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The nerve supply to coracobrachialis in apes

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ABSTRACT

The origin of the nerve supply to coracobrachialis from the brachial plexus in apes was investigated in 4 arms from 4 chimpanzees, both arms of a gorilla and 4 arms from 4 gibbons. The general architecture of the brachial plexus was the same as in the human. In the apes examined, the nerves supplying this muscle could be classified into 2 groups: (1) distal branches arising from the musculocutaneous nerve, and (2) proximal branches arising in the region of the lateral cord. On the basis of their origin and course, the proximal branches were classified into 3 types, namely a deep ramus arising from the middle trunk and passing dorsal to the upper trunk, a medial ramus arising from the upper trunk in the lateral cord, and a superficial ramus arising from the ventral surface of the middle trunk or the root of the pectoral nerve. This classification also applies to branches to coracobrachialis in man. The 3 types of proximal branch often communicated with each other to supply coracobrachialis, whereas the proximal and distal branches were separated from each other spatially. This indicates that coracobrachialis possesses characteristics both of the pectoral girdle muscles and the flexor muscles of the upper arm.

Key words: Primates; brachial plexus; skeletal muscle.

INTRODUCTION

During the changes in locomotion pattern from reptiles to mammals, the coracoid regressed into the coracoid process of the scapula (Klima, 1968, 1987, Starck, 1979) and the adductor shoulder muscles arising from the coracoid became greatly reduced into the coracobrachialis muscle (Romer & Parsons, 1977; Starck, 1979). Coracobrachialis in mammals originates from the coracoid process of the scapula and varies considerably in its insertion (Wood, 1867; Parsons, 1898). It inserts onto different parts of the humerus in the region between the medial epicondyle and the surgical neck and sometimes splits into 2 or 3 muscular slips having different insertions. In apes, some authors (Kohlbrügge, 1897; Sommer, 1907) reported that coracobrachialis is divided into 2 separate parts, whereas in man it is not. A study of the interspecific differences in coracobrachialis may thus be helpful in clarifying the evolution of the shoulder girdle muscles.

Using a technique for the precise analysis of innervation by peeling off the epineurium and tracing fasciculi (Homma & Sakai, 1991), Koizumi (1989) showed that the human and prosimian coracobrachialis constantly receives accessory branches that arise from the region of the lateral cord of the brachial plexus in addition to those from the musculocutaneous nerve. The precise innervation of coracobrachialis was not studied in other species of mammals. In this study, we have examined the anatomy of coracobrachialis in apes and the precise pattern of its innervation to elucidate the extent of interspecific variation. The morphological significance of coracobrachialis is discussed on the basis of the organization of the brachial plexus and the branching pattern of the branches from the plexus that reach this muscle.

MATERIALS AND METHODS

Four upper limbs from 4 chimpanzees, both from a gorilla and 4 from 4 gibbons were examined in this study. The details of each animal are shown in the

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Table. *Material examined*

Species	No.*	Side	Sex
Chimpanzee	8303	Right	?
(*Pan troglodytes*)	8304	Right	F
	8404	Right	?
	8405	Left	F
Gorilla	8407	Right	F
(*Gorilla gorilla*)	8407	Left	F
Gibbon			
Agile gibbon	8301	Right	M
(*Hylobates agilis*)	8302	Right	F
	8402	Right	F
Siamang	8403	Left	M
(*Hylobates syndactylus*)			

* All adult.

Table. All were obtained from the Primate Research Institute of Kyoto University in Inuyama, Aichi.

After exposing the brachial plexus, the spinal roots contributing to the plexus and related vessels were identified and separated from the body. The soft tissues of the upper arm surrounding the humerus were then removed to obtain the muscle-nerve specimens of the upper arm. In addition, the nerves to coracobrachialis were analysed under a stereomicroscope by stripping off their epineurium (nerve fascicle analysis). If necessary, the perineurium was also removed. In the chimpanzees, the intramuscular distribution of the nerves to coracobrachialis was also studied. In the Discussion reference is also made to the 24 human arms which were studied by Koizumi (1989).

RESULTS

Observations on the brachial plexus

The brachial plexus in the 3 species of apes was made up of 3 trunks: the upper trunk comprised the 5th

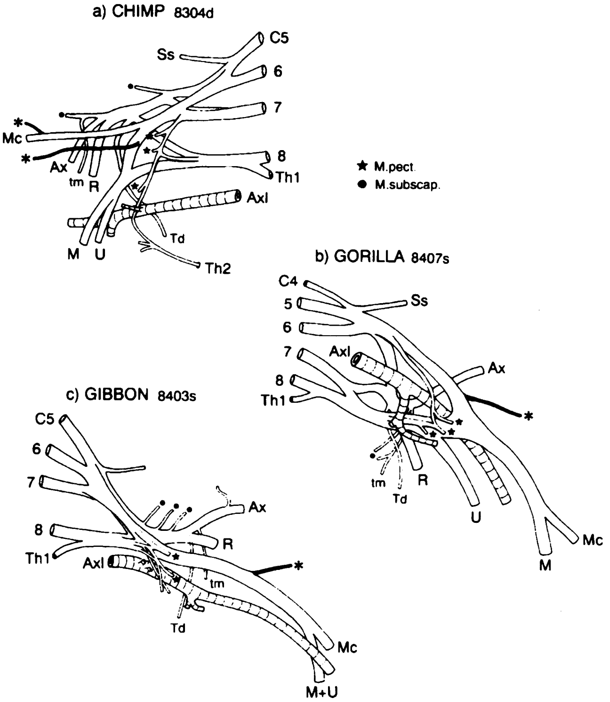

Fig. 1. Illustration of representative examples of the brachial plexus in chimpanzee (*a*), gorilla (*b*) and gibbon (*c*). The solid lines (*) indicate the branches to coracobrachialis. Abbreviations for this and subsequent figures: Ax, axillary nerve; Axl, axillary artery; brach, brachialis ; brev, short head of biceps brachii; cal, lateral cutaneous nerve of the forearm; cam, medial cutaneous nerve of the forearm; cbr, coracobrachialis; C4–8, 4th–8th cervical nerves; long, long head of biceps brachii; M, median nerve, Mc, musculocutaneous nerve; P, pectoral nerve; R, radial nerve; Rm, coracobrachial nerve from the upper trunk; Rmc, coracobrachial nerve ramus from the musculocutaneous nerve; Rp, deep (profundus) ramus of the coracobrachial nerve from the dorsal surface of the ventral division of the middle trunk; Rs, superficial ramus of the coracobrachial nerve from the middle trunk or the root of the pectoral nerve passing ventral to the upper trunk; Rs + m, ramus composed of Rs and Rm; Rs + m + p, ramus composed of Rs, Rm and Rp; Ss, suprascapular nerve; Td, thoracodorsal nerve; tm, teres major; Th1–2, 1st–2nd thoracic nerves; U, ulnar nerve.

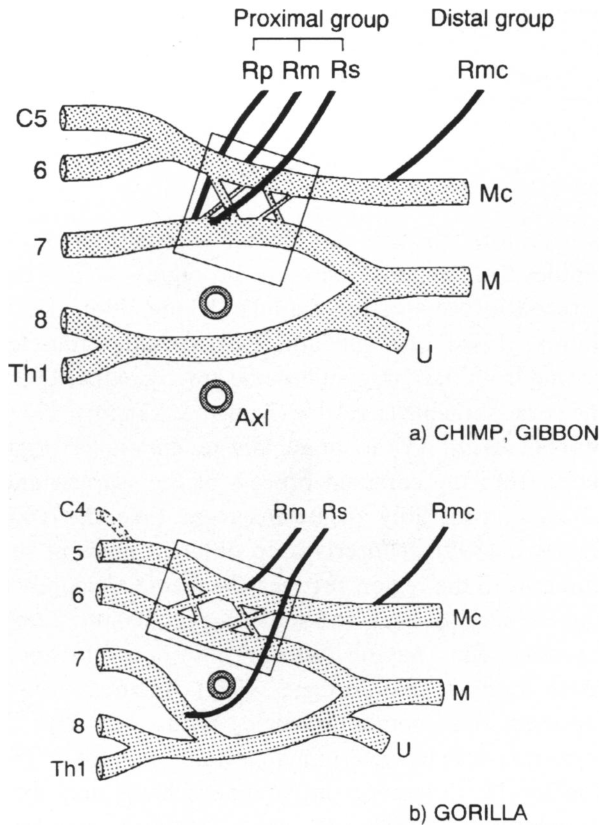

Fig. 2. Schematic drawings showing the origin and course of the branches from the brachial plexus to coracobrachialis. In the rectangular area, the epineurium has been peeled off to visualise the origin of the coracobrachialis nerves from the lateral cord of the brachial plexus. In the chimpanzee and gibbon (*a*), the middle trunk (C7) joins the lateral cord, whereas in the gorilla (*b*) it does not. The posterior cord is not shown in these drawings.

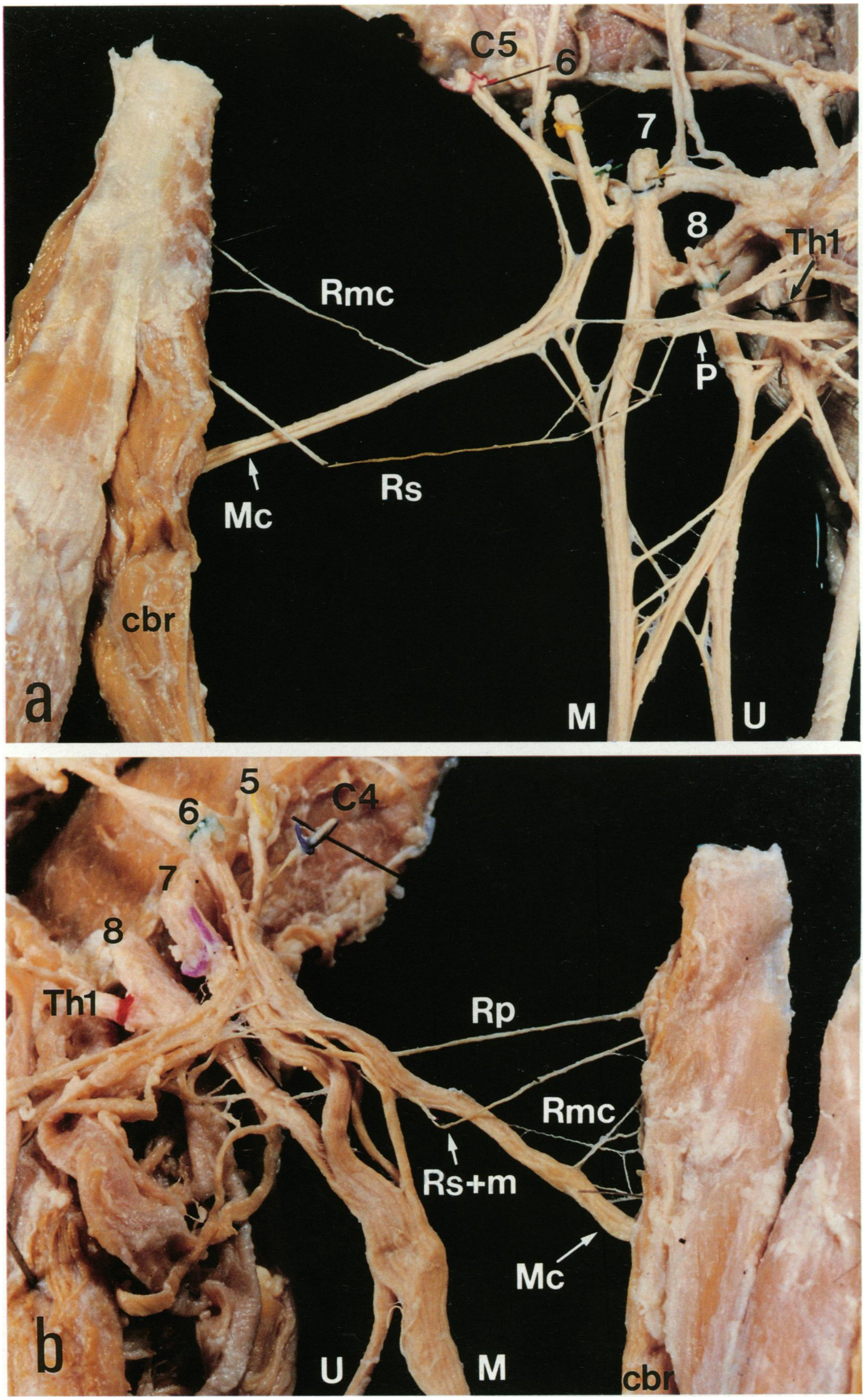

Fig. 3. Two examples of the fascicle tracing analysis of the brachial plexus and its coracobrachial branches in chimpanzees seen from the ventral side. (*a*) Rmc and Rs supply the coracobrachial muscle. (*b*) One Rp, one Rs+m and several Rmc are present.

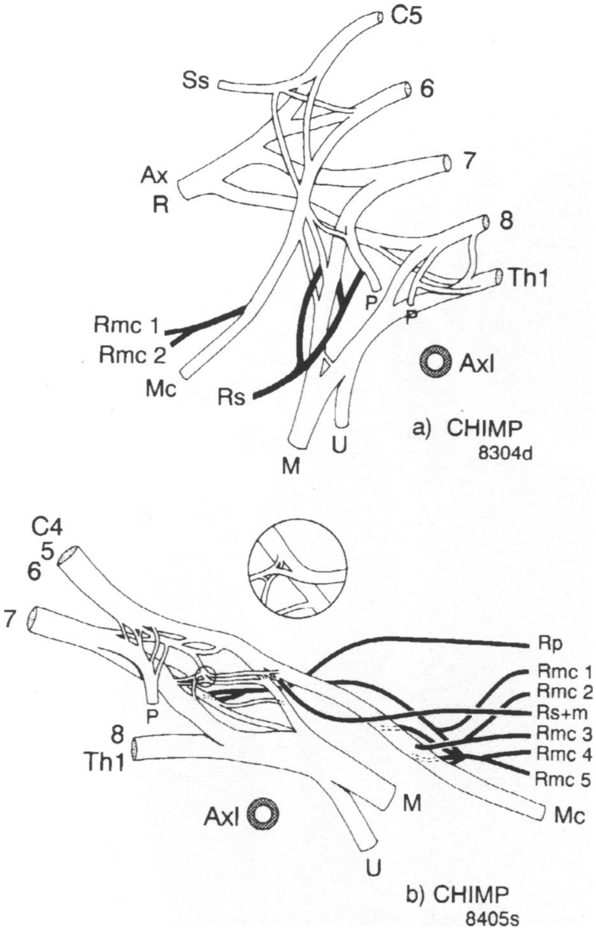

Fig. 4. Line drawings of the same examples shown in Figure 3. In the region of the lateral cord, the epineurium ensheathing the nerve bundles has been removed. Branches to coracobrachialis are shown in solid lines. (*a*) The Rmc arises from the musculocutaneous nerve (Mc) and the Rs from the region of the lateral cord and the root of lateral pectoral nerve. (*b*) In the area within the circle, the perineurium has also been peeled off. The Rp arises from the dorsal surface of the ventral division of the middle trunk. Rs and Rm arise from the minute branches in the region of lateral cord and 5 branches from the musculocutaneous nerve (Rmc) are present.

(C5) and 6th (C6) cervical nerves, the middle trunk the 7th cervical nerve (C7) and the lower trunk the 8th cervical (C8) together with the 1st thoracic (T1) nerves. Each trunk consisted of anterior and posterior divisions. The anterior divisions formed medial and lateral cords; the posterior divisions merged into a posterior cord. Some interspecific differences were observed concerning the composition of the lateral cord and the position of the axillary artery relative to the brachial plexus (Fig. 1).

Chimpanzee (4 plexuses). In the 2 chimpanzees, the 4th cervical nerve (C4) also joined the upper trunk. Nerve fascicle tracing showed that the middle trunk became the lateral root of the median nerve after receiving a communication from the upper trunk. In 2 plexuses the upper trunk became the musculocutaneous nerve after receiving fine twigs from the middle trunk and without receiving them in the remaining 2 cases.

Gorilla (2 plexuses). In the gorilla, C4, 5 and 6 (upper trunk) united to form the lateral cord; C7 (middle trunk) and C8 plus T1 (lower trunk) constituted the medial cord. The 2 cords then formed a common cord, which bifurcated into 2 branches: one was the musculocutaneous-median trunk containing the components for both of these nerves, and the other gave rise to the ulnar nerve. From the fascicular tracing, analysis of the lateral cord, the musculocutaneous nerve was derived mainly from C5 or C4 plus C5, and the median nerve mainly from C6.

Gibbon (4 plexuses). In the 3 gibbons, the ventral bundle from the upper and middle trunks formed the lateral cord and the lower trunk the medial cord. The lateral and medial cords then formed a ventral cord. The dorsal bundle of each trunk gave rise to the posterior cord. In 1 case the upper, middle and lower trunks united at the same point. The ventral cord ran downwards along the medial side of biceps brachii, gave rise to the musculocutaneous nerve at the middle third of the upper arm and bifurcated into the median and ulnar nerves at the lower end of upper arm.

From the fascicle tracing analysis, the middle trunk (C7) received fibres from the upper trunk (C5, C6) to form the lateral root of the median nerve in 3 cases. In the remaining case, only the middle trunk constituted the lateral root of the median nerve. On the other hand, the upper trunk received fine twigs from the middle trunk to form the musculocutaneous nerve.

Observations of the nerves innervating coracobrachialis

In all species examined, coracobrachialis had a single origin from the coracoid process and a single insertion into the medial side of the upper humerus. In each species, the muscle received one or more nerve branches which originated from the brachial plexus in the region of the musculocutaneous nerve, the lateral cord, the middle trunk, the root of the median nerve and the common ventral cord (observed only in gibbons).

Fascicular tracing analysis revealed that coracobrachialis received 2 groups of nerve branches which were distinguished from each other on the basis of their origin from the brachial plexus (Fig. 2). One group had branches which originated from the musculocutaneous nerve. The branches in the other group arose from the brachial plexus in the region of

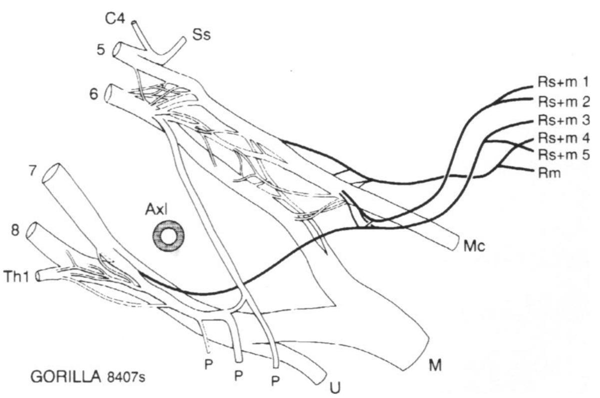

Fig. 5. Fascicle tracing analysis of the lateral cord of brachial plexus and the branches to the coracobrachial nerves (solid lines) in a gorilla. Ventral view. A branch from the root of medial pectoral nerve and several twigs from the upper trunk join to make 5 Rs + m and 1 Rm.

the lateral cord or from the root of the medial pectoral nerve. The former can therefore be termed the 'distal group' and the latter the 'proximal group'.

The nerves of the distal group were represented by one or more branches from the musculocutaneous nerve (musculocutaneous ramus). This ramus, as well as the musculocutaneous nerve itself, contained fibres mainly derived from C5 and C6 and probably also from C7 and C4 in some instances. In all cases, nerves of the proximal group were observed. These could be classified into the following 3 types depending on their origins and course in the brachial plexus: (1) those that originated from the upper trunk (medial ramus), (2) those which arose from the middle trunk or the root of the pectoral nerve and then ran laterally, ventral to the upper trunk (superficial ramus), and (3) those which were derived from the middle trunk and passed dorsal to the upper trunk (deep ramus).

Chimpanzee (4 specimens). In the chimpanzees, coracobrachialis was pierced by the musculocutaneous nerve and received branches from both the distal and proximal groups. Among those from the proximal group, only the superficial ramus was observed in 2 cases (Figs 3*a*, 4*a*). The superficial ramus, was joined by the medial ramus in the remaining 2 cases, in 1 of which a deep ramus was also observed (Figs 3*b*, 4*b*).

Gorilla (2 specimens). In the gorilla, the musculocutaneous nerve did not pierce coracobrachialis but ran distally, adhering to the median nerve along the medial side of biceps brachii. There were no distal group branches. In 1 case, only a medial ramus was observed, while in another case the medial and superficial rami communicated with each other (Fig. 5).

Gibbon (4 specimens). In the gibbons, coracobrachialis was not pierced by the musculocutaneous nerve and there were no distal group branches. In 3 cases, all proximal group branches communicated with each other (Fig. 6). In the remaining case, the medial ramus joined the deep ramus to form a common branch.

Observations on the intramuscular distribution of the nerves to coracobrachialis

In the chimpanzees, the distribution area of the proximal branches in the muscle could clearly be discriminated from that of the distal branches in 3

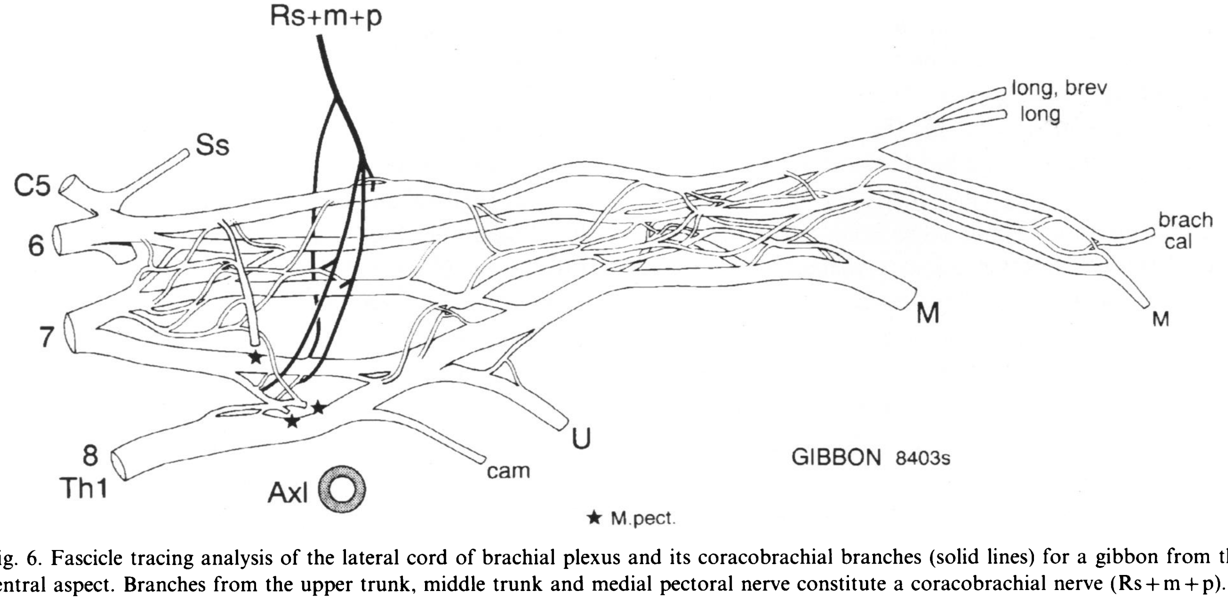

Fig. 6. Fascicle tracing analysis of the lateral cord of brachial plexus and its coracobrachial branches (solid lines) for a gibbon from the ventral aspect. Branches from the upper trunk, middle trunk and medial pectoral nerve constitute a coracobrachial nerve (Rs + m + p).

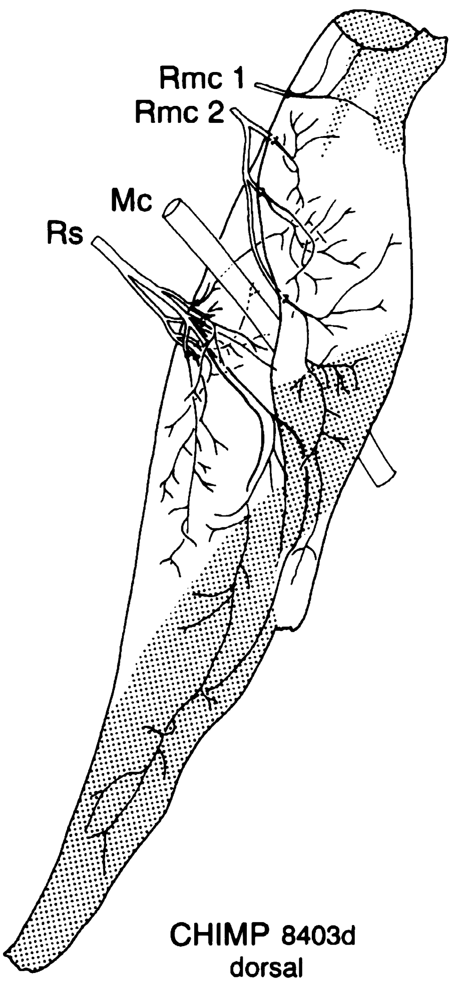

Fig. 7. Dorsal view of the intramuscular nerve distribution in coracobrachialis in the same specimen as in Figure 3 *a* (chimpanzee). The origin from the coracoid process of the scapula is at the top and the shaded area represents the tendinous part of the muscle. The musculocutaneous nerve (Mc) pierced the deep lateral part of the muscle. Two Rmc innervate the proximal deep part and 1 Rs supplies the remaining larger part.

cases (Fig. 7). In the remaining case, some communicating branches between the deep ramus (proximal branch) and the musculocutaneous ramus (distal branch) were observed in the muscle, and the boundary of the distribution area between them was not definite. Among the proximal branches, the distribution area of the superficial ramus was restricted to the superficial and proximal part of the muscle (2 cases), or expanded from the superficial and proximal area to the whole distal part of the muscle (1 case). In the remaining case, the superficial and medial rami innervated the proximal and superficial part and the deep ramus supplied the deep, proximal and medial parts.

In the gibbons and the gorilla, no distal group branches were observed. All nerves in the proximal group (superficial, medial and deep rami) joined to form a common bundle and then diverged into some fine branches to supply the muscle. Because the fibres from these 3 rami were thoroughly mingled in each branch, their intramuscular distributions could not be distinguished from each other.

DISCUSSION

Observations on the brachial plexus

In the 3 species of ape examined, the brachial plexus showed only slight variability in that C4 joined the upper trunk (C5, C6) in 1 chimpanzee and on 1 side of the gorilla, and the anterior division of the middle trunk entered either the lateral cord (chimpanzees and gibbons) or the medial cord (gorilla). They showed a common basic architecture consisting of roots, trunks, cords and individual branches. The architecture of the brachial plexus in apes has been studied by other authors (Eisler, 1890; Bolk, 1902; Miller, 1934; Raven, 1950; Preuschoft, 1962; Kusakabe et al. 1965; Nishimura et al. 1965). These authors reported much the same results as in the present study.

Analysis of the branches to coracobrachialis

The present study revealed that coracobrachialis in the apes received 4 types of nerve from the brachial plexus, namely a musculocutaneous ramus arising from the musculocutaneous nerve, a superficial ramus from the ventral aspect of the middle trunk, a medial ramus from the upper trunk, and a deep ramus from the dorsal aspect of the ventral division of the middle trunk. The musculocutaneous ramus provides the main innervation for coracobrachialis in most mammalian species. The other nerves to coracobrachialis have been described in many species including man (Testut, 1884; Frohse & Fränkel, 1908; Schaeffer, 1953; Romanes, 1972; Gardner et al. 1975; Williams & Warwick, 1980; Hollinshead, 1982; Koizumi, 1989), chimpanzees (Bolk, 1902; Sonntag, 1923), and gorillas (Raven, 1950). However, these studies did not analyse the origin of these nerves precisely enough to distinguish the superficial, medial and deep rami except for a study on man and prosimians by Koizumi (1989). Figures 8 and 9 show the relationships of each branch in apes and man.

In addition, we classified the 4 kinds of nerves to coracobrachialis into proximal and distal groups on the basis of their origin from the brachial plexus. The proximal group comprised the superficial, medial and deep rami arising from the region of lateral cord, whereas the distal group was represented by the

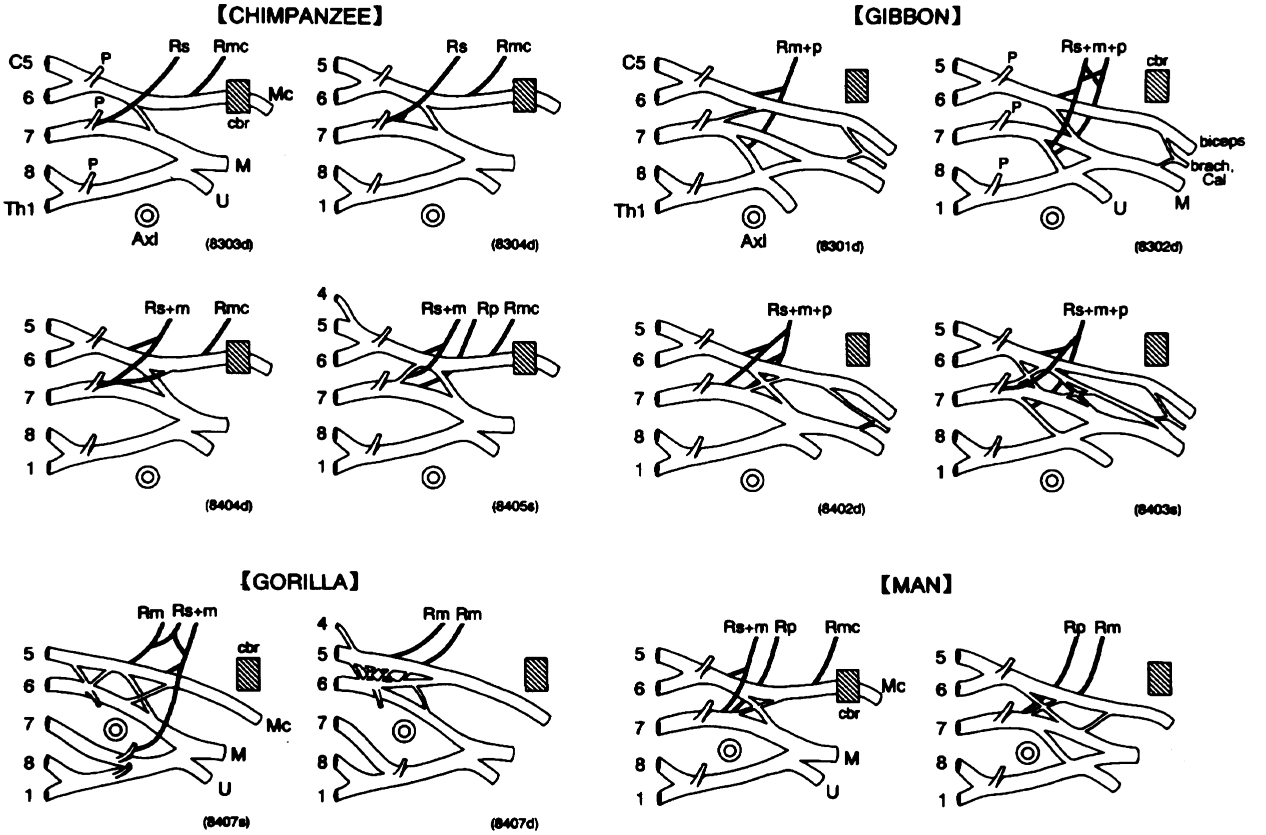

Fig. 8. Schematic diagrams showing the origin of the branches (solid lines) from the brachial plexus to coracobrachialis (striped rectangles) in apes and man. For apes, all cases observed in this study are shown. In man, 2 typical cases are shown, one with penetration of coracobrachialis by the musculocutaneous nerve and the other without.

		Chimp (4)	Gor (2)	Gibb (4)	Man			(24)
prox. group	Rs	○ ○ ○ ○	○ –	– ○ ○ ○	– – ④	–	①	–
	Rm	– – – ○	○ ○	○ ○ ○ ○	① – ④	–	–	⑥
	Rp	– – – ○	○ –	○ ○ ○ ○	① ⑩ ④	②	–	⑥
dist. group	Rmc	○ ○ ○ ○	–	–	① ⑩ ④	②	①	–
penetration of cbr by Mc		+	–	–	+	+*	+**	–

Fig. 9. Occurrence of various types of nerves to coracobrachialis in apes and man. Penetration of coracobrachialis by the musculocutaneous nerve is also indicated. The numbers of specimens observed in each species are shown in parentheses next to the name of the species. In man, the numbers of cases observed are given in each circle (○). The circle shows the existence of each type of nerve branch (Rs, Rm, Rp or Rmc). Vertical solid lines connecting the circles indicate communication between 2 types of branches outside the muscle. The vertical dotted line for chimpanzees means the existence of an intramuscular communication between the nerve branches. In man, the penetration site of coracobrachialis by the musculocutaneous nerve may vary: in 2 cases superficial (asterisk, with Rp and Rmc) and in 1 case deep lateral (double asterisks, with Rs and Rmc).

musculocutaneous ramus arising from the musculocutaneous nerve. The nerves of the proximal group communicated with each other before entering the muscle, but had no communication with the musculocutaneous ramus. Nerves from one region were therefore easily distinguished from those from the other region. Only in 1 case (the chimpanzee) did some intramuscular branches of the musculocutaneous ramus communicate with those of the proximal group.

Relationship between the two groups of nerves and coracobrachialis

In the descriptions of the brachial plexus of man and apes in the literature (Bolk, 1902; Harris, 1939; Braus & Elze, 1960; Romanes, 1972; Williams & Warwick, 1980), the muscular branches arising from the trunks/cords of the plexus (trunk/cord division) and those from the main nerves such as the musculocutaneous, median, ulnar and radial (main nerve division) are separated from each other into 2 distinct groups. Generally nerves in the trunk/cord division innervate the upper limb girdle muscles and those in the main nerve division supply the muscles of the free arm.

On the basis of the innervation pattern reported by Koizumi (1989) and found in the present study, we conclude that coracobrachialis is divided into 2 portions innervated by the nerves of the proximal and distal groups both in man and apes. The proximal and distal groups of the coracobrachialis nerves belong to the trunk/cord division and the main nerve division respectively. This innervation pattern indicates that coracobrachialis has 2 different characteristics, one being related to the flexor muscles of the upper arm and the other to the muscles of the upper limb girdle such as the pectoral muscles. Branches of the proximal group (superficial, medial and deep rami) had a tendency to communicate intimately with each other to supply coracobrachialis, so that the muscle component innervated by each of these rami could not be distinguished.

In traditional comparative anatomical studies, coracobrachialis is divided into 3 parts on the basis of the position relative to the musculocutaneous and the median nerves, namely brevis, medius and longus (or profundus, medius and superficialis) (Wood, 1867; Howell & Straus, 1932). The present study and that of Koizumi (1989) revealed that either part of coracobrachialis, superficial or deep to the musculocutaneous nerve, is innervated both by the distal and proximal groups. Therefore, from the standpoint of innervation, coracobrachialis cannot be divided simply on the basis of the course of the musculocutaneous nerve. Whether this nerve pierces coracobrachialis or not was closely related to the existence of a musculocutaneous ramus (distal group). In chimpanzees and in most humans who have a musculocutaneous ramus, the musculocutaneous nerve penetrates coracobrachialis. In the gorilla and gibbons, which have no musculocutaneous ramus, the musculocutaneous nerve did not pierce coracobrachialis. What causes this penetration remains to be established.

Relationship with the stratified structure of the brachial plexus

Formerly, the analysis of the brachial plexus emphasised the ventrodorsal arrangement of the nerve fibres (Bolk, 1902; Kida, 1990). However, the strata of the brachial plexus were not demonstrated throughout up to root level in any of the previous studies, so far as we are aware. In the brachial plexus, most nerves branch off at a considerable distance from the intervertebral foramina, so that it is quite difficult to demonstrate the stratum throughout from the roots to the branching point of each twig. The analysis of the coracobrachial nerves in the present study indicated that the sequence of the branching pattern rather than the stratification structure was evident in the brachial plexus. The proximal group had nerve branches arising both from the dorsal and ventral layers of the middle trunk (deep and superficial rami) which communicated frequently with each other to innervate coracobrachialis. The intramuscular distribution of each branch could not be defined clearly. On the other hand, a definite division existed between the branches of the proximal group and the distal group. This orderly branching pattern was commonly observed both in apes and man.

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