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The topography of root fibres within the sciatic nerve trunk of the dog

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INTRODUCTION

Numerous studies have revealed that the main terminal branches of the nerves in the upper and lower extremities usually contain fibres from three or more segmental nerves (Paterson, 1887*a*, *b*, 1893–4; Eisler, 1891; Bardeen & Elting, 1901; Bardeen, 1906; Haverka, 1928; Frede, 1934–5; Fry, 1961; Franzke & Heinze, 1962; Preuschaft, 1962; Hummel, 1965; Mizuno, 1966; Groumain, 1966; Fletcher, 1970; Ghoshall, 1972; Rao, Saigal & Sahn, 1972). Moreover, it has been shown that a single muscle receives fibres from two or more spinal nerves (Sherrington, 1892; Villiger, 1933; Browne, 1950; Jefferson, 1954; Haymaker, 1956; Fletcher, 1970), while a particular skin area of the body surface is supplied by fibres from three adjacent dorsal roots (Sherrington, 1893; Foerster, 1933; Villiger, 1933; Haymaker, 1956). These findings have been supported by macroscopic and experimental analysis of the internal structure of the peripheral nerve trunks. Further, it has been reported that the sciatic nerve trunk in man is made up of fasciculi in cable form (Stoffel, 1913). Similar observations have been made on many of the nerve trunks of the upper and lower extremities (Heinemann, 1916; Compton, 1917; Langley & Hashimoto, 1917; Dustin, 1918; McKinley, 1921; Goldberg, 1924; Sunderland, 1945; Sunderland & Ray, 1948; Sunderland, Marshall & Swaney, 1959), demonstrating that the fasciculi form, divide and reform new fasciculi within the nerve trunks.

The precise course of fibres derived from the various segmental nerves as they proceed along the peripheral nerve trunk, however, has not been studied in any depth. The present study was undertaken to determine the course of fibres from the constituent roots of the sciatic nerve and to acquire more detailed information on the internal structure of this peripheral nerve trunk.

MATERIALS AND METHOD

Fifteen dogs weighing 3–6 kg were divided into three groups of five. Under sodium pentobarbital anaesthesia, section of either the sixth or seventh lumbar, or the first sacral nerve was performed just distal to the dorsal root ganglion on the left side. Eighteen days after the operation the animals were killed with an overdose of sodium pentobarbital and perfused with 1000 ml of 10 % formalin through the left ventricle. The animals were skinned and the remains were immersed in Müller's fluid for over a month. After such fixation the animals were dissected and the sciatic nerve exposed and sketched precisely. The nerve was then cut transversely and obliquely into small segments ranging from 0·5 to 1·0 cm in length. These were numbered and sketched one by one in order to determine their orientation when embedded in paraffin. The specimens were then immersed in Marchi's reaction solution for two

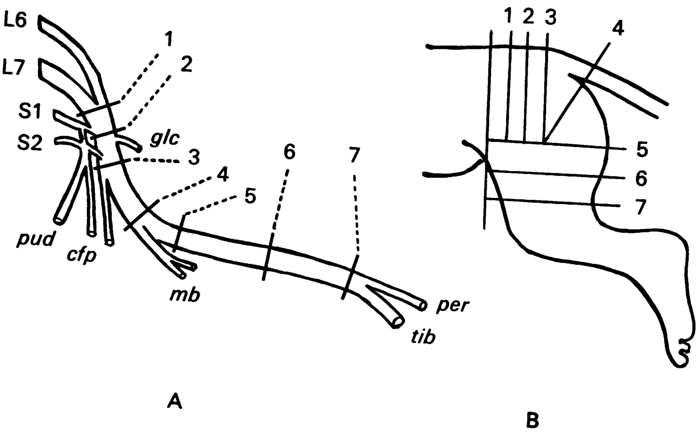


Fig. 1. Schematic drawing to show the formation of the sciatic nerve in the dog. The topography of root fibres within the sciatic nerve trunk was studied in the seven representative levels (A), which were projected upon the caudal half of the body surface (B). *cfp*, posterior femoral cutaneous nerve; *glc*, cranial gluteal nerve; *mb*, muscular branch to the hamstrings; *per*, common peroneal nerve; *pud*, pudendal nerve; *tib*, tibial nerve.

weeks, washed in tap water for one day, dehydrated with acetone, and embedded in paraffin. Serial sections were cut transversely at 15 μm. The sections on the glass slides were oriented according to the direction of the embedded nerve segment and the direction in which the block was cut.

RESULTS

Fasciculi within the sciatic nerve trunk

The sciatic nerve trunk contained a small fascicular plexus formed by division and anastomosis of the constituent fasciculi before it divided into the common peroneal and tibial nerves. At the level of the union of the sixth and seventh lumbar nerves it usually consisted of one to four fasciculi invested by perineurium and they were either separated by perineurial septa or isolated. During their descent, however, they again united into a common trunk proximal to the point of division into the common peroneal and tibial nerves in six cases out of the ten examined. In the remaining four cases, one to four fasciculi within the proximal part of the sciatic nerve were found to break up into four to nine fasciculi (Fig. 5, arrows) which formed either the common peroneal or tibial nerve in the vicinity of the greater sciatic foramen. The common peroneal and/or tibial nerves also contained a few fasciculi in the gluteal region and upper two-thirds of the thigh, and many in the lower third of the thigh as well, most of which became terminal branches.

Thus the sciatic nerve trunk of the dog had a fascicular plexus only in a limited part of its course, but a number of crossing or obliquely running fibres were blended with longitudinally running ones within the constituent fasciculi throughout the course (Fig. 6).

Sites of degenerated fibres within the sciatic nerve trunk following spinal nerve section

Seven days after spinal nerve section a number of coarse Marchi degeneration granules were found on a yellowish background in the cross sections of the sciatic nerve, while normal myelin sheaths stained a dark brown (Fig. 7).

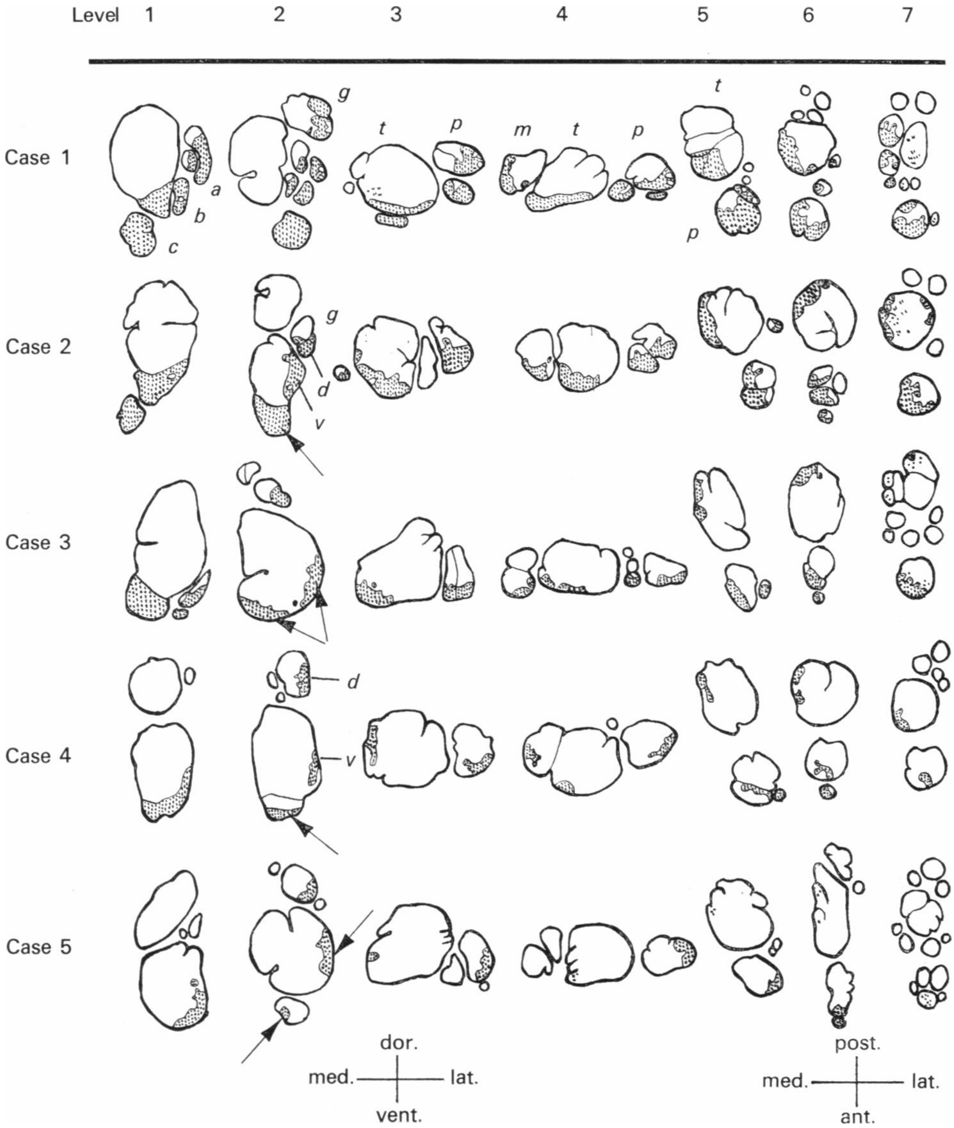


Fig. 2. Diagram illustrating the site of degenerated myelinated fibres (dots) within the sciatic nerve trunk at seven successive levels following section of the sixth lumbar nerve. *g*, cranial gluteal nerve; *m*, muscular branch to the hamstrings; *p*, common peroneal nerve trunk; *t*, tibial nerve trunk.

The site of degeneration produced by section of each of the sixth and seventh lumbar and the first sacral nerves was studied at seven levels, as shown in Figure 1; namely (1) just distal to the point of the union of a branch from the sixth lumbar nerve and the ventral ramus of the seventh lumbar nerve, (2) distal to the point where the cranial gluteal nerve was given off, (3) distal to the point where the first and second sacral nerves join the above nerve trunk (Hummel, 1965), (4) distal to the site where muscular branches for the hamstrings were given off; and in (5) the proximal, (6) the middle, and (7) the distal thirds of the thigh.

Sixth lumbar nerve section (*Fig.* 2)

Transverse sections of the sciatic nerve in the pelvic cavity were oval, with their long axis directed ventrodorsally. At level 1, degenerated fibres of the sixth lumbar nerve anastomosed with the ventral part of the ventral ramus of the seventh lumbar nerve. After giving off the cranial gluteal nerve a short distance proximal to the greater sciatic foramen, the main nerve trunk divided into common peroneal and tibial nerves. Proximal to this level (levels 1 and 2 in Fig. 2) three arrangements of degenerated fibres were recognized within the nerve trunk. In the first arrangement (Cases 2 and 4) a mass of degenerated fibres was divided into two groups. One migrated to the lateral part along the lateral surface of the nerve trunk; this was further subdivided into dorsal and ventral parts (Cases 2 and 4: level 2, *d* and *v*) by a perineurial septum which ran diagonally from the dorsal to the lateral surface. The dorsal portion entered the cranial gluteal nerve while the ventral occupied the lateral part of the nerve trunk. The other group was situated in the ventral part of the nerve trunk (cases 2 and 4: level 2, arrows). In the second arrangement (Cases 3 and 5) there were two groups of degenerated fibres. One migrated dorsally and left the parent nerve trunk together with some of the normal fibres from the seventh lumbar nerve to form the cranial gluteal nerve, the other was subdivided into lateral and medial portions (Cases 3 and 5: level 2, arrows). In the third arrangement (Case 1) a fasciculus consisting of a branch of the sixth lumbar nerve divided into three (Case 1, *a*, *b*, *c*) before it anastomosed with that of the ventral ramus of the seventh lumbar nerve. One division entered the cranial gluteal nerve while the other two fused with the ventral ramus of the seventh lumbar nerve to form a common trunk which lay in the lateral and ventral parts.

As the sciatic nerve left the pelvic cavity through the greater sciatic foramen the shape of the transverse section gradually became oval, with its long axis directed horizontally in the gluteal region (levels 3 and 4 in Figs. 2–4). In the cranial part of the gluteal region degeneration was present in the ventral parts of both the common peroneal and tibial nerves in three cases (1, 2 and 3: level 3 in Fig. 2; Fig. 8) where the sciatic nerve contained a relatively large number of fibres from the sixth lumbar nerve. In the remaining two cases (4 and 5) degenerated fibres were situated in the ventrolateral part or lateral periphery of the common peroneal nerve, and in the medial periphery of the tibial nerve. A large fasciculus for the flexor muscles of the thigh received degenerated fibres of the sixth lumbar nerve by way of the tibial nerve in the caudal part of the gluteal region (level 4, m in Fig. 2). Degenerated fibres within the tibial nerve did not shift in position in three cases (1, 2 and 3), while in two they migrated ventrally to lie in the ventromedial part (Cases 4 and 5), the sciatic nerve receiving a relatively small number of degenerated fibres (level 4 in Fig. 2).

In the thigh the long axis of the cross section of the sciatic nerve trunk was directed anteroposteriorly (levels 5–7 in Figs. 2–4), the nerve trunk undergoing a 90° rotation as it curved around the hip joint to enter the region. Dorsal to the hip joint the muscular branch to the hamstrings left the tibial nerve. In the proximal one third of the thigh degenerated fibres occupied the anterior (Cases 1, 4 and 5) or the anteromedial part of the common peroneal nerve (Cases 2 and 3). Within the tibial nerve degenerated fibres were seen along the medial surface (Cases 2–5) or in the anteromedial quadrant (Case 1). The degeneration within the tibial nerve was displaced slightly in the posterior direction along the medial surface during its descent in the proximal two thirds of the thigh (level 5 in Fig. 2) in three cases (Cases 1–3), but in the other two cases (Cases 3 and 4) it maintained its position. Within the common peroneal nerve degenerated fibres retained nearly the same position in all animals. Although the tibial nerve began to be divided into many small fasciculi for the innervation of the muscles of the leg in the lower part of the middle third of the thigh, such fasciculation only occurred in the common peroneal nerve in the lower part of the distal one third of the thigh.

Seventh lumbar nerve section (Fig. 3)

The results obtained with the seventh lumbar nerve section also confirmed the studies of the course of the fibres from the sixth lumbar and the first sacral nerves, since a large mass of fibres of the seventh lumbar nerve was situated between the groups of fibres derived from the sixth lumbar and first sacral nerves.

Degeneration resulting from section of the seventh lumbar nerve was located in the dorsal portion of the nerve trunk in the cranial pelvic region of its course (level 1 in Fig. 3). At a level where a fasciculus for the cranial gluteal nerve was given off (level 2 in Fig. 3) three types were noted. In the first type the cranial gluteal nerve was formed by the dorsal portion of the nerve trunk. It was separated by a perineurial septum, and contained both a group of degenerated fibres and a group of normal fibres of the sixth lumbar nerve which had migrated from the ventral to the lateral part (Cases 7 and 10: level 2, g; Figs. 3 and 11). In the second type, well delineated groups of degenerated and normal fibres were separated from the dorsal portion of the nerve trunk to form the cranial gluteal nerve (Cases 8 and 9, *g*). In the third type (Case 6) the nerve was formed by two fasciculi, one consisting of a group of degenerated fibres separated from the dorsal part of the nerve trunk of level 1, and the other consisting of both degenerated and normal fibres separated from the lateral part of the nerve trunk.

As seen in Cases 7–10 (level 2), degenerated fibres occupied the entire dorsomedial part of the main sciatic nerve trunk, a group of normal fibres from the sixth lumbar having migrated dorsally along the lateral surface. This corresponded with the results obtained from the cases of sixth lumbar nerve section. However, in Case 6, in which the sciatic nerve received a relatively large number of fibres from the sixth lumbar nerve, the degenerated fibres remained in the dorsal part.

In the cranial part of the gluteal region, degenerated fibres occupied the dorsal part of the common peroneal nerve in all cases (levels 3 and 4 in Fig. 3). In the tibial nerve they occupied the entire dorsolateral (Cases 6, 7 and 8), lateral (Case 9) or anterolateral (Case 10) region, and a narrow strip placed between two normal bundles arising respectively from the sixth lumbar and first sacral nerves since the group of normal fibres invaded the dorsomedial quadrant from the sacral trunk (S_1 and S_2) (level 3, arrows in Fig. 3). In the caudal part muscular branches to the hamstrings were given off from the tibial nerve which contained degenerated fibres of the seventh lumbar nerve (level 4, *m* in Fig. 3) and normal fibres, probably originating from both the sixth lumbar and the first sacral nerves (Figs. 3 and 5).

In the thigh (level 5 in Fig. 3) degeneration in the common peroneal nerve was seen in the posterior part in four cases (6–8 and 10) and the posterolateral in one (Case 9). During the descent of the sciatic nerve there was no change in the location of degenerated fibres in the proximal two thirds. In the distal third, however, the bundle of degenerated fibres gradually changed its position and shape, being divided into small subgroups in the lower part of the distal third. In the proximal third

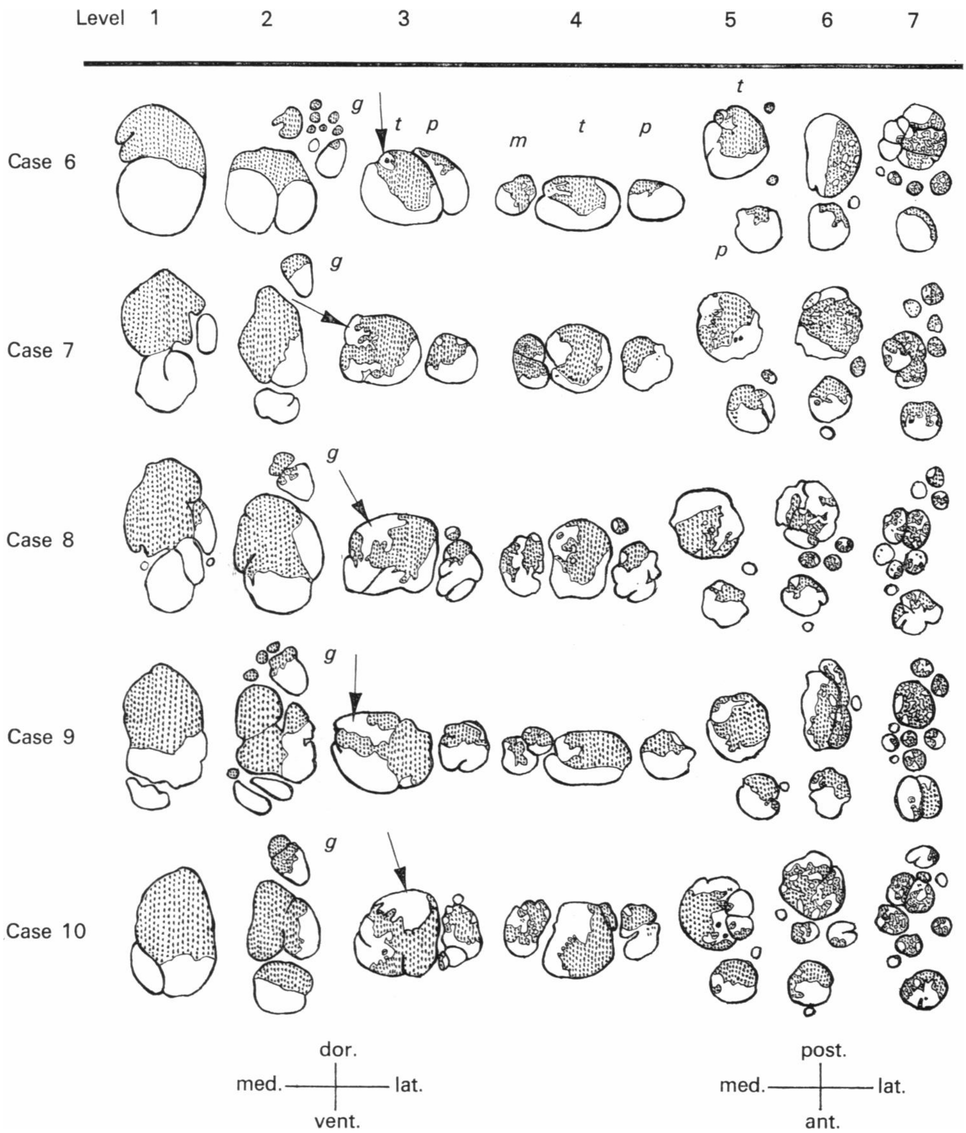


Fig. 3. Diagram illustrating the site of degenerated myelinated fibres (dots) within the sciatic nerve trunk at seven successive levels following section of the seventh lumbar nerve. *g*, cranial gluteal nerve; *m*, muscular branch to the hamstrings; *p*, common peroneal nerve trunk; *t*, tibial nerve trunk.

(level 5 in Fig. 3) degeneration in the tibial nerve occupied either a large posterolateral part (Cases 6 and 9), or a broad band extending from the posterolateral to the medial surface (Case 7), or the anteromedial or medial part (Cases 8 and 10). In the middle third (Fig. 3, level 6; Fig. 9) the area occupied by the degenerated fibres in the tibial nerve was blended with many small bundles of normal fibres originating from the sacral trunk.

Distal to this level, fibres from the sixth lumbar nerve (see Fig. 2 for their location), however, still formed a compact bundle, in contrast to those of other origins which broke up into small bundles.

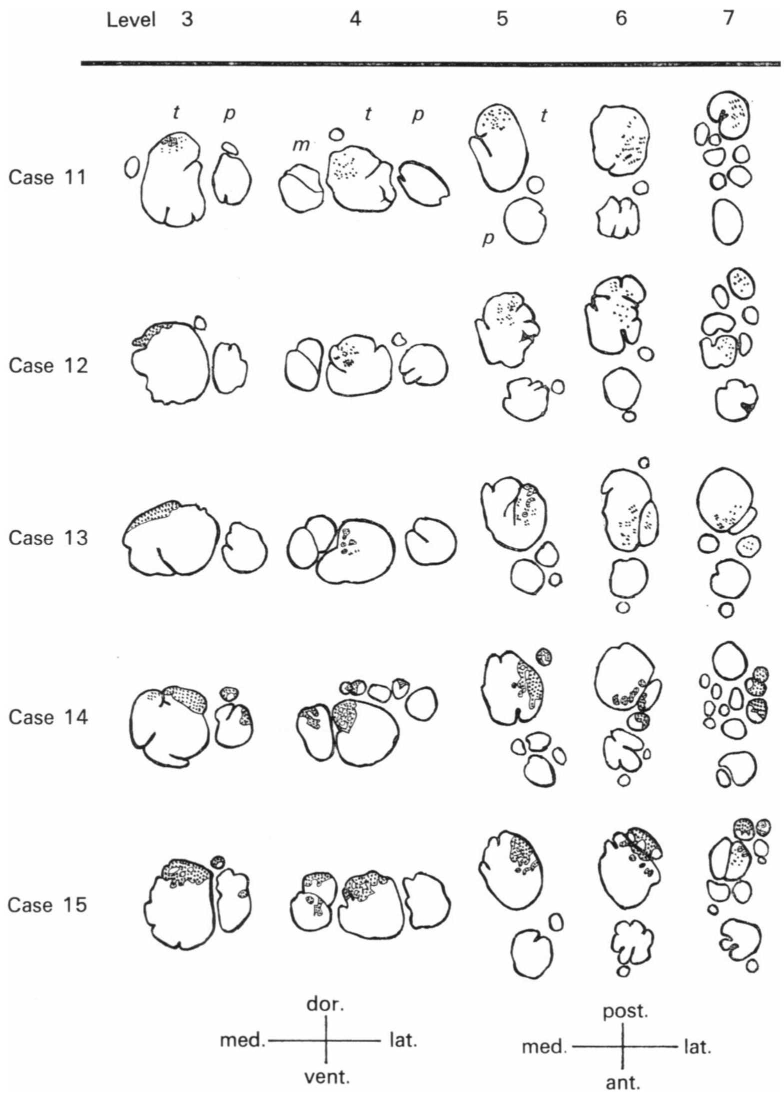
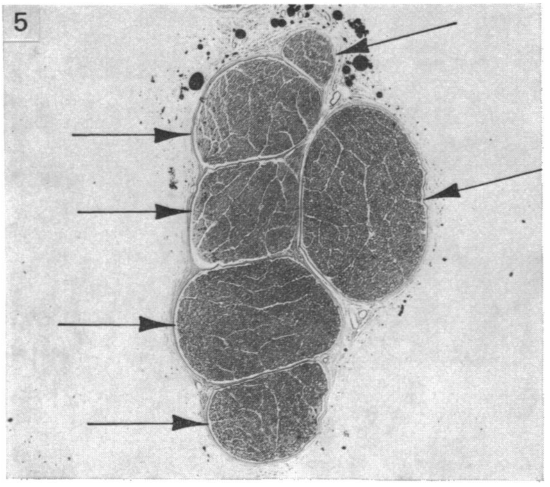


Fig. 4. Diagram illustrating the site of degenerated myelinated fibres (dots) within the sciatic nerve trunk at seven successive levels following section of the first sacral nerve. *g*, cranial gluteal nerve; *m*, muscular branch to the hamstrings; *p*, common peroneal nerve trunk; *t*, tibial nerve trunk.

First sacral nerve section (Fig. 4)

The fibres originating from the first sacral nerve entered the sciatic nerve immediately distal to the point where it divides into the common peroneal and tibial nerves with a common perineurium. Thus no degeneration was seen proximal to this point. The degenerated fibres either passed almost entirely to the posterior part of the tibial nerve (11–13, Fig. 4) or a significant number also entered the lateral part of the common peroneal nerve (14 and 15, level 3). At the caudal part of the gluteal region (between levels 3 and 4 in Fig. 4) degenerated fibres were scattered in the dorsomedial quadrant of the tibial nerve (11–13, Fig. 10). However, in two cases (14 and 15) a relatively large number of degenerated fibres were seen to enter the dorsal part of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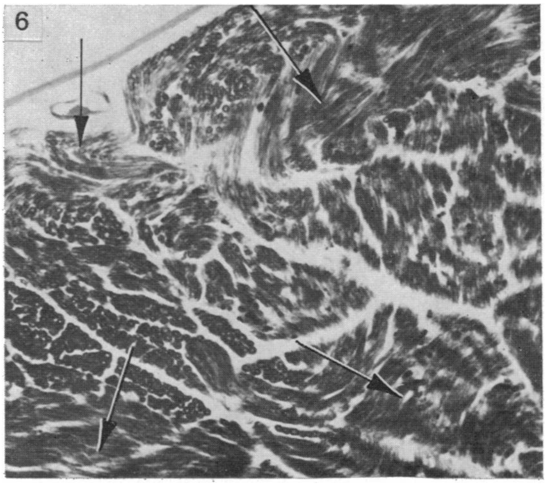
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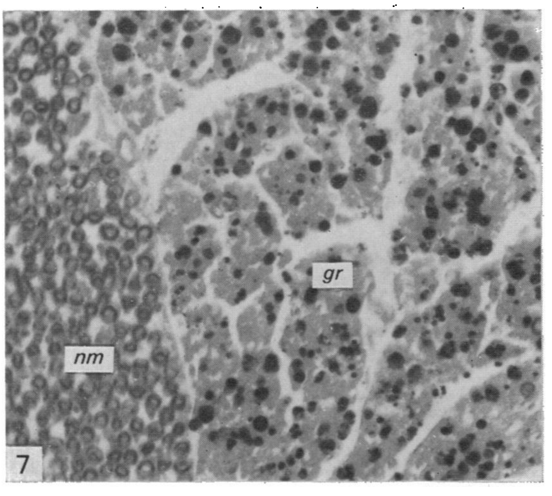
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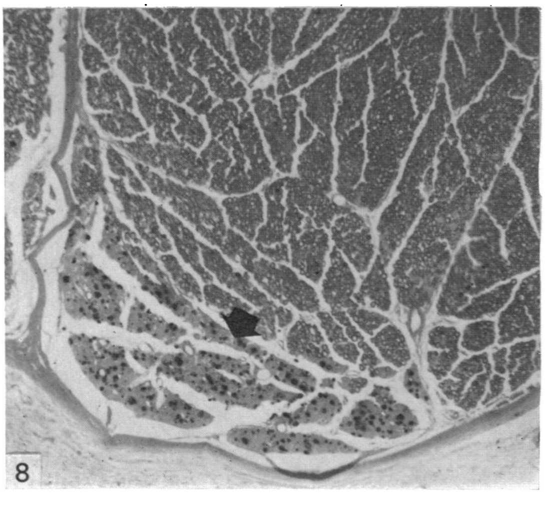
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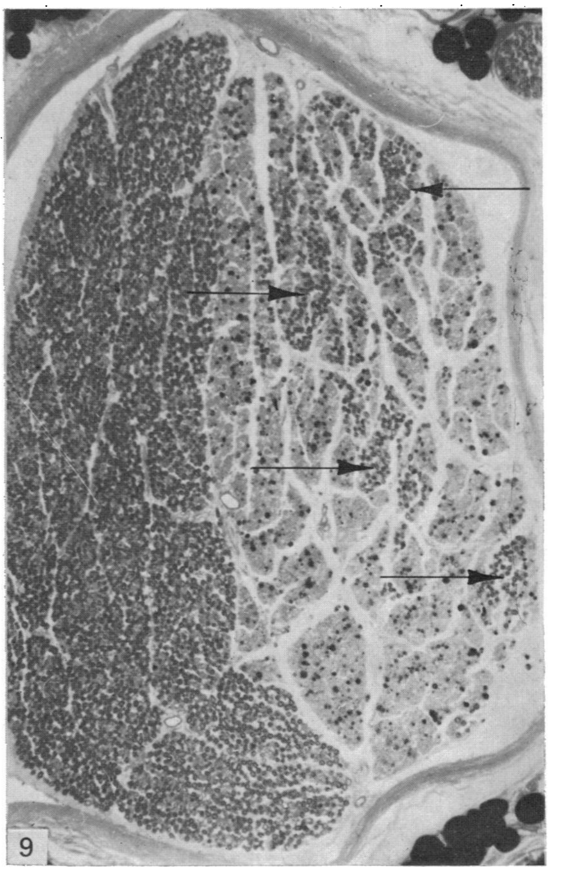
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the tibial nerve, where they were intermingled with small bundles of normal fibres derived from the second sacral nerve.

In the proximal third of the thigh (level 5 in Fig. 4), degenerated fibres were scattered in the posterior or posterolateral part of the tibial nerve in three cases (11–13), in which the sciatic nerve received only a small number of fibres from the first sacral nerve. In the remaining cases (14 and 15), which received a large number of fibres from the first sacral nerve, degenerated fibres were collected, *en masse*, in the lateral part or posterolateral quadrant. During the descent of the nerve in the proximal two thirds of the thigh there was a tendency for degenerated fibres to migrate progressively forwards along the lateral surface (Cases 11, 13 and 14). However, in Case 15, which contained a compact bundle of degenerated fibres, no such shift was observed.

Degeneration within the terminal branches given off from the sciatic nerve

The sciatic nerve gives off several cutaneous and muscular branches, e.g. the cranial gluteal nerve, in the pelvic cavity just before entering the greater sciatic foramen, and the caudal gluteal nerve and muscular branches to the gemelli, obturator internus, quadratus femoris and hamstrings in the gluteal region. In the lower part of the thigh common peroneal and tibial nerves gave off terminal branches in all of which degenerated fibres were still traceable as bundles or fasciculi (Figs. 11–14).

DISCUSSION

Longitudinal bundles consisting of fibres from the same root

The fibres from a single nerve root could be traced throughout the sciatic nerve in serial cross sections following section of an individual spinal nerve. The fibres entering the sciatic nerve from each spinal nerve took a specific course within the nerve trunk (Figs. 2–4) regardless of the numerous fibres crossing or running obliquely in various directions (Fig. 6, arrows). A similar lamination of root fibres was recognized in the median, ulnar and radial nerves of the rabbit (Arakawa *et al.* 1965) and the dog (Arakawa, Uemura & Ueyama, 1968). Based on the findings obtained from the dissections of human embryos and adults, Bardeen (1906) considered that fibres from the respective roots of origin were arranged in layers in the femoral, obturator and sciatic nerves, and that the fibres innervating the same muscle formed an elongated bundle with its long axis directed at right angles to the layers. He did

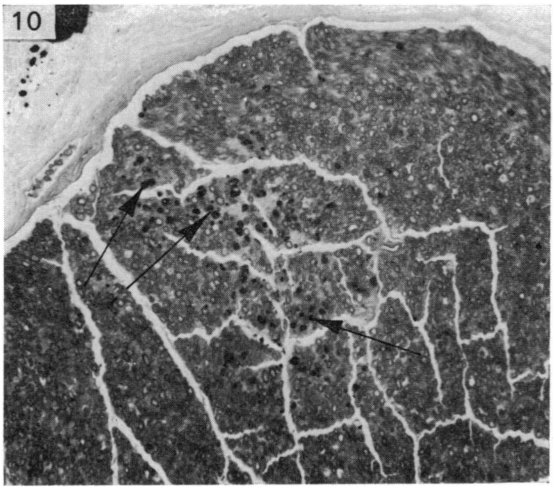
Fig. 5. Fasciculi within the pelvic part of the sciatic nerve trunk (arrows). Marchi method. × 14.

Fig. 6. Obliquely running fibres (arrows) within the tibial nerve trunk at the level of the hip joint. Marchi method. × 165.

Fig. 7. Degenerated fibres of granular appearance (*gr*) and normal myelin sheaths (*nm*) in a transverse section of the sciatic nerve trunk in the pelvic region 18 days after section of the seventh lumbar nerve. Marchi method. × 390.

Fig. 8. Transverse section of the tibial nerve trunk in the cranial part of the gluteal region following section of the sixth lumbar nerve. Degenerated fibres (arrows) are situated in the anterior part. Marchi method. × 156.

Fig. 9. Transverse section of the tibial nerve trunk at the level of the middle third of the thigh. Some groups of normal fibres (arrows) entering from the sacral trunk distribute to the area occupied by the degenerated fibres resulting from section of the seventh lumbar nerve. Marchi method. × 166.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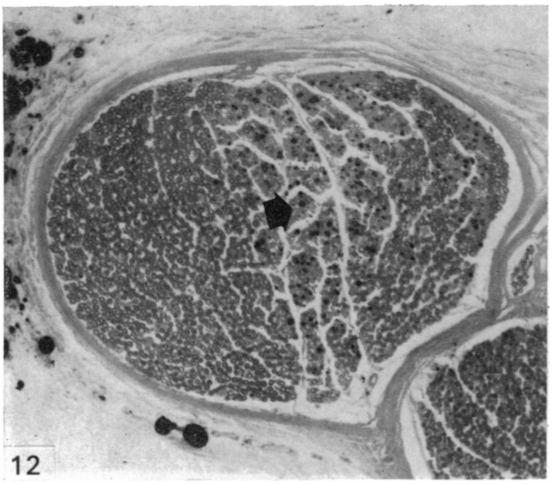
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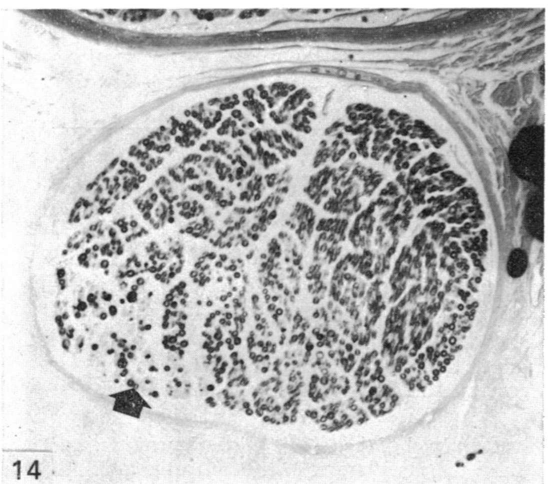
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not, however, attempt to determine the course of constituent fibres of these nerves in the nerve trunks. On the other hand, many authors have noticed that intermingling of the constituent fibres gradually occurs in the sciatic nerve trunk (Langley & Hashimoto, 1917; Kraus & Ingham, 1920; McKinley, 1921; Goldberg, 1924; O'Connell, 1936; Sunderland & Ray, 1948). In the terminal branches the constituent fibres of a fasciculus or fasciculi progressively diffused over the other fasciculi as they ascended proximally along the sciatic nerve (McKinley, 1921; Sunderland & Ray, 1948). Therefore, every fasciculus, at the proximal level, contained fibres which entered all or most of the terminal branches (Sunderland & Ray, 1948). This is in accord with the anatomical and physiological studies of McKinley (1921), who demonstrated that various partial lesions in either the common peroneal or tibial nerve dorsal to the hip joint produced a diffuse degeneration in all terminal branches, and that electrical stimuli of various groups of fibres within either nerve resulted in a contraction of all muscles supplied by the same nerve trunk that was stimulated. Moreover, Kilvington (1940) showed diffuse degeneration within the median, ulnar and radial nerves at distal levels following partial lesions of their proximal parts.

The present study shows that each spinal nerve entering the plexus sends a small group of fibres to the branches of the plexus. Each group is separated from the other fibres of that nerve a short distance proximal to the point of branching and comes to lie at the periphery of the nerve trunk. The groups forming the branch are then separated from the parent nerve trunk by a perineurial septum which is continuous with the perineurium of the branch (Figs. 11, 12). This corresponds to the functional localization described by McKinley (1921) and is in accord with previous observations that complexity of the fascicular plexuses in the nerve trunk of the human increases a short distance above the origin of a terminal branch (Langley & Hashimoto, 1917). Moreover, the fasciculi composing the proximal parts of the common peroneal and tibial nerves split up into a large number of small fasciculi where a terminal branch is formed (McKinley, 1921).

Sites of longitudinal bundles

The present study shows that each longitudinal fibre bundle derived from a spinal nerve takes its own course within the sciatic nerve trunk in the pelvic cavity, although the size of each bundle varies from animal to animal. Within the tibial nerve there are usually three sub-bundles, each arising from a different spinal nerve. The position of

Fig. 10. Degenerated fibres (arrows) scattered in the dorsomedial quadrant of the tibial nerve trunk in the caudal part of the gluteal region following section of the first sacral nerve. Marchi method. ×226.

Fig. 11. Transverse section of the most proximal part of the cranial gluteal nerve. Note that the fasciculus is invested by the perineurium. Arrowhead points to the degenerated fibres resulting from section of the sixth lumbar nerve in the lateral part. Marchi method. ×144.

Fig. 12. Transverse section of the muscular branch to the hamstring, just distal to the point of separation from the tibial nerve trunk. Degenerated fibres (arrowhead) following section of L7 are seen running in a band between two groups of normal fibres of sixth lumbar (left) and first sacral nerves (right) origin. Marchi method. ×126.

Fig. 13. Transverse section of a terminal branch to one of the muscles of the leg. It separates from the tibial nerve in the distal one third of the thigh. Degenerated fibres following section of L7 (arrowheads) are grouped in the right sides of the two fasciculi. Marchi method. ×251.

Fig. 14. Transverse section of a terminal branch to one of the muscles of the leg, which separates from the tibial nerve in the distal one third of the thigh. It contains a small number of degenerated fibres (arrowhead) following section of the sixth lumbar nerve. Marchi method. ×233.

these bundles varies depending on whether the lumbosacral plexus is pre-fixed (proximal) or post-fixed (distal) – the number of fibres from the sixth lumbar nerve increasing or decreasing reciprocally with the number from the first sacral as the plexus type alters from pre-fixed to post-fixed (Langley, 1892; Romanes, 1951; Fletcher, 1970). For example, in the gluteal part, bundles within the tibial nerve appear to be displaced in a clockwise direction (as observed from above on the left side) along the surface according to the shift of the lumbosacral plexus from pre-fixed to post-fixed. On the other hand, bundles within the common peroneal nerve, which consisted mainly of fibres from the sixth and seventh lumbar nerves, did not undergo displacement despite the reciprocal changes in the size of both bundles. This suggests that there is a relationship between the course of the longitudinal bundles and the condition of the lumbosacral plexus in the tibial nerve but not in the common peroneal nerve.

Clinical considerations

The present study shows that the fibres forming a terminal fasciculus which later becomes a terminal branch (or branches) are grouped in a certain part of the periphery of the nerve trunk and that a fasciculus is found to leave the parent trunk, as a terminal branch in a macroscopic sense, only after it has run a certain distance along the trunk separated from other fasciculi by a perineurial septum. This is in good accord with the observations in man (Sunderland & Ray, 1948; Sunderland, 1968) that the fasciculi localized in the periphery of the nerve trunk are composed solely or predominantly of fibres for a terminal branch or branches that are soon to leave the nerve trunk. In the remaining regions of the nerve trunk, however, the fibres derived from different spinal nerves form longitudinal bundles corresponding to the position of the parent nerve.

The effect of a partial lesion in the sciatic nerve trunk, therefore, depends on its level. In fact, Sunderland (1968) has shown that a partial nerve injury at one level may either escape detection or result in a widely distributed paresis, while a corresponding lesion at another level may produce a localized paralysis or sensory loss. Owing to the localization of segmental fibres it is also likely that a partial lesion of the nerve trunk may leave intact many of the fibres passing to particular terminal fasciculi. This probably accounts for Seddon's (1942) observation that an incomplete proximal lesion (as opposed to a distal lesion) in certain nerves produces surprisingly little paralysis or loss of sensation. Babcock (1928) reported that one third of a nerve trunk can be divided proximally without producing any demonstrable sensory loss, but quite small lesions near branching points can sever most or all of the fibres entering a particular terminal branch.

Figures 2–4 show that the sites of the longitudinal bundles shift to some extent from level to level, and even from animal to animal. However, terminal fasciculi which produce branches of the sciatic nerve in the pelvis and buttock and lower half of the thigh are localized sharply within the nerve trunk a short distance above the branching point (Sunderland & Ray, 1948; Sunderland, 1968). Consequently, the effects resulting from the partial lesion vary, depending on the site of the lesion.

SUMMARY

The architecture of the fibres in the sciatic nerve of the dog has been analysed by following the degeneration of fibres resulting from division of the individual spinal nerves which contribute to the sciatic nerve. A pattern has been demonstrated which

varies in part with the size of the contribution to the sciatic nerve from each of the spinal nerves L6, L7 and S1. The redistribution of the fibres of each spinal nerve to form the various branches of the sciatic nerve is also described, and the significance of these arrangements is discussed.

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