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Anatomical Study of the Forearm and Hand Nerves of the Domestic Cat (*Felis catus*), Puma (*Puma concolor*) and Jaguar (*Panthera onca*)

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With 4 figures and 1 table

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Summary

The innervation of the forearm and hand regions of cats has not been well described despite its importance for any surgery or any neurological disorder. It is probably the main area where disorders of peripheral nerves in this species are observed. In felines, the forelimbs facilitate the jump and represent the most important way for capturing prey. The main muscles and nerves involved in this activity are located in the region of the forearm and hand. The aim of the present study was to provide a detailed description of the innervation of the forearm and hand regions of the jaguar and puma, in comparison with that of the domestic cat, contributing thus with the anatomical knowledge of the area for applying it to surgery and pathology. The forearms of three pumas and two jaguars (all of them fixed in formalin) and of six domestic cats (fresh) were dissected. The nerves path and their forearm distribution patterns of all three species were described. The analysed results indicate that the observed variations between species are minimal; thus, the anatomy described for domestic cats can be widely applied to American wild felids.

Introduction

In terrestrial mammals, it can be easily seen from the position of the centre of gravity and the consequent weight distribution of the body that the principles of static construction must differ in the two pairs of limbs. When standing still and when in motion, forelimbs carry more of the body weight (55–65%) than do hindlimbs (Carlson et al., 1979). Moreover, cats are carnivores that are able to use their forelimbs extremely skilfully and perform broad strokes (Andersson, 2004). These movements are digging, climbing, grasping prey or other objects, catching objects while hunting or playing and hitting out at opponents (Getty et al., 1982; Nickel et al., 1986; Meachen-Samuels and Van Valkenburgh, 2009).

Pronation and supination movements of felines (80º) are more extensive than in other carnivores, such as dogs (40–45º) (Caliebe et al., 1991; Evans, 1993). The anatomical components (joints, muscles and nerves) involved in this activity are mainly located in the region of the forearm and hand (Concha et al., 2004). Through the careful regulation of weak but complex muscles, cats are able to perform such intricate movements with their forepaws (Done et al., 2010).

The innervation of the forearm and hand regions of cats is widely used as a model for any surgery or neurological disorders (Jubb and Huxtable, 1993; Summers et al., 1995; Bradshaw et al., 2004). Those regions may probably be the areas where disorders of peripheral nerves are observed most in this species (Aubert et al., 2004; Lorenzo Fernandez and Bernardini, 2007). Feline forearm nerves derive from the brachial plexus, which is formed by the ventral rami of the sixth, seventh and eighth cervical nerves and the first thoracic nerve (Ghoshal, 1972; Nickel et al., 1992; Nomina Anatomica Veterinaria (NAV), 2005). Brachial plexus injuries are very common in carnivores. In domestic cats and wild felines, especially in those breeding in captivity such as the jaguar and the

puma, different diseases affecting the brachial plexus were reported, such as laceration, traumatisms or inflammatory disorders (Kornegay, 1991).

In cats, the origin of the brachial plexus shows some anatomical variations (Ghoshal, 1972). However, the fibres of the spinal nerves that contribute to form the forelimb peripheric nerves are constant (Reighard and Jennings, 1966; Done et al., 2010). The knowledge of the anatomical distribution of the motor and cutaneous branches of radial, musculocutaneous, axillary, median and ulnar nerves is essential to understand the clinical signs of nerve diseases in which they are involved.

Patterns of cutaneous sensory loss and motor disorders should be observed and accurately recorded to initiate prompt treatment either surgical or conservative (Nakamura et al., 2004).

Although there is a great difference in body size and behavioural patterns between wild and domestic cats, these species show homologous anatomical architecture. Therefore, the aim of the present study was to provide a detailed description of the innervation of the forearm and hand regions of the jaguar and puma, in comparison with that observed in the domestic cat.

Materials and Methods

Five adult wild felids (three pumas and two jaguars) and six adult domestic cats were used. The pumas and jaguars were donated by the Zoo of La Plata city. The average body weight of one female and two male pumas was 54 kg. Jaguars (one male and one female) averaged 78 kg body weight. The wild felids died or were euthanized because of terminal illness (traumatic or oncological disease) that did not affect limbs. Domestic cats (six males with a body weight ranging 3–4.5 kg) were provided by the necropsy service at the School of Veterinary Sciences. They were euthanized because of cardiac or tumour conditions that did not affect limbs.

Pumas and jaguars were perfused via carotid artery with a 10% solution of buffered formalin. Fixed animals were placed in supine position. Domestic cats were dissected in fresh and then preserved in cold chamber.

Incision was made in the ventral midline of the neck, from the thyroid cartilage of the larynx to the sternum xiphoid. Another incision was made perpendicular to former, from the sternum to the radio-humeral medial arm. After removing the skin and subcutaneous tissue, superficial and deep pectoral muscles were cross-sectioned near the sternum. Finally, nerves of the brachial plexus were exposed and identified.

In all specimens, forelimbs were dissected to compare their course and distribution in each species. Nerves dissected by planes were photographed with a digital camera (Sony Cyber-Shot DSC-P10; Sony Corporation, NY, USA). Captured images were then processed using a commercial editing and processing image software (Adobe Photoshop CS; Adobe System Incorporated, San José, CA, USA).

Results

No differences were observed in the nerve arborization between individuals of the same species. Therefore, observations of this study suggest an anatomical general pattern for puma, jaguar and domestic cats.

In domestic cat and puma, the musculocutaneous nerve passes down the medial region of the arm between the biceps brachii and brachial artery and innervates the coracobrachialis, biceps brachii and brachialis (Table 1). Reaching the elbow region, the musculocutaneous nerve generated a communicating branch to the median nerve. It then continues down the forearm as medial cutaneous antebrachial nerve and divides into a medial and an intermediate branch. In the jaguar, the medial branch continues distally to innervate the finger I and join the medial branch of the radial nerve (Figs 1b and 4b). The

Table 1. Distribution of motor and sensory innervation in the forelimb of the domestic cat

Nerve	Motor innervation	Sensory innervation
Musculocutaneous	Coracobrachialis, biceps brachii and brachialis	Medial skin of the forearm, carpus and metacarpus
Axillary	Teres major, subscapularis (caudal border), deltoideus, teres minor	Skin of the forearm cranial
Radial	Triceps brachii, anconeus, tensor fasciae antebrachii, extensor carpi radialis, extensor digitorum communis, extensor digitorum lateralis, extensor carpi ulnaris, brachioradialis, supinator, abductor pollicis longus, extensor digiti I, extensor digiti II	Craniolateral skin of the forearm and dorsal aspect of the hand
Median	Flexor carpi radialis, flexor digitorum superficialis, flexor digitorum profundus, pronator teres, pronator quadratus, interflexorius	Skin of the palmar of the hand
Ulnar	Flexor carpi ulnaris, abductor digiti V, flexor digiti V, adductor digiti V, abductor digiti I (pollicis) brevis, flexor digiti I (pollicis) brevis, adductor digiti II, interossei and lumbricales	Skin of the caudal region of the forearm and dorsal and palmar regions of the hand

Fig. 1. (a) Dorsal view of the hand of the Jaguar. 1- Dorsal branch of the ulnar nerve. 2- Lateral branch for finger III, from the superficial branch of radial nerve. (b) Medial view of the hand of the Jaguar. 1- Medial branch of the medial antebrachial cutaneous nerve to finger I, from the musculocutaneous nerve. 2- Lateral branch from the superficial branch of radial nerve. 3- Medial branch from the superficial branch of radial nerve. (c) Medial view of arm and forearm of Jaguar. The foramen supracondylar of the humerus is observed. 1- Median nerve. 2- Brachial artery. 3- Brachial vein. (d) Medial view of the hand of the Jaguar. 1- Medial branch of medial antebrachial cutaneous nerve to finger I, from the musculocutaneous nerve.Bar = 2 cm.

intermediate cutaneous branch, just as described for the domestic cat, is distributed in the skin of the medial and caudal region of the forearm to the carpus (Fig. 2b).

The axillary nerve of all feline species innervates some of the flexor muscles of the shoulder, and then, it continues as cranial cutaneous antebrachial nerve to distribute branches to the skin of the cranial region of the forearm. This nerve terminates in the dorsal carpal region, joining the medial branch of the radial nerve (Fig. 3b).

The radial nerve of domestic and wild felids is divided into a superficial and a deep branch in the lateral and distal third of the arm region (Fig. 2a). The superficial branch is directed distally to the cranial surface of the forearm and a thick fascia surrounds it. This branch perforates the heavy fascia and splits immediately into a larger lateral branch (ramus lateralis) and a smaller medial branch (ramus medialis). These branches continue to the carpus in relation to the lateral and medial branches of the cranial superficial antebrachial artery. Thus, they closely flank the medial and lateral side of the cephalic vein as they transverse the antebrachium. The lateral cutaneous antebrachial nerve arises from the lateral branch of the superficial portion of the radial nerve. It innervates a variable cutaneous area around and distal to the lateral epicondyle of the humerus. In the domestic cat, the medial branch gives rise to a narrow abaxial dorsal proper digital nerve I while the lateral branch provides the dorsal proper digital nerves to fingers II and III (Fig. 4a). In the jaguar, the medial branch gives rise to the dorsal proper digital nerves for finger II while the lateral branch only supplies the dorsal digital proper nerves for finger III (Figs 1a and 4b). In the puma, the distribution of the medial branch of the radial nerve is similar to that of the cat (Fig. 3b). However, this branch receives anastomotic fibres from the musculocutaneous nerve and then continues to innervate finger I (dorsal proper digital nerves I), resembling the anatomical distribution observed in the jaguar (Fig. 1d).

The deep branch of radial nerve did not show differences among species. It descends caudal to the superficial branch, between long and short heads of the muscle extensor carpi radialis and brachioradialis, to reach the extensor carpi and fingers to which it innervates.

In the wild felids, the median nerve passes through the supracondylar foramen of the humerus together with the brachial artery and vein (Fig. 1c). It descends in the forearm, giving rise to the forearm interosseous nerve that innervates the pronator quadratus muscle and the periosteum, to end in motor branches for the caudal region muscles (Table 1). The median nerve of the domestic cat passes through the supracondylar foramen accompanied only by the brachial artery. The satellite vein follows the same route but outside the foramen. On the other hand, the forearm interosseous nerve is a small branch that innervates the regional periosteum.

The median nerve continues through the carpal tunnel, and it is divided into a medial and lateral branch ending up as palmar dorsal proper digital nerves. The medial branch is short, and it splits into dorsal proper digital nerves I and II. The lateral branch is bigger than the former, and it is distributed on dorsal proper digital nerves II and III and giving also a communicating branch to the ulnar nerve to end in finger IV of the domestic cat (Fig. 4a). However, in wild felids, the median nerve does not emit a communicating branch to the ulnar nerve, and thus, it is not associated with the finger IV innervation (Fig. 4b,c).

In the distal arm, the ulnar nerve of all the studied felines is observed as a trunk separated from the median nerve. At this point, the nerve gives rise to the caudal cutaneous antebrachial nerve, and it runs between both

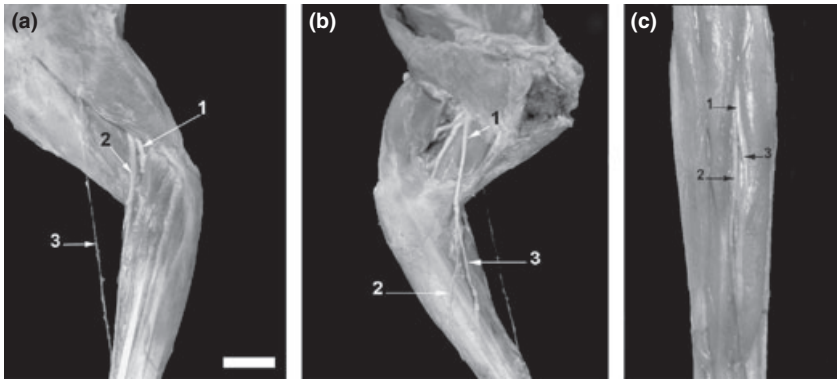

Fig. 2. (a) Side view of arm and forearm of the domestic cat. The division of the radial nerve can be observed. 1- Deep branch. 2- Superficial branch 3- Cephalic vein. (b) Medial view of arm and forearm of the domestic cat. The Musculocutaneous nerve division is observed. 1- Medial antebrachial cutaneous nerve. 2- Intermediate Branch. 3- Medial Branch. (c) Caudal view of the forearm of the domestic cat. The division of the ulnar nerve is observed. 1- Ulnar nerve. 2- Dorsal branch. 3- Palmar branch. Bar = for A and B = 1 cm; for C = 0.8 cm.

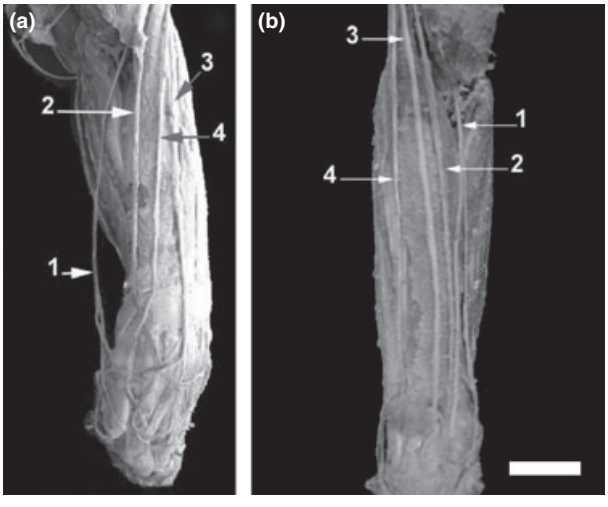

Fig. 3. (a) Medial view of the forearm and hand of the Puma. 1- Medial Branch of the medial antebrachial cutaneous nerve to finger I, from the Musculocutaneous nerve. 2- Cephalic Vein. 3- Lateral branch from the superficial branch of radial nerve. 4- Medial branch from the superficial branch of radial nerve. (b) Cranial view of the forearm of Puma. 1- Cranial antebrachial cutaneous nerve, from the axillary nerve. 2- Cephalic vein. 3- Medial branch from the superficial branch of radial nerve. 4- Lateral branch from the superficial branch of radial nerve. Bar = 2 cm.

heads of the flexor carpi ulnaris muscle. In the proximal third of the forearm, the ulnar nerve divides into a dorsal and palmar branch (Fig. 2c). The dorsal branch communicates with the lateral branch of the radial nerve superficial branch (lateral cutaneous antebrachial nerve) and innervates the dorsal region of fingers IV and V (dorsal proper digital nerves IV and V) (Fig. 4a). On the other hand, the palmar branch is divided into a superficial branch and a deep branch. In wild felids, the superficial branch innervates fingers IV (abaxial palmar proper digital nerve IV) and V (palmar proper digital nerve V) (Fig. 4b,c). In domestic cats, finger IV (axial and abaxial palmar proper digital nerve IV) is also innervated by the median nerve, while the deep branch innervates the small muscles of the hand (Table 1).

Discussion

The present study is the first morphological report on the jaguar and puma forearm and hand regions, which describes changes that may affect the distribution of cutaneous and motor innervation. These details are necessary for clinical (diagnostic and prognostic) and experimental purposes (Ghoshal and Getty, 1968; Corrêa Guimarães et al., 2007).

Several aspects of the ecology, reproduction and nutritional patterns of wild felids such as puma (*Puma concolor*) and jaguar (*Panthera onca*) are currently known. However, most features of their anatomy studied until now are very general. Moreover, there is a growing dilemma to obtain fresh cadaveric material to study protected felines of South America and frequently homologies with domestic cats are preferred (Concha et al., 2004). Therefore, the aim of the present study was to provide knowledge about the peripheral nerves of the forearm and hand regions of these native cats and compare them with those of domestic cats to determine whether homology of muscles and main route of the nerves can be established.

In general, the studied region showed a considerable homology between domestic and wild felids. Skin areas of the axillary, radial, musculocutaneous and ulnar nerves overlap extensively in the antebrachium as other authors describe in the domestic cat (Ghoshal, 1972; König and Liebich, 2004).

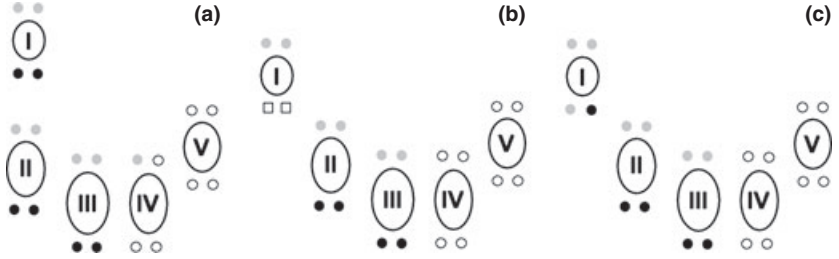

Fig. 4. Schematic representation of the right hand region, palmar view, showing the distribution of nerves for each finger. (a) Domestic cat. (b) Jaguar. (c) Puma. (●) Radial nerve, (○) Ulnar nerve, (◍) Median nerve, (□) Musculocutaneous nerve.

The main differences observed between species were found in the distribution of the superficial branch of the radial nerve at the level of the hand and its distribution for each of the fingers. Thus, in the puma, unlike in the jaguar, the distribution of the medial branch of the radial nerve is similar to that of domestic cats (Ewer, 1973; NAV, 2005). We also found some differences in the distribution of the medial antebrachial cutaneous nerve from the musculocutaneous nerve in the jaguar in comparison with the other species studied. Several authors described this nerve ending in the carpus region of domestic cats (Reighard and Jennings, 1966; Ghoshal, 1972) while others described its ending at the metacarpal region (Schaller, 1996). Our dissections showed that in domestic cats and puma, the medial antebrachial cutaneous nerve ends in the distal carpal region while in the jaguar, it is extended to the first finger.

In wild felids, we observed the median nerve accompanied by the brachial artery and vein when passing through the supracondylar foramen of the humerus, while in domestic cats, it is described a separation of the vein at that point (Shively, 1993; Dyce et al., 1999, 2007). On the other side, in wild felids, unlike to what is seen in domestic cats, the forearm interosseous nerve is a thick branch to the pronator quadratus muscle and the periosteum (Nickel et al., 1992; NAV, 2005).

The observed results indicate that variations in the course of nerves in the forearm and hand of the puma and jaguar are minimal compared with domestic cats (Ghoshal, 1972; Hudson and Hamilton, 1993; Aubert et al., 2004; Done et al., 2010).

While the number of studied wild felids is not appropriate to make a statistical analysis, the fact that no anatomical differences were found between all the individuals of the same species may suggest that the results could be extended to all animals of the same species.

For this reason, most of the surgical techniques and clinical examination of forearm and hand structures can be minimally modified when applied to wild felids. Knowledge about the anatomical and histological organization of the puma and jaguar provide data that will be complemented by ethological studies, to improve the conservation of these species.

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