

Original paper

Comparative anatomy of the brachial plexus in Coypu (*Myocastor coypus*; Rodentia)

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Abstract: This study reports the morphology of the brachial plexus in the coypu (*Myocastor coypus*) of the suborder Hystricomorpha, Rodentia, for which no detailed description has been reported. In addition, the morphology of the brachial plexus of the coypu is compared with that of other species in Hystricomorpha. The brachial plexus of the coypu comprises the 5th cervical nerve (C5) to the 1st thoracic nerve (T1), resembling the morphology of the chinchilla, which is the species most closely related to the coypu among the rodents compared here. The present results suggest that two morphological character of the brachial plexus can be successfully used to group Hystricomorpha: 1) the presence or absence of trunks and 2) the presence or absence of the union of the median and ulnar nerves.

I. Introduction

The morphology of peripheral nerves reflects the phylogeny of a species; therefore, peripheral nerve morphology is useful for phylogenetical analysis (Backus et al. 2015). In particular, many studies have analyzed the branching patterns of the brachial plexus (e.g. Miller 1934), and comparisons among Carnivora, Artiodactyla, and Perissodactyla have revealed that classification based on the branching patterns of the brachial plexus is practicable at the order level (Backus et al. 2015). Also, if provided with full grasp of variations within families, the morphology of the brachial plexus has been suggested to be useful in phylogenetic analysis at the family level (Backus et al. 2015).

The order Rodentia is subdivided into suborders Sciuromorpha, Myomorpha, and Hystricomorpha (Simpson 1945, Wilson and Reeder 2005). In particular, Hystricomorpha is reported to contain characteristics that the absent in the other suborders in musculus cutaneus maximus and muscles around the shoulder, which are innervated by the brachial plexus (Wood and White 1950, Woods 1972, Woods and Howland 1977). A change in the amount of muscle induces complications or simplifications of nerve branching and a change in the number of constituent components (Miller 1934). Therefore, Hystoricomorpha containing muscles absent in the other suborders may be characterized by a peculiar morphology of the brachial plexus. However, there have only been small number of morphological studies of the brachial plexus in Hystricomorpha. Phylogenetic analysis of the morphology of the brachial plexus remains unfeasible as only a few common characteristics have been identified.

The coypu (*Myocastor coypus*) has been relatively recently reclassified to an independent family within Hystricomorpha (e.g. Honeycutt 2009). Myocastoridae comprises 1 genus, Myocastor, comprising only one species, namely Myocastor and coypu, respectively. The coypu is a taxonomically unique species. A morphological description of the brachial plexus of the coypu has been attempted by Langenfeld (1972). However, his study focused on only the musculocutaneous and axillary nerves. For phylogenetic analysis, partial descriptions of some peripheral nerves are insufficient as a description of all nerves in the brachial plexus as a whole is required. Within this context, the present study attempts to clarify the overall morphology of the brachial plexus of the coypu.

II. Materials and Method

Four of the coypu specimens (*M. coypus*) stored at the Okayama University of Science (OUS) Zoology Department (OUS-LCA 74, 302, 311, 323; all wild-born and captured during pest control in Okayama Prefecture) were dissected after fixation with 10% formalin.

The description of the muscles follows the nomenclature adopted by Woods (1972) and Woods and Howland (1977), and the nomenclature of

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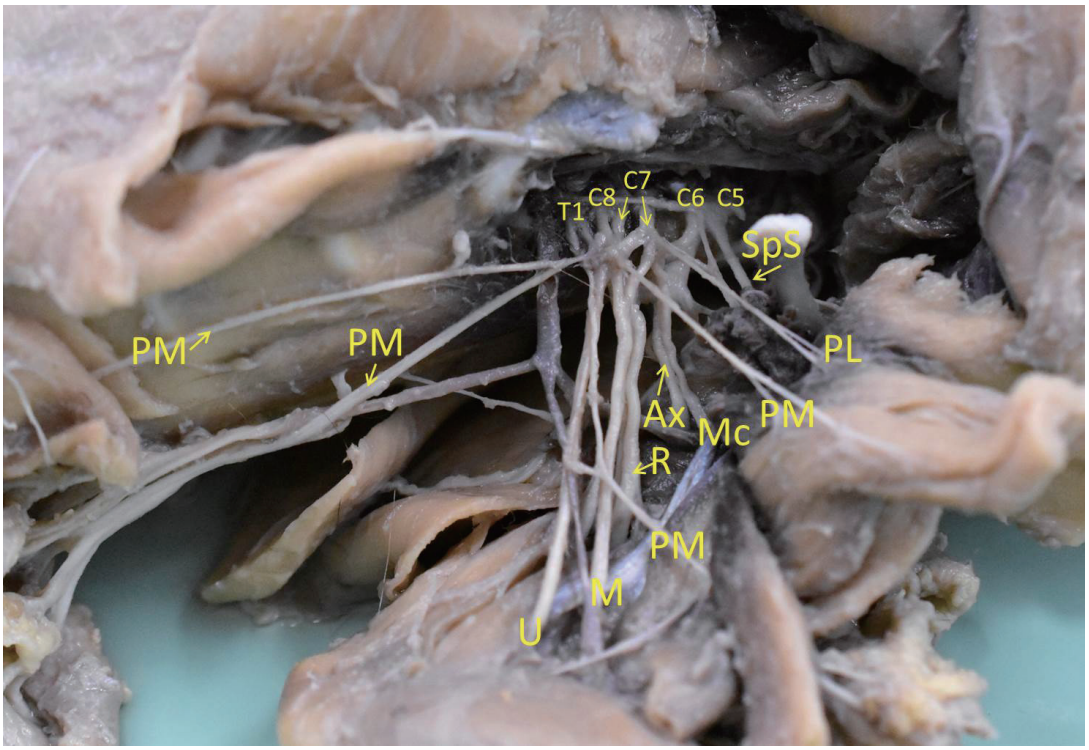

Fig. 1. Ventral view in photo of the left brachial plexus in the coypu (*Myocastor coypus*) (OUS-LCA 323). SpS, N. suprascaplaris; PL, N. pectoralis lateralis; PM, N. pectoralis medialis; Ax, N. axillaris; Mc, N. musculoctaneus; R, N. radialis; M, N. medianus; U, N. ulnalis.

the nerves by Greene (1963). The taxonomy of Rodentia follows Fabre et al. (2015), and the molecular estimation of phylogeny follows Honeycutt (2009). The Latin nouns for muscles (musculus), nerve (nervus), and nerves (nervi) are abbreviated as M., N., and Nn., respectively, where they cause no confusion.

III. Results

Plexus brachialis (Figs. 1, 2 and 3) of the coypu is composed of the 5th cervical nerve (C5) to the 1st thoracic nerve (T1).

Nervus dorsalis scapulae (Fig. 2, DS) is composed of only C5, inserted to the rhomboid muscle without crossing any other nerve branches.

Nervus suprascapularis (Figs. 1, 2 and 3, SpS) is composed of C5 and C6, united and then branching along with Nn. subscapulares. N. suprascapularis bifurcates into divisions inserted in M. supraspinatus and M. infraspinatus. The latter division passes between the scapula and the spine of scapula.

Nervi subscapulares (Fig. 2 and 3, SbS) are composed of C5, C6, and C7. The division formed by fusion of C5 and C6, and the dorsal rami of C7, though mainly C6, unite to form Nn. subscapulares. Nn. subscapulares have 3 divisions, namely 2 innervate M. subscapularis, and one M. teres major.

Nervus subclavius (Figs. 2 and 3, SbC) is composed of C6 and C7. The ventral rami of C6 and C7 unite to form N. subclavius, which branches distally to innervate M. subclavius. Further distally, the division innervating M. scapuloclavicularis bifurcates.

M. scapuloclavicularis, which originates on the clavicle and terminates on the spine of the scapula, is unique to Hystricomorpha (Wood and White 1950, Woods 1972). Parsons (1894) reported that this muscle is innervated by N. subclavius.

Langenfeld (1972) reported that N. subclavius innervates M. teres major in the coypu, though not confirmed with the specimens used here.

Nervus thoracicus longus (Figs. 2 and 3, TL) is formed by the union of the divisions from the dorsal rami of C6, C7, C8, and T1. It is inserted distally to M. serratus anterior without crossing any other division.

Nervus thoracodorsalis (Fig. 2, TD) is formed by the union of the dorsal rami of C7. It is inserted distally to M. latissimus dorsi without crossing any other division.

Nervus pectoralis lateralis (Figs. 1 and 3, PL) emerges singly out of C7. It branches off from the ventral rami of C7, and distally innervates M. pectoralis superficialis.

Nervus pectoralis medialis (Figs. 1 and 3, PM) is composed of C8 and T1. C8 and the cranial part of T1 meet at the fusion point to be trifurcat-

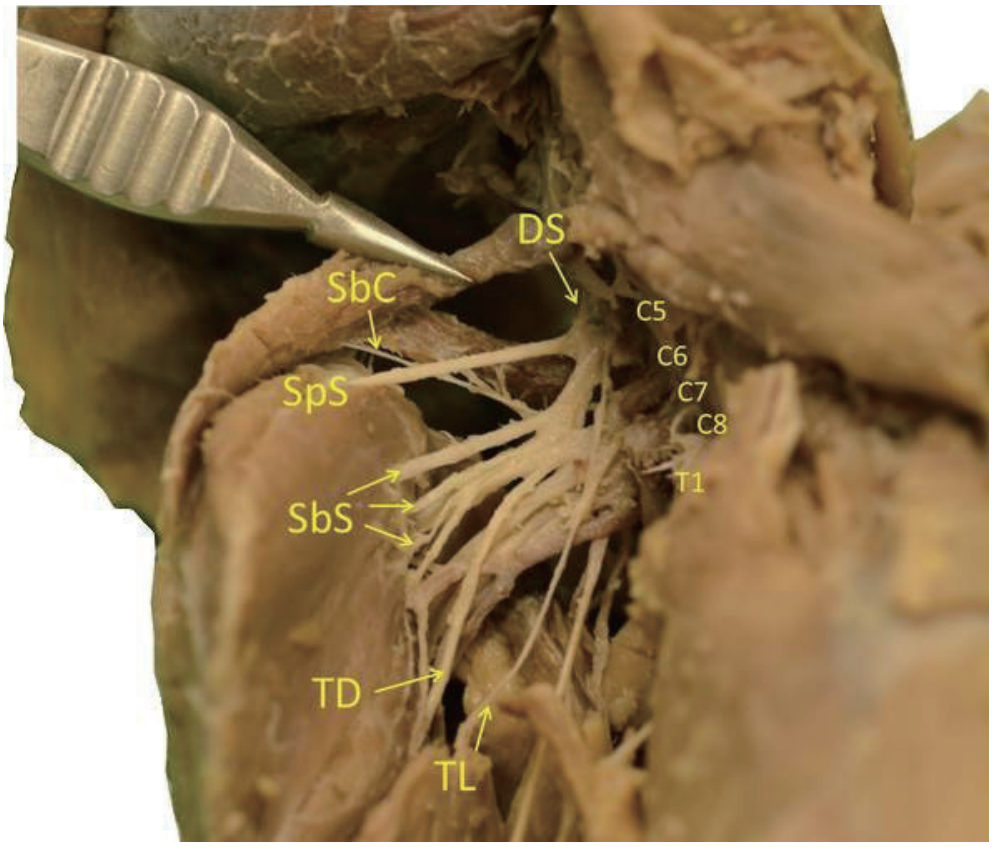

Fig. 2. Dorsal view in photo of the left brachial plexus in the coypu (*Myocastor coypus*) (OUS-LCA 311). DS, N. dosalis scapulae; SbS, Nn. subscaplaris; SbC, N. subclavius; TL, N. thoracicus longus; TD, N. thoracodorsalis.

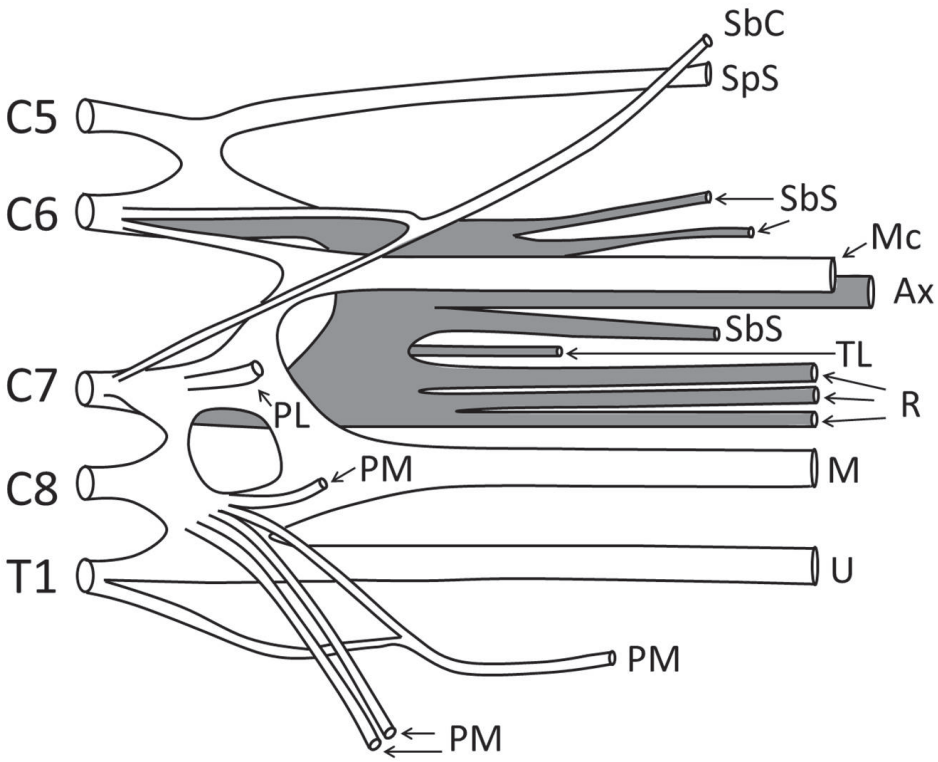

Fig. 3. Ventral view in drawing of the left brachial plexus in the coypu (*Myocastor coypus*).

ed. One of the 3 branches innervates M. pectoralis major. The other 2 branches run in parallel for some distance, and one innervates M. pectoralis abdominalis and M. cutaneus maximus, Pars ventrale. The remaining branch innervates M. pectoralis minor, M. scalenus, and M. cutaneus maximus, Pars ventrale.

In addition, the division from C8 and the cranial part of T1 arising from the fusion, and the nerve formed out of the caudal part of T1 are part of N. pectoralis medialis. N. pectoralis medialis is inserted to M. cutaneus maximus, Pars ventrale.

Nervus musculocutaneus (Figs. 1 and 3, Mc) is composed of C6 and C7. The ventral rami of C6 and C7 unite to form N. musculocutaneous. First, the divisions to M. coracobrachialis, to M. brachialis, and into M. coracobrachialis are separated. The division passing deep through M. coracobrachialis further bifurcates distally into one inserted to M. biceps brachii and the other to the lateral side of forearm. There are 2 nerve divisions inserted to M. biceps brachii. The division extended to the lateral side of the forearm runs deep through the M. triceps brachii, Caput longus, and, posterior to the emerging point under the skin, which is inserted in the lateral epidermis of the forearm.

Nervus axillaris (Figs. 1 and 3, Ax) is composed of C6 and C7. The dorsal rami of C6 and C7, though mainly the former, unite to form the axillary nerve. From this position, the nerve branches out to innervate the deltoid and M. teres minor, between the M. spinodeltoideus, the M. triceps brachii, Caput longum and Caput laterale. Emerging out of these 3 muscles, it further bifurcates into one inserted in M. cutaneus maximus, Pars ventrale and the other piercing through the cutaneus muscle, to emerge under the lateral skin of brachium.

Nervus radialis (Figs. 1 and 3, R) is composed of C6 and C7. The dorsal rami of C6 and C7, though mainly the latter, unite to form the radial nerve. The formed N. radialis bifurcates. One division further bifurcates into two, one of which, between the M. triceps brachii, Caput longum and Caput laterale, innervates M. dorsoepitrochlearis, M. anconeus, and M. triceps brachii. The other division trifurcates posterior to its passage between M. biceps brachii and M. triceps brachii, Caput laterale. One passes through M. extensor carpi radialis longus to emerge under the dorsal skin of the forearm, and is inserted to the dorsal epidermis of the 1st and 2nd digits. The 2nd division further bifurcates into the one inserted in M. extensor carpi radialis longus and M. extensor carpi radialis brevis, and, passing under the dorsal skin of the forearm, inserted to the dorsal epidermis of the 2nd and 3rd digits, and the other inserted to M. cutaneus maximus, Pars ventrale. The 3rd division forks into one inserted to M. supinator, and those passing through M. supinator to innervate M. extensor digitorum, M. extensor digiti minimi, M. abductor pollicis longus, and M. extensor carpi ulnaris.

Among mammals in general, N. radialis also innervates M. brachioradialis. However, this muscle is reported to be missing in Hystricomorpha including the coypu, except the Canadian porcupine (*Erethizon dorsatum*) (Woods 1972). This study also has confirmed the absence of M. brachioradialis in the coypu specimens studied here.

Nervus medianus (Figs. 1 and 3, M) is composed of C7, C8, and T1. The division formed in union of C8 and T1 again unites with the ventral rami of C7, though mainly C8, to form N. medianus. N. medianus divides proximal to the lesser tuberosity of the humerus. N. medianus divisions further fork into 4 subdivisions innervating, M. flexor digitorum superficialis, M. flexor digitorum profundus, M. pronator teres, and M. flexor carpi radialis, respectively and an additional one extended to the forearm. The division extended to the forearm, at 1/4 proximate on the forearm, bifurcates into one inserted to M. pronator quadratus and the other to the muscles of the manus. The division innervating M. pronator quadratus passes between the ulna and the radius. The division innervating the muscles of the manus passes deep through M. flexor carpi radialis, and emerges under the ventral skin of the forearm.

Nervus ulnaris (Figs. 1 and 3, U) is composed of C8 and T1. C8 and T1, though mainly the latter, unite to form N. ulnaris. Around the lesser tuberosity of the humerus, N. ulnaris extends the divisions innervating M. palmaris longus, M. flexor carpi ulnaris, M. flexor digitorum profundus, M. epitrochleoanconeus, epidermis of the digitus quintus, and the muscles of the manus. The division innervating the epidermis of the digitus quintus passes through the deep layer of M. flexor carpi ulnaris, and emerges under the dorsal skin of the forearm. The division inserted to the muscles of the manus passes through the deep layer of M. palmaris longus.

Although M. palmaris longus is innervated by N. medianus in mammals in general, Woods (1972) reported that M. palmaris longus is innervated by N. ulnaris in Hystricomorpha. Innervation by N. ulnaris of M. palmaris longus has also been confirmed in the coypu specimens studied here.

IV. Discussion

In suborder Hystricomorpha, excluding the coypu (*M. coypus*), the morphology of the brachial plexus has been reported for *Hystrix cristata* (North African crested porcupine) (Aydin 2003), *Erethizon dorsatum* (Canadian porcupine; sharing infraorder Hystricognath with the coypu) (Palmer 1933), and *Chinchilla lanigera* (chinchilla; Hystricognath) (Çevik-Demirkan et al. 2007). Among the species compared in the present study, the brachial plexus differed in various characters such as the components of roots, conformation of trunks, positioning of ventral and dorsal divisions. In addition, the morphologies of N. medianus and N. ulnaris differed among species compared. Cords were not formed in the species examined the present study.

1. Components of roots of the brachial plexus

The brachial plexus of the coypu is composed of C5-T1. In the North African crested porcupine, the brachial plexus is composed of C5-T2 (Aydin 2003). The brachial plexus of the Canadian porcupine is composed of C6-C8 (Palmer 1933). The brachial plexus of the chinchilla is composed of C5-T2 (Çevik-Demirkan et al. 2007). It is evident that the aforementioned species share no common characteristics in the components of the brachial plexus.

2. Conformation of trunks

The brachial plexuses of both the North African crested porcupine (Aydin 2003) and the Canadian porcupine (Palmer 1933) contain cranial and caudal trunks. In the North African crested porcupine, the components in the caudal trunk are reported to be greater than those of the cranial trunk (Aydin 2003). In addition, in both species, the two trunks are linked with a connective branch. However, in the North African crested porcupine, the cranial and caudal trunks divide, bordering at C6 and C7 (Aydin 2003), while the border between the cranial and caudal trunks lies at C7 and C8 in the Canadian porcupine (Palmer 1933).

The brachial plexuses of both the coypu and the chinchilla form no trunk (Çevik-Demirkan et al. 2007). The nerves of the brachial plexus of the coypu unite immediately after branching off the rami. The same morphology has also been reported for the chinchilla (Çevik-Demirkan et al. 2007). However, in the brachial plexus of the coypu, as only C6 and C7 unite farther distally than the other unions, it appears as if the brachial plexus is branched into the cranial and caudal trunks. In reality, the C6 and C7 of the brachial plexus of the coypu directly unite, differing in morphology from those of the North African crested porcupine and the Canadian porcupine.

3. Positioning of the ventral and dorsal divisions

Photos of the North African crested porcupine ("Figures 1 and 2", Aydin 2003) and an illustration of the Canadian porcupine ("Plate XXXIII, Fig. 2", Palmer 1933) show that the dorsal divisions are not clearly separated.

In the coypu (present study) and the chinchilla (Çevik-Demirkan et al. 2007), in comparison with the other 2 species, the separation between the ventral and dorsal divisions is recognizable.

In general, for elucidating the positioning of the ventral and dorsal divisions, it is necessary to scrutinize criteria for the dorsal and ventral distinction and information on their positional relationships (Yoshitomi et al. 2004). Unfortunately, however, some studies cited in the present study do not provide sufficient information necessary for scrutinization. Therefore, no conclusive discussion can be held in regard to the differences in the positioning of the ventral and dorsal divisions.

4. Morphologies of the nervus medianus and nervus ulnaris

Besides in the components of brachial plexus, this study revealed differences in the morphology of N. medianus and N. ulnaris.

The photos of the North African crested porcupine (Aydin 2003) and the illustration of the Canadian porcupine (Palmer 1933) show that the N. medianus and N. ulnaris remain united farther distally in comparison with other nerves. Finally, the connected N. medianus and N. ulnaris divide into N. medianus and N. ulnaris, respectively.

In a photo of the chinchilla ("Fig. 1: A, B", Çevik-Demirkan et al. 2007), the N. medianus and N. ulnaris are separately formed without any union as in the coypu. This is the same morphology as described for humans (Standring 2016).

In summary, the above results indicate that the chinchilla's brachial plexus is the closest to that of the coypu. The chinchilla is the species taxonomically closest to the coypu among the species compared here. In other words, the results presented here agree with the phylogeny and taxonomy presented by Honeycutt (2009) and Fabre et al. (2015).

The present study suggests that at least 2 characters of the brachial plexus enable grouping of Hystricomorpha. One character is the presence or absence of the trunks, and the other is the presence or absence of the union of N. medianus and N. ulnaris. As to the morphology of trunks, some species are sortable by the separtion of the

cranial and caudal trunks, but the border between the cranial and caudal trunks varies between species. Therefore, only the presence or absence of trunks is regarded as a stable criterion usable as a taxonomic character.

V. Acknowledgements

During the course of this study, Prof. M. Natori at the Zoology Department in Okayama University of Science (ZOUS) provided guidance, encouragement, and support. Seminar mates at ZOUS Laboratory of Comparative Anatomy provided advices. Prof. H. Takasaki at ZOUS provided help in drafting the English translation of the manuscript. For the acquisition of the specimens used in the study, Mr. H. Higa (graduate student at ZOUS Laboratory of Natural History) and Prof. S. Kobayashi at ZOUS provided help. I am grateful to these people and institutions.

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竹谷麻里：ヌートリア（*Myocastor coypus*）における腕神経叢の比較解剖学的研究

摘要：本研究では，ヤマアラシ亜目ヌートリア（*Myocastor coypus*）を用いて，これまで詳細な記載がなされていない腕神経叢の形態について報告する．加えて，先行研究において，すでに腕神経叢の形態が明らかにされているヤマアラシ亜目の種と比較する．ヌートリアの腕神経叢は第５頚神経（C５）から第１胸神経（T１）までで構成されていた．ヌートリアの腕神経叢の形態はチンチラに類似していた．チンチラは，今回比較した齧歯目のなかで最もヌートリアと近縁である．また，今回の結果から，ヤマアラシ亜目の腕神経叢は少なくとも２つの形質でグループ分けできることが示唆された．１つ目は神経幹の有無，２つ目は正中神経・尺骨神経の吻合がみられるかどうかである．

(Accepted 28 November 2016)