary (c); musculocutaneous (d); radial (e); median (f); ulnar (g); thoracodorsal (h); lateral thoracic (i); caudal pectoral nerve (arrowhead)

vegicus albinus) and by Fioretto et al. (2003) in capybaras in that it consists of the branches C_4 to T_1. It is also similar to what has been described in mammals such as the monotreme (Miller 1934; Koizumi and Sakai 1997). On the other hand, it differs from that found in the guinea pig (Cooper and Schiller 1975), which consists of the branches C_5 to T_2; in the chinchilla (Gamba et al. 2007) and the nutria (Guimaraes et al. 2013) the brachial plexus consists of C_6 to T_1, and in Spix's yellow-toothed cavies (Araujo Jr et al. 2016) it consists of C_6 to T_2. None of these formations were found in the gerbil. A hypothesis to be considered is based on the idea that this difference may have occurred due to the modification of morphological characteristics over time according to the behaviour of the species, such as ability to hold food with hands or excavation on the ground.

Table 1. Origin of the nerves corresponding to the brachial plexus in the gerbil (*Meriones unguiculatus* Milne-Edwards, 1867), analysed in the right (RA) and left (LA) antimeres

Nerve	Origin	Frequency (%)	
		RA	LA
Suprascapular	C_4–C_5	60	55
	C_4–C_6	20	25
	C_5–C_6	20	20
Subscapular	C_4–C_5	10	10
	C_5–C_6	90	90
Musculocutaneous	C_5–C_6	10	15
	C_5–C_7	90	70
	C_6–C_7	0	15
Axillary	C_5–C_6	30	30
	C_5–C_7	70	70
Cranial pectoral	C_5–C_6	100	100
Caudal pectoral	C_5–C_6	10	10
	C_7–T_1	90	90
Radial	C_6–T_1	20	20
	C_7–C_8	5	10
	C_7–T_1	75	70
Median	C_6–T_1	15	15
	C_7–T_1	85	85
Ulnar	C_7–T_1	85	85
	C_8–T_1	15	15
Thoracodorsal	C_7–T_1	100	100
Lateral thoracic	C_7–T_1	100	100
Long thoracic	C_7–T_1	100	100

The participation of cranial branches in the formation of the brachial plexus in the gerbil through C_4 and C_5, characterises it as a pre-fixed plexus as observed in monkeys from the New World and in *Lagothrix* (Sugiyama 1965; Hill 1972). Parada et al. (1989) suggest that, during the evolutionary process, the origin of the brachial plexus was cranially detached, reaching C_4 in monkeys and C_3 in humans. This observation demonstrates the significance of studies involving the brachial plexus in phylogenetic analyses that establish the evolutionary distances between taxa.

The suprascapular nerve had as its most frequent origin the branches C_4 and C_5, and its nervous territory consists of the supraspinal and infraspinal muscles, differing from that described by Guimaraes et al. (2013) when studying the plexus in the nutria and by Aydin (2003) in the thorn hog where the roots C_5 and C_6 were described. These results also differ from our previous study in Spix's yellow-toothed cavy (Araujo Jr et al. 2016), where we found that it emerges from C_6 and C_7. The C_6 or C_7 branches do not participate in the formation of this nerve in the gerbil.

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For the subscapular and cranial pectoral nerves, the nerve roots C_5 and C_6 innervate the subscapular and deep pectoral muscles, respectively. Scavone et al. (2008) reported in the spotted paca the origin of this nerve only from C_6, while Gamba et al. (2007) in the chinchilla describe the origin in C_6 and C_7, differing from what is observed in the gerbil. The cranial pectoral nerve is similar to that found in rats (Greene 1963), emerging from C_5 and C_6, and it is different in the nutria (Guimaraes et al. 2013), which emerges solely from C_6, in Spix's yellow-toothed cavy (Araujo Jr et al. 2016), in which both nerves are formed by C_6 and C_7 and also in the chinchilla (Gamba et al. 2007) where it is formed only from C_7.

The musculocutaneous and axillary nerves emerge from C_5 to C_7 and they are distributed to the coracobrachial, brachial and biceps brachial muscles, subscapular and deltoid muscles, respectively. In the chinchilla (Gamba et al. 2007), the musculocutaneous and axillary nerves have a common origin in C_6 and C_7, whereas in Spix's yellow-toothed cavy (Araujo Jr et al. 2016), these nerves stem from C_7 and C_8. In both cases, the situation is different in the gerbil. As for the axillary nerve, in the red squirrel (Aydin 2011), it stems from C_5 and C_6; in the rat (Greene 1963), in the chinchilla (Gamba et al. 2007) and in Spix's yellow-toothed cavy (Araujo Jr et al. 2016) it consists of C_6 and C_7, differing from what is observed in the gerbil, since the latter do not have the branches C_5 or C_7.

The caudal pectoral nerve in the gerbil distributes to the superficial pectoral muscles from the branches C_7, C_8 and T_1, in contrast to what has been reported in the literature for rodents. According to Guimaraes et al. (2013), in the nutria the origin consists only of C_6 and in our previous work (Araujo Jr et al. 2016) in Spix's yellow-toothed cavy we found this nerve to originate in the branches C_7 and C_8. Gamba et al. (2007) reported that this nerve stems from C_8 and T_1 in the chinchilla. In rodents, thoracic branches are rarely absent in the formation of this nerve.

As for the radial nerve, the thickest and most important component of the brachial plexus, it consisted of C_7, C_8 and T_1, similar to the chinchilla (Gamba et al. 2007), the spotted paca (Scavone et al. 2008) and the nutria (Guimaraes et al. 2013). On the other hand, this finding differs from the situation in the capybara (Fioretto et al. 2003), in which it consists of the branches C_6 to T_1. Trauma in the radial nerve can cause loss of the autonomic sensitive area of the hand and arm, since it constitutes a greater nerve territory of the brachial plexus, mainly by innervating the anconeus, brachial triceps, brachialis, forearm tensor fasciae and flexor digiti muscles.

The median nerve, in turn, is the second most calibrated nerve, formed by the roots C_7, C_8 and T_1, or also the branch C_6, corroborating what was found in the chinchilla (Gamba et al. 2007) regarding the origin and distribution of this nerve, which innervates the flexor musculature of the carpus and the round pronator muscle. However, Greene (1963), in the rat, and Guimaraes et al. (2013), in the nutria, reported that this nerve emerges from C_8 to T_1, in contrast to what was observed in the gerbil, which is characterised by the absence of the C_7 branch. Our findings also differ from our own earlier findings regarding the brachial plexus in Spix's yellow-toothed cavy (Araujo Jr et al. 2016), where we reported the median nerve to originate from C_7 to T_2. It is noteworthy that, in the gerbil, the median nerve has no participation of T_2.

In relation to the ulnar nerve, its origin consisted in the roots C_7, C_8 and T_1, similar to what was described by Gamba et al. (2007) in the chinchilla and, owing to the absence of C_7, differing from what was reported in the nutria (Guimaraes et al. 2013), in which it emerges from the branches C_8 to T_1. We reported in Spix's yellow-toothed cavy that this nerve is formed by C_8 to T_2 or C_7 to T_2 (Araujo Jr et al. 2016). Despite appearing similar due to the nerve territory, i.e., anconeus, flexor carpi ulnaris and flexor digiti muscles, the formation of this nerve differs in the gerbil due to the absence of T_2.

The thoracodorsal, lateral thoracic and long thoracic nerves had similar origins (C_7, C_8 and T_1) and were responsible for innervation of the large dorsal muscle, cutaneous trunci muscle and the thoracic wall close to the ventral serratus muscle, respectively. In contrast to the thoracodorsal nerve in rats (Greene 1963), this occurs in C_6 and C_7 along with the axillary nerve, while in the chinchilla (Gamba et al. 2007) and the nutria (Guimaraes et al. 2013), they occur only in C_8. In the spotted paca (Scavone et al. 2008) and in Spix's yellow-toothed cavy (Araujo Jr et al. 2016) they originate from C_8 to T_2, while in the spotted paca (Scavone et al. 2008) and in Spix's yellow-toothed cavy (Araujo Jr et al. 2016), they originate from C_8 to T_2.

Fioretto et al. (2008) reported that the lateral thoracic nerve in the capybara is formed by C_7,

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C_8 and T_1, whereas in the chinchilla (Gamba et al. 2007) it is formed only by C_8 and T_1. On the other hand, in the spotted paca (Scavone et al. 2008) and Spix's yellow-toothed cavy (Araujo Jr et al. 2016) this nerve also receives contribution of root T_2 that is formed by C_8–T_2. Neither of these observations applied to the gerbil.

Despite distinct conformations, the long thoracic nerve gives the branches of the last two cervical nerves (C_7 and C_8) in most reports from rodents, as found in the chinchilla (Gamba et al. 2007), spotted paca (Scavone et al. 2008) and Spix's yellow-toothed cavy (Araujo Jr et al. 2016) or with C_6 participation in the case of capybara (Fioretto et al. 2003). In nutria (Guimaraes et al. 2013), this nerve is not described, because the long thoracic nerve is covered by scalene muscle running along the ventral serratus muscle of the thorax where it ends its path or because this region receives contribution from branches of another nerve.

Since the brachial plexus in the gerbil is similar to that observed in humans (Gardner et al. 1975; Costabeber et al. 2010), some authors occasionally report the participation of T_2 in the human brachial plexus (Kerr 1918; Brunelli and Brunelli 1989; Berry et al. 1995). The Mongolian gerbil may be useful as an experimental model in studies on anaesthesia, lesions and nerve degenerations in the brachial plexus, in addition to neuropathies.

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