

BRACHIAL PLEXUS DISEASE IN THE DOG AND CAT: A LITERATURE REVIEW AND CLINICAL CASE STUDY

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SUMMARY

The aim of this thesis is to detail the clinical, ancillary and, in some cases, pathological findings in thirteen cases of brachial plexus disease which were presented to Glasgow University Veterinary School during the period October 1991 to June 1993. Clinical findings ranged from mild foreleg lameness, in the absence of specific neurological deficits, to profound bilateral forelimb paresis. Neoplasia was the most common cause of brachial plexus disease in this series, affecting seven out of the thirteen cases. Three cases were traumatic in origin and three were due to inflammatory or idiopathic disease. One dog with brachial neuropathy of unconfirmed aetiology had a concurrent insulinoma, suggesting a possible metabolic cause. In most cases, the diagnosis was reached on the basis of history and clinical findings but certain ancillary investigative techniques, notably electrophysiological examination, were found to be useful in some cases. The diagnosis was confirmed by pathological examination in six cases. These findings are discussed in the light of a broad review of the literature pertaining to brachial plexus disease in dogs and cats and relevant comparative aspects in man.

DECLARATION

The work in this thesis was carried out by the author, except where duly acknowledged, and has not been submitted previously for the award of a degree at any other university.

Fiona Haining

In memory of my godmother
June Smith

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"....exceptionally well informed and far more often right than wrong."

Sunday Times

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INTRODUCTION

The brachial plexus is a large nerve plexus located in the region of the axilla from which the peripheral nerve trunks of the forelimb are derived. It is formed by ventral branches of the sixth cervical to the first thoracic spinal nerves with minor individual variations (Sharp and others 1990, 1991). In the strict anatomical sense, the brachial plexus refers to the area deep in the axillary region where the ventral branches intermingle. This is also described as the common plexus bundle. In clinical terms, however, brachial plexus disease usually includes lesions of the nerve roots, spinal nerves and ventral branches as these can rarely be differentiated from lesions of the common plexus bundle on the basis of clinical findings, with the exception of some nerve root lesions at specific sites. Lesions involving individual peripheral nerve trunks are usually identified by the clinical deficits which result.

The brachial plexus is susceptible to a number of disease processes, which may be restricted to this region or which may be more generalised. Recognised conditions affecting the brachial plexus in small animals include trauma, particularly traction injuries (Griffiths and others 1974, Griffiths 1977); neoplasia, which may be of primary or secondary origin (Carmichael and Griffiths 1981, Targett and others 1993, LeCouteur 1989); neuritis, which may specifically affect the brachial plexus (Cummings and others 1973); and occasionally vascular disease (MacCoy and Trotter 1977).

Diagnosis and management of brachial plexus disease is complicated by the fact that in addition to the nature of the disease process, the extent of damage within the plexus and the severity of nerve injury are of equal importance in determining both the manner in which these cases present and the prognosis. A basic knowledge of the anatomy of the brachial plexus and the pathology of peripheral nerve disease is therefore vital to the understanding of brachial plexus disease.

SECTION 1

LITERATURE REVIEW

SECTION 1: PART 1

ANATOMY OF THE BRACHIAL PLEXUS AND RELATED NERVES

NERVES CONTRIBUTING TO THE BRACHIAL PLEXUS

The spinal cord of the dog comprises eight cervical, thirteen thoracic, seven lumbar, three sacral and four to seven caudal segments. At the level of the C6 to T1 segments the diameter of the spinal cord is increased by approximately two millimetres to form the cervical enlargement (Fletcher and Kitchell 1966). This region is associated with innervation of the forelimbs and is characterised by expansion of the ventrolateral grey matter in which the cells of origin of somatic efferent neurones, commonly described as lower motor neurones, are located.

SPINAL NERVES

Each spinal cord segment gives rise to a pair of spinal nerves. These are formed by fusion of a dorsal and ventral nerve root which carry sensory and motor fibres respectively. Fusion occurs at the level of the intervertebral foramen distal to the spinal ganglion, which is a localised swelling of the dorsal root containing the cell bodies of sensory neurones. The dorsal and ventral roots are enclosed within separate dural sheaths which are confluent with the epineurium of the spinal nerve. After emerging through the intervertebral foraminae the spinal nerves abruptly divide into three or four branches (Figure 1).

The ventral branch is the largest of the spinal nerve branches. The brachial plexus is formed by the ventral branches of spinal nerves which arise from the cervical enlargement. Ventral branches which form the plexus pass between the scalenus muscle laterally and the longus capitis muscle medially to enter the axillary space. During this course the nerves divide and then recombine in a variable manner with adjacent ventral branches in the common plexus bundle to form the peripheral nerve trunks of the forelimb. Allam and others (1952) described the presence of three major nerve cords (trunci plexus) interposed between the ventral branches and the peripheral nerves.

The dorsal branch sub-divides into medial and lateral branches which innervate epaxial structures.

The meningeal branch re-enters the spinal canal via the intervertebral foramen to innervate vertebral ligaments, blood vessels and meninges.

An additional visceral or sympathetic branch arises from the T1 and T2 spinal nerves. This branch carries preganglionic sympathetic fibres to the sympathetic trunk via the ramus communicans.

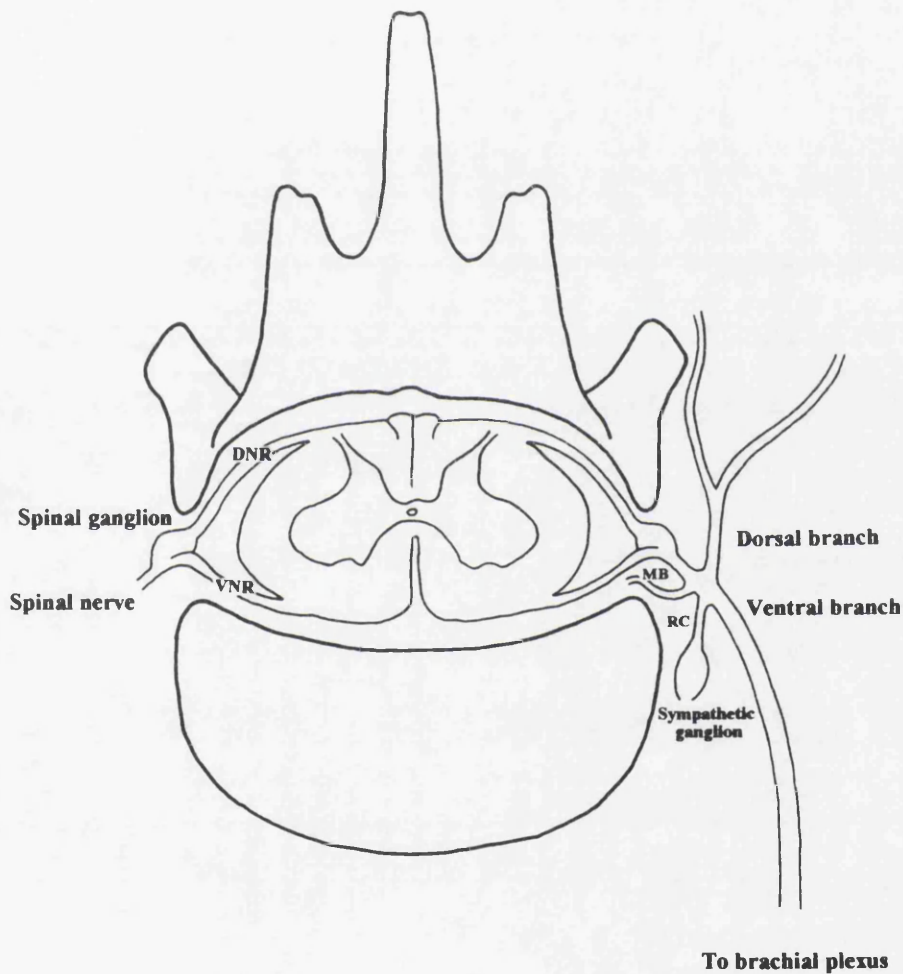


Figure 1

Anatomy of the spinal nerve branches.

(DNR) dorsal nerve root; (VNR) ventral nerve root; (MB) meningeal branch; (RC) ramus communicans.

SEGMENTAL ORIGINS OF THE BRACHIAL PLEXUS

While the general pattern of the brachial plexus is standard within a species, there is individual variation both in the number of segments which contribute to the plexus and in the way in which fibres from these segments are distributed to the peripheral nerves.

A number of different techniques have been used to investigate the segmental origins and peripheral distribution of the brachial plexus including anatomical dissection (Miller 1934, Allam and others 1952, Bailey and others 1982), retrograde cell degeneration methods (Sterling and Kuypers 1967), axonal transportation of horseradish peroxidase and other tracers (Nyberg and Blomqvist 1985, Mutai and others 1986) and electrophysiological techniques (Kitchell and others 1980, Bailey and others 1982, Sharp and others 1990, Sharp and others 1991).

These investigations have shown that the C6 to T1 cord segments consistently contribute significant numbers of axons to the brachial plexus. Occasionally, branches of the C5 and T2 spinal nerves may also be involved. Allam and others (1952), in a series of fifty-eight dissections, found that the plexus originated from segments C6 to T1 in thirty-four dogs (59%). An additional contribution from C5 was found in twelve dogs (21%) and from T2 in ten dogs (17%). Contributions from both C5 and T2 were present in only two dogs (3%). Bailey and others (1982) also found these four patterns of innervation; however, in their study of ten dissections the C6 to T2 pattern was most frequently encountered. In electrophysiological studies of motor nerves by Sharp and others (1990, 1991) and cutaneous nerves by Bailey and others (1982), contributions from the C5 segment were not found. Where branches of the C5 and T2 spinal nerves were involved in plexus formation their contribution was minor compared with that of other segments. Grossly, these branches were less than one millimetre in diameter (Evans 1993) and in the quantitative studies by Sharp and others (1990, 1991) the T2 segment contributed less than twelve per cent of fibres to any of the peripheral nerves.

NERVES ARISING FROM THE BRACHIAL PLEXUS

The nerves arising from the brachial plexus supply all the intrinsic and some extrinsic muscles of the forelimb and the cutaneous trunci muscle of the flank. In addition, all of the cutaneous nerves of the forelimb arise from the brachial plexus. The segmental contributions to each nerve are discussed and are summarised in Figure 2. The motor functions of the major peripheral nerves of the forelimb are detailed in Table 1.

Cutaneous innervation of the forelimb of the dog has been mapped by Kitchell and others (1980), Bailey and others (1982) and Bailey and Kitchell (1984) and is illustrated in Figure 3.

NERVES SUPPLYING INTRINSIC FORELIMB MUSCLES

Suprascapular Nerve

The suprascapular nerve arises principally, and in some cases solely, from the C6 segment (Evans 1993). The C7 segment commonly contributes fibres (Allam and others 1952, Sharp and others 1991) and a minor input from C5 has also been described (Miller 1934). This nerve supplies the supraspinatus and infraspinatus muscles which act principally to extend and abduct the shoulder respectively. The suprascapular nerve has no cutaneous branches.

Subscapular Nerve

This nerve is formed by approximately equal contributions from the C6 and C7 nerve roots (Miller 1934, Allam and others 1952, Sharp and others 1991). Occasionally, the fibres arising from the two nerve roots do not anastomose, resulting in a double nerve (Evans 1993). Cranial and caudal branches of this nerve innervate the subscapularis muscle which adducts and extends the shoulder and advances the humerus. The nerve is proportionately longer than the distance between the nerve roots and the muscle, to allow for extensive movement of the proximal limb relative to the thorax during locomotion. The subscapular nerve has no cutaneous branches.

Axillary Nerve

The majority of fibres forming the axillary nerve arise from the C7 segment. Allam and others (1952) described it as the sole contributor. Sharp and others (1990) found that approximately ninety per cent of the motor fibres forming the axillary nerve arose from the C7 ventral root with the remainder originating from C6 in most cases. Miller (1934) stated that the nerve arises from segments C7 and C8. Contributions from C8 were uncommon in the dogs studied by Sharp and others (1990) and where present, they contributed only 0.2% of fibres. Studies of the cutaneous branch of the axillary nerve conducted by Bailey and others (1982) supported the findings of Sharp and others (1990). The axillary nerve innervates the flexor muscles of the shoulder and provides cutaneous sensation to the lateral brachium via the cranial lateral cutaneous brachial nerve (Kitchell and others 1980).

Musculocutaneous Nerve

Most authors agree that the major contribution to this nerve comes from the C7 segment and in one study this was thought to be the sole origin (Allam and others 1952). Miller (1934) recognised contributions from both the C7 and C8 nerve roots. Sharp and others (1990) found that the greatest number of fibres came from the C7 nerve roots but that C6 and C8 also contributed in all the dogs in their study. In addition, two dogs were found to have a minor contribution from T1. In studies of the cutaneous branch of the musculocutaneous nerve Bailey and others (1982) reported similar findings to those of Sharp and others (1990). C8 was not found to contribute to the cutaneous branch in a single individual studied by Nyberg and Blomqvist (1985). The musculocutaneous nerve innervates the flexors of the elbow via three muscular branches; the most proximal of these occasionally arising as a separate structure from C8, T1, or both (Evans 1993). An anastomotic branch separates from the main nerve trunk to anastomose with the median nerve at the level of the proximal collateral radial artery (Evans 1993). The musculocutaneous nerve terminates as the medial cutaneous antebrachial nerve which provides cutaneous sensation to the medial antebrachium to the level of the carpus.

Radial Nerve

This is the largest and most important nerve of the plexus in terms of limb function. The radial nerve may receive fibres from all the ventral roots which contribute to the plexus and thus its composition varies between individuals. Sharp and others (1991) showed that the C8 segment contributed the greatest number of fibres followed by the T1 and C7 segments. Fibres from these segments were consistently present in all the radial nerves studied. In some animals, minor contributions from C6, or more rarely T2, were also noted. The findings of Miller (1934) and Allam and others (1952) were similar except that contributions from T2 were thought to be more frequent than those from C6. Bailey and others (1982) found that C7 and C8 fibres consistently contributed to the medial and lateral branches of the superficial radial nerve. Additional fibres from T1 were frequently present in the lateral branch, in contrast to the medial branch where C6 fibres were more commonly found.

The deep branch of the radial nerve innervates the extensors of the elbow, carpus and digits. The superficial branch, which arises just proximal to the elbow, supplies the skin of the cranial lateral antebrachium and the dorsum of the paw (with the exception of the dorsolateral fifth digit) via the cranial and lateral cutaneous antebrachial nerves.

Median Nerve

Sharp and others (1990) stated that the median nerve arises principally from the C8 and T1 nerve roots with minor contributions from C7 and T2. Miller (1934) also described a minor contribution from C6. Branches from C6 and C7 were not encountered by Allam and others (1952) in their dissection studies. In the proximal third of the brachium the median nerve is loosely attached to the cranial aspect of the ulnar nerve. The combined nerve trunks lie between the brachial artery and vein and separate in the distal third of the brachium. The median nerve supplies motor fibres to flexors of the carpus and digits. The cutaneous branch of the median nerve divides into medial and lateral branches which provide cutaneous sensation to the palmar aspect of the medial paw via the palmar common digital nerves I-III. These nerves anastomose with branches of the ulnar nerve to supply the digits. The palmar digital nerve supplying the first digit arises directly from the medial branch.

Ulnar Nerve

In a study by Sharp and others (1990), over half the fibres forming the ulnar nerve arose from the T1 segment. C8 consistently made a significant contribution and a small number of fibres from T2 and C7 were noted in some individuals. Mutai and others (1986) found a similar pattern, although C7 fibres were not found to contribute in their study. This is consistent with the findings of Allam and others (1952). Miller (1934) also listed C5 and C6 as minor contributors. The ulnar nerve supplies flexors of the carpus and digits and the interosseous muscles of the foot. Cutaneous sensation over the caudolateral antebrachium is provided by the caudal cutaneous antebrachial nerve. The dorsal cutaneous nerve supplies the lateral side of the palmar aspect of the manus and the dorsum of the fifth digit via palmar and dorsal branches. Terminations of these branches anastomose with branches of the median nerve to innervate the skin, joints and pads of the digits.

NERVES SUPPLYING EXTRINSIC FORELIMB MUSCLES

Brachiocephalic Nerve

This nerve is derived mainly from the C6 segment. Sharp and others (1991) found that significant additional contributions from C7 were common and an occasional input from a small branch of C5 was reported by Allam and others (1952). Bailey and others (1982) found that the cutaneous branch of the brachiocephalic nerve contained fibres originating

from C6 in all dogs included in their study, with additional fibres from C7 in a small number of animals.

This nerve supplies the brachiocephalicus muscle, whose main action is to advance the limb. Innervation of this muscle is shared with medial branches of the third and fourth cervical nerves (Evans 1993). A small cutaneous branch supplies the skin of the cranial brachium.

Cranial Pectoral Nerves

A variable number of cranial pectoral nerves arise from the C6, C7 and C8 ventral branches (Evans 1993) to innervate the superficial pectoral muscles which adduct the limb and contribute to protraction or retraction of the limb.

Long Thoracic Nerve

This nerve arises from C7 to supply the thoracic portion of the serratus ventralis muscle (Evans 1993).

Dorsal Thoracic Nerve

This motor nerve is recognised by most authors to arise predominantly from C7 and C8 (Miller 1934). Allam and others (1952) found that fibres from C6 augmented the nerve in one dog whereas a small contribution from T1 was found in a significant number of dogs by Sharp and others (1991). The thoracodorsal nerve innervates the latissimus dorsi muscle which acts to draw the limb backward as the shoulder is flexed.

Lateral Thoracic Nerve

This nerve arises predominantly from C8 and T1 with a minor contribution from T2 in some dogs (Sharp and others 1990). It supplies motor fibres to the cutaneous trunci muscle of the flank. Branches of this nerve also supply parts of the deep pectoral muscles (Evans 1993). It has no cutaneous sensory function.

Caudal Pectoral Nerves

A number of branches originating from C8, T1, T2 and the proximal lateral thoracic nerve innervate the deep pectoral muscles (Evans 1993). These muscles contribute to shoulder extension and backward movement of the limb.

OTHER RELATED NERVES

Phrenic Nerve

The paired phrenic nerves, which innervate the diaphragm, are not generally considered to be part of the brachial plexus as their fibres branch from the fifth, sixth, seventh and occasionally fourth cervical nerves proximal to the common plexus bundle (Evans 1993). They are included here as they may be affected by brachial plexus disease due to their common segmental origins and anatomical proximity to the plexus. The left and right phrenic nerves provide both motor and sensory innervation to the diaphragm. Unilateral phrenic nerve lesions result in hemiparesis or hemiplegia of the diaphragm and bilateral lesions cause complete paralysis. Such lesions are rarely associated with respiratory signs (Molenaar and others 1987).

Sympathetic nerve supply to the pupil

Cell bodies of preganglionic sympathetic fibres are located in spinal cord segments T1 to T3. These fibres exit the cord through the ventral nerve roots and pass via the ramus communicans to the thoracic sympathetic trunk. They pass cranially through the cervicothoracic (stellate) and middle cervical ganglia and synapse with postganglionic fibres in the cranial cervical ganglion. Postganglionic fibres then pass via the ophthalmic branch of the fifth cranial nerve to the eye where they innervate smooth muscle of the periorbital, eyelids, third eyelid and dilator muscle of the iris (Collins and O'Brien 1990). Brachial plexus lesions involving the first or second thoracic ventral nerve roots may interrupt this pathway.

Suprascapular	(C5)	C6*	C7			
Subscapular		C6*	C7			
Axillary		C6	C7*	(C8)		
Musculocutaneous		C6	C7*	C8	(T1)	
Radial		(C6)	C7	C8	T1	(T2)
Median		(C6)	(C7)	C8	T1	(T2)
Ulnar	{C5}	{C6}	(C7)	C8	T1*	(T2)
Brachiocephalic	(C5)	C6*	C7			
Cranial pectoral		C6	C7	C8		
Long thoracic			C7*			
Dorsal thoracic		(C6)	C7*	C8	(T1)	
Lateral thoracic				C8	T1*	(T2)
Caudal pectoral				C8*	T1	T2
Phrenic		C5	C6	C7		
Ocular sympathetic					T1	T2 T3

Figure 2

Summary of segmental contributions to the major peripheral nerve trunks of the canine forelimb. Segments in parentheses contribute inconsistently or make up <10% of the nerve (Sharp and others 1990, 1991). * indicates that fibres from this segment form > 50% of the nerve. {} denotes that contributions from these segments are rare.

NERVE	MUSCLE	PRINCIPAL ACTION
Suprascapular	Supraspinatus Infraspinatus	Extends shoulder Draws limb forward Abducts / outwardly rotates humerus Contributes to flexion and extension of shoulder
Subscapular	Subscapularis	Adducts / extends shoulder Advances humerus
Axillary	Teres major Deltoides Teres minor	Flexes shoulder Draws humerus backward. Flexes shoulder Flexes shoulder
Musculocutaneous	Coracobrachialis Biceps brachii Brachialis	Extension / abduction of shoulder Flexes elbow Flexes elbow
Radial (Deep branch)	Triceps brachii Anconeus Extensor carpi radialis Supinator Common digital extensor Lateral digital extensor Ulnaris lateralis Abductor pollicis longus Extensor pollicis longus et indicus proprius	Extends elbow Extends elbow Extends carpus Supinates forearm Extends digits II to V Extends digits III to V Extends carpus Abducts / extends digit I Extends digits I and II Adducts digit I
Median	Pronator teres Flexor carpi radialis Deep digital flexor (DDF) Superficial digital flexor Pronator quadratus	Flexes elbow Pronates forearm Flexes carpus Flexes carpus and digits Flexes digits II to V Pronates paw
Ulnar	Flexor carpi ulnaris Humeral head DDF Ulnar head DDF	Flexes paw with abduction Flexes carpus and digits Flexes carpus and digits
Brachiocephalic	Brachiocephalicus	Advances limb
Cranial pectoral	Superficial pectoral	Adducts limb Advances or retracts limb
Long thoracic	Serratus ventralis (thoracic portion)	Moves shoulder forward or back
Thoracodorsal	Latissimus dorsi	Draws limb backward as shoulder is flexed
Lateral thoracic	Cutaneous trunci and part of deep pectorals	Twitches skin over flank
Caudal pectoral	Deep pectoral	Extends shoulder Retracts limb caudally

Table 1
Motor innervation of the canine forelimb.

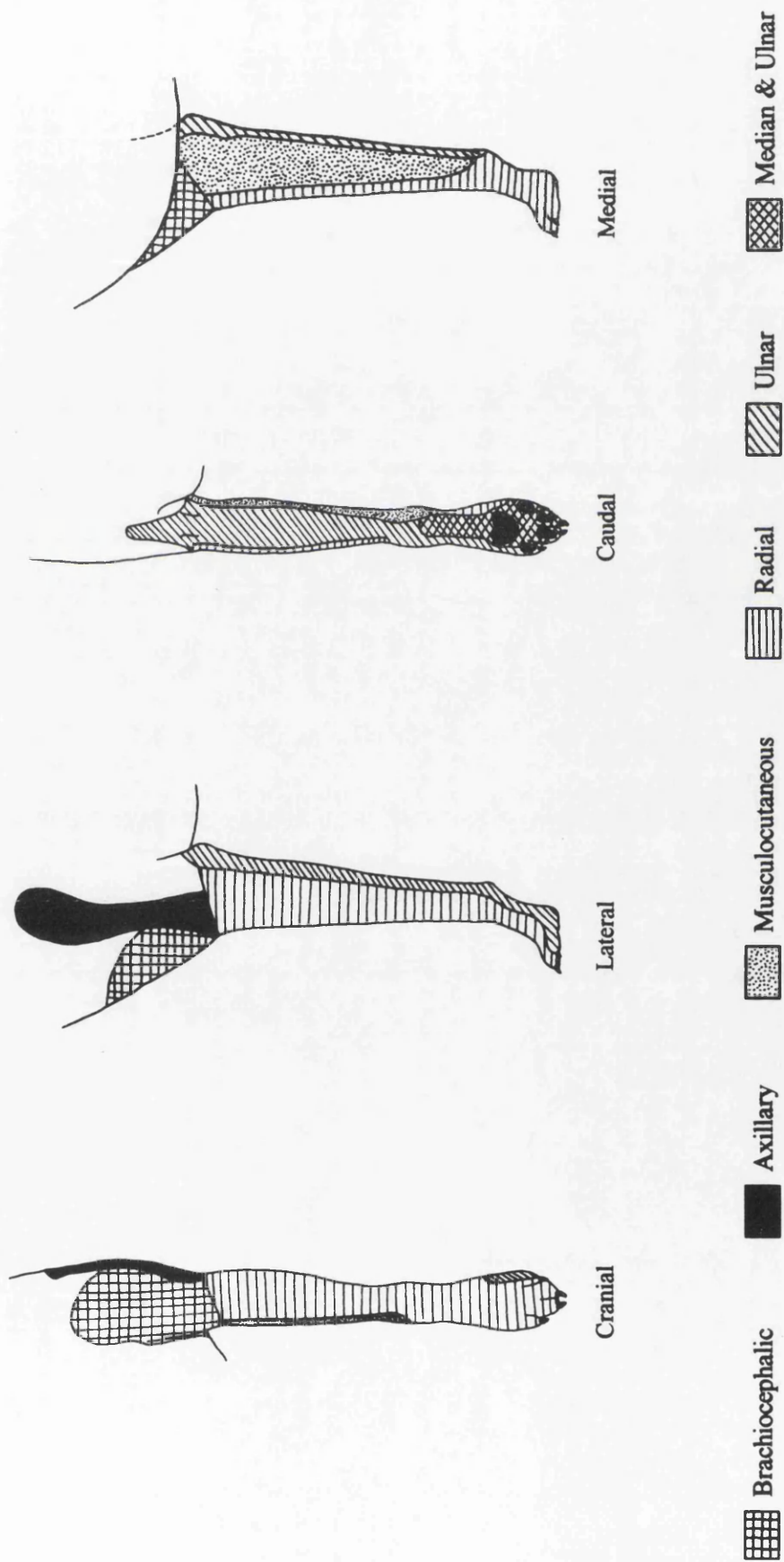


Figure 3A

Cutaneous innervation of the canine forelimb showing the major nerve supply in each area. Overlapping of adjacent cutaneous zones means that the areas shown do not correspond accurately with areas of cutaneous sensory loss seen with peripheral nerve injury.

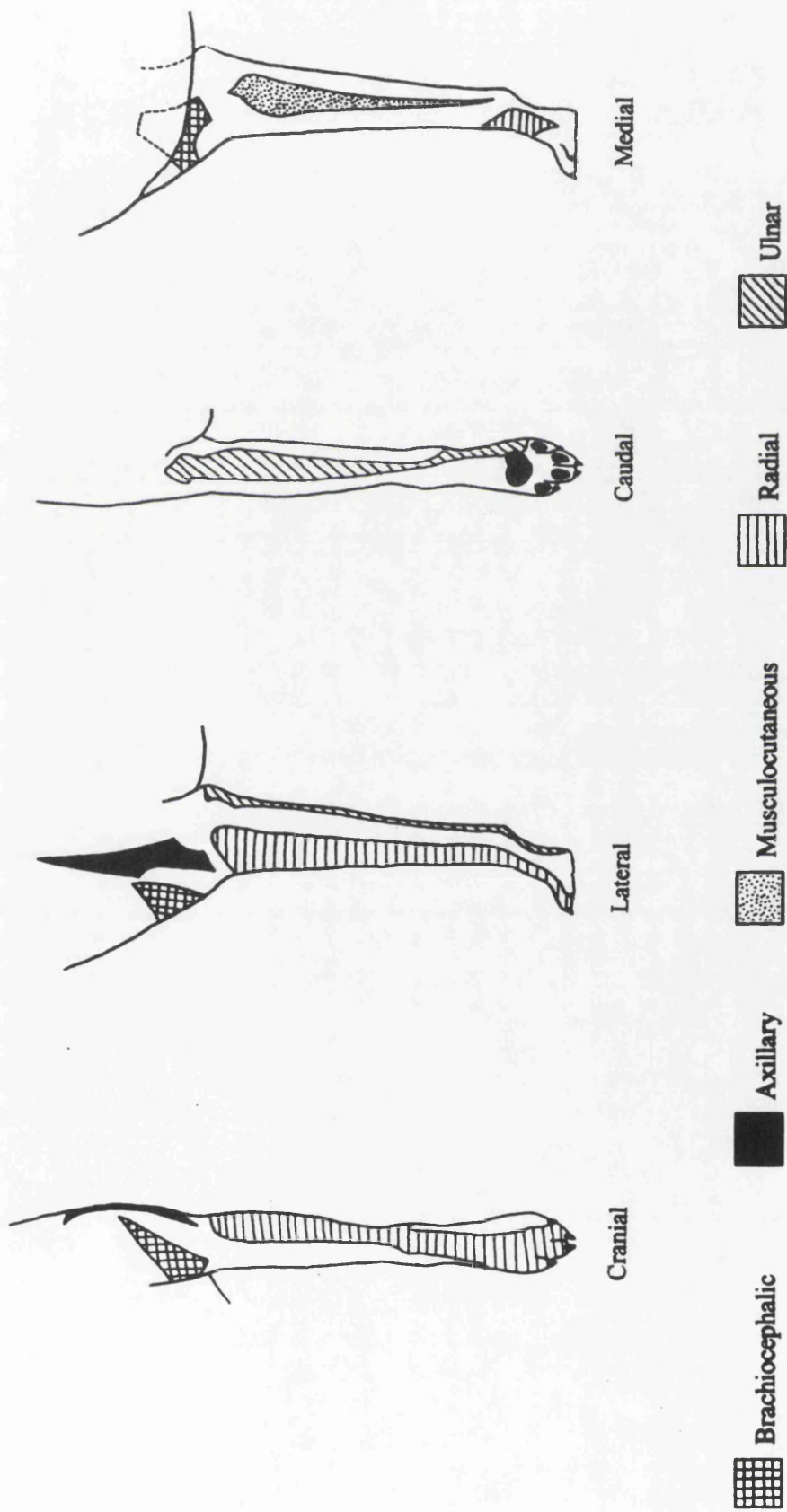


Figure 3B

Autonomous zones of the canine forelimb. Following injury to an individual peripheral nerve sensory loss is restricted to the areas shown. (Adapted from Bailey and Kitchell 1984).

GENERAL COMMENTS

The anatomy of the brachial plexus shows considerable variation between species with the structure being directly related to the functions required of the limb (Miller 1934). While the general pattern of the plexus remains standard within a species, minor variations in the segmental composition of the plexus and peripheral nerves commonly occur. Some of these reported variations may be due, in part, to the wide variety of techniques employed to study this area, however the character of these variations is consistent. Nerve roots which contribute inconsistently to the plexus (i.e. C5 and T2) are on the periphery of the plexus and contribute only a small number of fibres. Similarly, in individual peripheral nerves, variation was only seen with nerve roots which made minor contributions to the nerve. Quantitative studies by Sharp and others (1990, 1991) showed that nerve roots which contributed inconstantly to a particular nerve (i.e. were not present in all dogs studied) made up less than seventeen per cent of the nerve. When a particular nerve root contribution was found in less than half the animals this figure fell to less than two per cent.

Innervation of the limb muscles demonstrates a general pattern in that muscles which lie cranially and proximally in the limb receive their innervation from cranially orientated nerve roots and muscles which are caudal and distal in the limb are innervated by caudally derived nerve roots. Sharp and others (1990, 1991) noted a number of exceptions to this general rule and attributed this variation to tissue migration during embryological development. In the embryo, muscle precursor cells are grouped into myotomes with each myotome receiving its motor innervation from a single spinal nerve (Jenkins 1978). As the embryo matures, these myotomes migrate and differentiate into skeletal muscle. Individual muscles are composed of cells from more than one myotome and each myotome contributes to a number of different muscles. Based on the findings of Sharp and others (1990, 1991) each forelimb muscle usually comprises tissue from two or three myotomes, however the teres major muscle may be derived from a single myotome (C7) and the extensor carpi radialis muscle from as many as four. This is of some significance to the clinical assessment of limb function in that injury occurring at the myotomal level, i.e. the nerve root or ventral ramus, results in partial dysfunction of a number of muscles rather than isolated paralysis of individual muscles.

The work of Kitchell and others (1980) and Bailey and others (1982) demonstrated that the cutaneous innervation of the limb follows a similar pattern to motor innervation in that proximal and cranial regions tend to be supplied by spinal roots from the cranial end of the cervical enlargement whereas caudal and distal parts receive their innervation from

caudal nerve roots. The intermingling of sensory fibres in the plexus results in a complex pattern of cutaneous innervation in the limb, in comparison to the relatively simple dermatomal pattern of the thoracic nerves. Cutaneous innervation to the limb is generally described in terms of peripheral cutaneous nerve fields, or cutaneous areas, defined as the total area of skin supplied by a particular cutaneous nerve. This area is divided into an autonomous zone which describes the area of skin supplied solely by that nerve, and an overlap zone in which the skin is also innervated by fibres from adjacent overlapping cutaneous areas. The cutaneous areas comprise tissue derived from a number of dermatomes, a dermatome being the mass of dermal tissue which is innervated by a single spinal nerve. An exception to this is the cutaneous branch of the brachiocephalic nerve which commonly consists of fibres from C6 only (Bailey and others 1982). An understanding of cutaneous innervation is relevant to the clinical evaluation and localisation of brachial plexus diseases. Injuries affecting specific cutaneous nerves can be identified by sensory deficits in the relevant autonomous zone. Lesions occurring at the level of the nerve roots or ventral branches result in a dermatomal distribution of sensory loss which is more difficult to evaluate clinically unless several dermatomes are affected.

SECTION 1: PART 2

PATHOLOGICAL CONSIDERATIONS

This section presents a summary of the pathological changes which may occur as a consequence of brachial plexus injury or disease and briefly describes mechanisms of reinnervation and factors which influence the healing process. A basic understanding of these processes is essential to the evaluation and management of brachial plexus diseases as they determine the potential for recovery and influence the choice of therapy. Some knowledge of these processes is also required for the interpretation of certain diagnostic procedures, notably electrophysiological testing.

NERVE INJURY

The pathological changes which result from acquired brachial plexus or peripheral nerve disease are limited to two major types, irrespective of aetiology. These changes may affect the axons themselves, resulting in axonal degeneration, or may target the Schwann cells, leading to demyelination. In many diseased nerves the two processes co-exist, but one type may predominate. In some conditions the nerve may be infiltrated by inflammatory or neoplastic cells or, rarely, infectious agents. Nerve injury and reinnervation are described with particular reference to trauma as this is the most common and closely studied form of nerve damage, however the general principles also apply to other forms of brachial plexus disease.

TRAUMATIC INJURY

Classification of Nerve Injuries

The classical nerve injury results from trauma which may be due to cutting, stretching, tearing, compression or burning (Dyck and others 1984). In 1943, Seddon classified nerve injury into three groups; neuropraxia, axonotmesis and neurotmesis. This classification was extended by Sunderland (1951) who described five degrees of nerve injury. Both classifications are based upon the extent of damage to the axon and connective tissue components of the nerve. Many natural injuries are mixed lesions in that individual fibres are affected to different degrees. In partial lesions a proportion of fibres are spared. A detailed review of the anatomy and physiology of nerve injury was provided by Sunderland (1990). The basic morphology of a mixed peripheral nerve is illustrated in Figure 4.



H & E x 12

Figure 4

Cross-section of a mixed peripheral nerve demonstrating the basic morphology. Myelinated and non-myelinated nerve fibres are surrounded by the endoneurium (En) and are grouped into fascicles which are separated by the perineurium (Pn). The outermost connective tissue layer, the epineurium (Ep), surrounds the entire nerve trunk.

First degree injury is the least severe form of injury in which there is failure of intact axons to transmit impulses across the injured part of the nerve. This commonly results from compression or mild traction (Thomas and Holdorff 1984). Focal demyelination may occur at the site of injury. If mixed nerves are affected pain sensation is often preserved. First degree injury is equivalent to neuropraxia (Seddon 1943).

In second degree injury the axon is transected within an intact endoneurium. The injury often results from stretching or crushing of the nerve. Second degree injury is equivalent to axonotmesis as described by Seddon (1943).

In third degree injury, there is loss of continuity of both axon and endoneurium but the fascicular structure of the nerve is preserved. These injuries are complicated by intrafascicular haemorrhage, inflammation and fibrosis (Sunderland 1990). Some of the cases classified as axonotmesis by Seddon (1943) demonstrated features of third degree injury.

In fourth degree injuries there is rupture of the perineurium with disruption of the nerve fascicles. Nerve trunk continuity is maintained by disorganised strands of epineurium. Fifth degree injury describes complete transection of the nerve trunk. Fourth and fifth degree injuries are equivalent to neurotmesis which Seddon (1943) defined as "a lesion of such severity that all essential parts of the nerve are destroyed".

Effects of Transection Injuries on the Nerve

Wallerian Degeneration

If a nerve fibre is transected, either mechanically or by focal disease, the distal portion which is separated from the cell body degenerates. This process is termed Wallerian, or secondary, degeneration. The structural changes which occur have been summarised by Dyck and others (1984). Degeneration progresses distally from the site of injury and breakdown of the nerve fibre is usually complete by two to three weeks (Jenkins 1978).

Retrograde Degeneration and Chromatolysis

Changes typical of Wallerian degeneration also occur in the proximal stump of transected nerves adjacent to the site of injury. The extent of retrograde degeneration is partly related to the type of injury sustained (Banks 1986). Following surgical section of the nerve, retrograde changes are minimal involving only a few internodes. In more extensive injuries, such as those resulting from tearing of the nerve, retrograde degeneration may extend proximally for several millimetres (Jenkins 1978).

Following injury to the axon, the cell body also undergoes a number of changes, collectively described as chromatolysis or the axonal reaction. These have been reviewed by Price and others (1984). In many cases these changes are reversible and the axon is capable of regeneration but in some circumstances, notably injuries situated close to the cell body, this process of chromatolysis may result in cell death and permanent loss of the axon.

Distal nerve stump atrophy

Following Wallerian degeneration, axon and myelin debris are removed by phagocytosis. The endoneurial tubes gradually shrink in diameter over a three month period following injury (Sunderland 1990). The cross-sectional area of the fasciculi is reduced by up to seventy percent during this period with the majority (85%) of shrinkage occurring in the first two months. These changes are irreversible and may hinder functional recovery by preventing full maturation of regenerated fibres. This would suggest that, in cases where surgical repair of nerve injuries is indicated, prompt repair is desirable although this may only be a significant factor in injuries which are located sufficiently close to the target tissue that reinnervation could be achieved within the critical period.

Effects of Nerve Transection on Muscle

Degeneration of motor neurones produces secondary degenerative changes in denervated muscle fibres. The resting membrane potential falls, extrajunctional sensitivity to acetylcholine increases and muscle acetylcholinesterase activity decreases (Max and Mayer 1984, Drachman 1986). More importantly from a clinical perspective, the muscle fibres atrophy. The denervated muscle fibres become electrically unstable resulting in random firing of individual fibres, known as spontaneous electrical activity (Bowen 1987). The precise mechanisms which bring about these changes are not fully understood. It has been suggested that trophic factors, essential for normal muscle function, are synthesised in the nerve cell body and conducted to the muscle by axonal transport mechanisms. Following denervation the muscle would be deprived of such factors, resulting in degeneration. This topic has been reviewed by Max & Mayer (1984). The potential role of acetylcholine as a trophic factor has been reviewed by Drachman (1986).

It is worth noting that muscle atrophy and spontaneous electrical activity are not observed following neuropraxic injuries as the axon remains intact. The muscle is therefore not denervated, even though it may be paralysed.

NON-TRAUMATIC NERVE DISEASE

Axonal Degeneration

Wallerian-type degeneration may result from external compression by an adjacent mass, ischaemic transection, compression by infiltrating neoplastic cells, or at sites of active segmental demyelination (Dyck and others 1984). Occasionally, the cause may be obscure, as in brachial plexus neuritis (Cummings and others 1973, Cummings and de Lahunta 1977). Some polyneuropathies are characterised by primary axonal degeneration but these would rarely present as brachial plexus disease.

Demyelination

This may result from primary Schwann cell disease or may be secondary to axonal degeneration. Causes of primary demyelination which may affect the brachial plexus include mild trauma and compression, polyradiculoneuritis and globoid cell leukodystrophy (Weller 1992).

Cellular Infiltration

Nerves may be infiltrated by neoplastic cells arising from the nerve sheath (Goedegebuure 1975, Le Couteur 1989), metastatic cells such as malignant lymphocytes (Fox and Gutnick 1972) and neoplastic cells which directly invade the nerve from adjacent non-neural tumours (Targett and others 1993).

Nerves or nerve roots may also be infiltrated by inflammatory cells. Leukocytic infiltration is typically seen with polyradiculoneuritis. Cell composition is variable but mononuclear cells and mast cells predominate (Cummings and others 1982). Increased numbers of mast cells have been reported with brachial plexus neuritis (Cummings and others 1973).

REINNERVATION

Functional recovery of denervated muscle can only occur if regenerating axons make appropriate connections with distal endoneurial sheaths and are redirected back to the target site. Reinnervation of muscle can be achieved by two principal mechanisms; regeneration of transected fibres from the proximal stump and collateral axonal sprouting of intact or regenerating fibres. The prognosis, in terms of the course of recovery and functional end-result, is dependent on several factors which are discussed.

Regeneration

If the cell body has survived, the axon will regenerate from the proximal stump. Multiple axonal sprouts proliferate from the termination of each axon. If conditions are favourable, the growing axons enter the endoneurial connective tissue sheaths of the distal stump and grow distally along this framework at the rate of approximately one to two millimetres per day (Trojaborg 1970).

Factors affecting Regeneration

Severity of Injury

Injuries which cause damage to the connective tissue components of the nerve, namely third, fourth and fifth degree injuries, are complicated by haemorrhage, oedema and ischaemia within the nerve. This leads to the formation of fibrous tissue which is the most significant obstacle to nerve regeneration. Rupture of the endoneurium and perineurium also enables regenerating axons to make aberrant, non-functional connections with the distal nerve stump with distortion of the innervation pattern. This subject has been comprehensively detailed by Sunderland (1951). The following is a summary of the most significant points.

In neuropraxic injuries the axon remains intact so axonal degeneration does not occur and the pattern of innervation is not disrupted. The duration of the conduction block, caused by undefined axonal disturbances, varies from minutes to up to sixty days in extreme cases (Sunderland 1951). In animals, the average duration of paralysis resulting from such injuries appears to be approximately one to two weeks. This is followed by rapid and complete recovery. Proximal and distal muscles recover at the same rate.

With axonotmesis regenerating fibres are retained within the endoneurium and are guided back to their original terminations so complete functional recovery is predictable. Recovery is first noted in proximal muscles and progresses distally. The rate of recovery is determined by the distance that the fibre must regenerate.

In the case of third degree injury endoneurial continuity is disrupted and regenerating fibres may enter inappropriate distal sheaths and be lost. Intrafascicular fibrosis or neuroma may develop and obstruct regenerating fibres. This type of injury is therefore associated with incomplete recovery of function.

Neurotmesis results in disruption of the fascicular structure of the nerve and attempts at regeneration are, in the main, misdirected or obstructed by fibrosis with subsequent neuroma formation. This type of injury carries a very poor prognosis for spontaneous recovery.

Distance between severed ends

Small gaps between proximal and distal nerve sheaths can be bridged by regenerating axons, however if the majority of the nerve trunk is severed, as in fourth and fifth degree injuries, then the ends retract, leaving a substantial gap which rapidly becomes filled with connective tissue. The nerve stumps may also fall out of alignment which further reduces the chance of regenerating axons connecting with the distal stump. Primary surgical repair of fourth and fifth degree injuries is indicated to maximise the potential for recovery (Sunderland 1990). This is the only factor which can currently be modified by therapy.

Retrograde Degeneration

A significant factor in the potential for regeneration is the number of fibres which are lost due to the effects of retrograde degeneration. If the cell body is destroyed then the neurone is permanently lost. Retrograde degeneration is largely dependant upon the nature of the injury and the proximity to the perikaryon. Tearing or extensive crushing injuries cause more widespread damage to the nerve and greater degeneration (Banks 1986). More severe grades of injury also have a higher rate of proximal degenerative changes. Lesions which are sited close to the cell body are more likely to result in irreversible chromatolysis (Jenkins 1978).

Length of the distal stump

The further the regenerating axon must travel to reach the target tissue then the longer the healing process takes and the less complete the recovery is likely to be. This may be due in part to distal stump atrophy but degenerative changes in the limb such as irreversible muscle fibrosis and contractures and joint fixation are also significant.

Collateral axonal sprouting

Intact axons, which have escaped injury or have successfully regenerated, may also produce axonal sprouts from the nerve endings (terminal sprouts) or nodes of Ranvier (nodal sprouts) (Max and Mayer 1984). These axonal sprouts reinnervate neighbouring muscle fibres of denervated motor units. The proportion of intact fibres and those affected by first and second degree injury is therefore a significant factor in the potential for further recovery. Axonal sprouting results in motor units of increased size (Griffiths and Duncan 1974) and fibre type grouping is observed on histochemical examination of muscles reinnervated in this way (Braund 1991).

SECTION 1: PART 3

CLINICAL AND DIAGNOSTIC FEATURES OF BRACHIAL PLEXUS DISEASE

GENERAL CLINICAL ASPECTS OF BRACHIAL PLEXUS DISEASE

The clinical features of brachial plexus disease are variable depending upon the aetiology, the anatomical distribution of the lesion within the plexus and the severity of nerve injury. Complete evaluation of brachial plexus disease is achieved by neurological and systemic examination, consideration of signalment and history and the judicious use of ancillary diagnostic techniques. Brachial plexus disease is identified and differentiated from other conditions on the basis of clinical examination of motor and sensory function which also provides information regarding the distribution of the lesion and its severity (Griffiths 1992). A complete neurological examination should include assessment of demeanour, gait, postural reactions, spinal reflexes and cranial nerve functions. The procedure for neurological examination and details of specific tests are extensively described in the literature (Oliver and Mayhew 1987, Chrisman 1991, Griffiths 1992). General systemic examination is indicated to determine the presence of concurrent abnormalities which may be related to the nervous signs and may suggest an aetiology, or which may be unrelated but which may have a bearing on the management of the case. Cardiovascular disease or pulmonary trauma may render the animal unsuitable for certain investigative procedures involving general anaesthesia. Musculoskeletal disease, for example osteoarthritis, may limit management options such as limb amputation. The signalment, history and time course of the disease often provide information concerning the aetiology.

Clinical Features

The major presenting sign of brachial plexus disease is a gait abnormality of one or both forelimbs which may vary in severity from mild lameness to complete paralysis. Lameness may be due to pain or paresis or both. Wheelbarrow or hopping tests may be necessary to demonstrate extensor weakness in less severely affected cases. Tests of conscious proprioception may also be abnormal indicating that lameness is due to neurological rather than musculoskeletal disease. This is a particularly useful finding in mildly affected animals.

Paresis resulting from brachial plexus disease, as with any peripheral nerve disease, is caused by damage to lower motor neurones which conduct impulses from the CNS to the skeletal muscle. They also form the effector portion of the spinal reflex arc which is the functional unit responsible for maintenance of muscle tone, phasic stretch reflexes and nociceptive reflexes. Consequently, all or some of the forelimb reflexes are typically diminished or absent with lesions involving the brachial nerves. Passive flexion and extension of the limb may demonstrate hypotonia, which can be generalised or restricted to certain muscle groups. In the forelimb, phasic stretch reflexes are inconsistent, even in normal animals, and are of little clinical value. The pedal, or withdrawal, reflex may demonstrate lesions affecting flexor muscles. Lesions of the axillary, musculocutaneous and median and ulnar nerves or their origins result in loss of shoulder, elbow and carpal flexion respectively. Lesions affecting afferent fibres will also compromise the reflex. Radial nerve injuries, for example, cause loss of sensation over the dorsum of the paw with the exception of the fifth digit so stimulation of this region fails to elicit a pedal reflex even though flexor muscle function is normal. Normal reflex function would be demonstrated by stimulating the palmar aspect of the foot or the fifth digit.

Lower motor neurone degeneration is associated with atrophy of affected muscles. This becomes clinically evident about ten to fourteen days after injury and is reversible if the muscle is reinnervated.

The panniculus reflex may be altered with lesions involving the C8 and T1 ventral branches proximal to the plexus or the lateral thoracic nerve. Unilateral lesions result in loss of both the ipsilateral and consensual motor response on the affected side. Integrity of the sensory portion of the reflex is confirmed by observing a consensual response to stimulation of the affected side. Bilateral lesions abolish the reflex.

Cutaneous sensation may be altered with brachial plexus disease, in which case the distribution of sensory deficits may help to establish the level of the lesion. Injuries of the peripheral nerve trunks tend to result in a predictable pattern of sensory loss, in contrast to nerve root or ventral branch lesions which are associated with a more variable dermatomal distribution of hypalgesia. The patterns of cutaneous desensitisation seen with both peripheral nerve and nerve root lesions have been described previously (Kitchell & others 1980, Bailey 1984, Bailey and Kitchell 1984).

Lesions involving the T1 ventral nerve root or spinal nerve affect pre-ganglionic sympathetic fibres supplying the smooth muscles of the iris, resulting in a partial Horner's syndrome with miosis of the pupil. Pupillary light reflexes are preserved as these are

controlled by the parasympathetic system. Fibres supplying the smooth muscle of the eyelids and periorbita arise mainly from the T2 and T3 segments so enophthalmos and protrusion of the membrana are not commonly seen, although some cases show a degree of ptosis. A full Horner's syndrome may occur if invasive lesions, such as nerve root tumours, extend into the stellate ganglion.

An estimation of the lesion distribution within the structures of the plexus may be obtained from the neurological examination. Proximal lesions, involving the nerve roots, ventral branches or common plexus bundle produce deficits affecting more than one peripheral nerve field and may involve the panniculus reflex or ocular sympathetic pathway. The distribution of these lesions indicates whether all contributing nerve roots or ventral branches are involved or whether the injury is restricted to cranial or caudal structures. Deficits that are restricted to a single nerve field indicate that the lesion lies distal to the common plexus bundle. The nerve involved can usually be identified from the deficits produced. The magnitude of motor and sensory dysfunction gives an indication of the severity of the lesion in terms of partial or complete nerve damage.

Differentiation of Forelimb Paresis

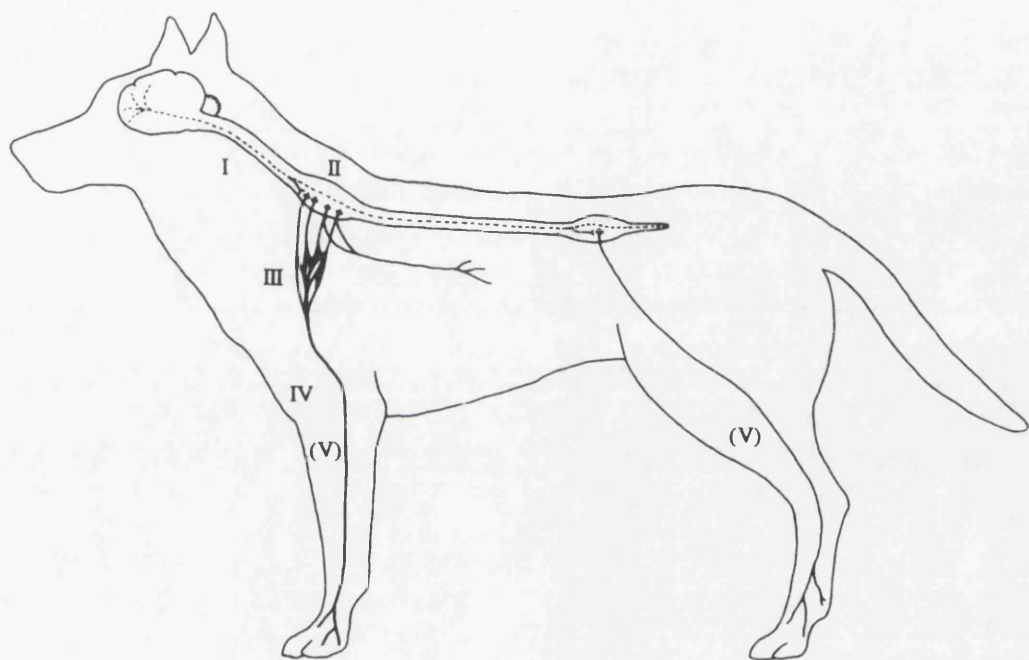
Brachial plexus disease must be differentiated from other causes of forelimb paresis, including cervical spinal cord disease, polyneuropathy and local or generalised musculoskeletal disease. This may be achieved by determining the distribution and character of motor deficits as illustrated in Figure 5.

If brachial plexus disease does not extend into the spinal canal then hindlimb function is normal. Primary nerve sheath tumours may develop within the spinal canal or extend proximally from the spinal nerve to invade or, more commonly, compress the spinal cord. This may lead to signs of a caudal cervical myelopathy.

Lesions of the caudal cervical spinal cord which involve the ventral horn cells of segments C6 to T1 also cause lower motor neurone deficits in the forelimbs. In contrast to peripheral nerve disease however, lesions at this site usually disrupt upper motor neurone pathways descending to the hindlimbs causing hemi- or paraparesis with preservation of local hindlimb reflexes. Spinal cord lesions at the brachial enlargement may resemble brachial plexus disease if there is selective destruction of the grey matter with relative sparing of the white matter tracts. This may occur with spinal cord infarction resulting from fibrocartilagenous embolism.

Polyneuropathy is typically generalised, causing lower motor neurone deficits in all four limbs, although the distribution can be asymmetric and one limb may be more severely

affected than the others. If there is predominantly forelimb involvement then the presentation may be suggestive of brachial plexus disease. Careful examination of these cases may reveal subtle lower motor neurone deficits in the hindlimbs or cranial nerves, alerting the examiner to the presence of a generalised condition.



Lesion Site		Forelimbs	Hindlimbs
I	C1 to C5	UMN	UMN
II	C6 to T1	LMN	UMN
III	Brachial plexus	LMN (deficits in more than one PN field)	Normal
IV	Peripheral nerve trunk	LMN (deficits in single PN field)	Normal
V	Polyneuropathy	LMN	LMN

Figure 5
Localisation of lesions causing forelimb paresis.

ANCILLARY DIAGNOSTIC TECHNIQUES

The clinical findings reflect the anatomical location and severity of the disease but rarely provide specific evidence of the aetiology. The signalment and history may indicate the cause but in many cases of brachial neuropathy, further investigation is indicated to confirm the diagnosis or to fully evaluate the underlying nature of the problem. This section provides a general overview of the techniques which may be employed in the investigation of brachial plexus disease and the type of information which they provide. Indications for each procedure vary with the different types of disease so the approach to the investigation must be guided by the clinical findings in individual cases. The application of ancillary techniques to specific diseases is discussed further in Part Four. Techniques which are employed in the investigation of brachial plexus disease include electrophysiological testing, radiography, surgical exploration and biopsy and blood and cerebrospinal fluid examination.

ELECTROPHYSIOLOGICAL EXAMINATION

Electrodiagnostic investigations include electromyography and nerve conduction studies, or electroneurography. These combined techniques provide an objective assessment of the distribution and relative severity of nerve lesions and give an indication of the type of pathology affecting abnormal nerves but do not provide an aetiological diagnosis. The choice of particular nerves or muscles for study is based upon the clinical findings. The necessary equipment, examination techniques and underlying electrophysiological principles of electrodiagnostic testing have been reviewed by several authors (Griffiths and Duncan 1978, Steinberg 1979a, Bowen 1987, Niederhauser and Holliday 1989).

Electromyography

Electromyography (EMG) is used principally to detect spontaneous electrical activity in denervated muscles. Techniques for examining voluntary muscle activity in animals have also been reported but are less commonly applied (Griffiths and Duncan 1974).

Spontaneous electrical activity, in the form of fibrillation potentials and positive sharp waves (PSWs), is a feature of axonal degeneration (Drachman 1986). These potentials are not present immediately after injury but take up to seven days to develop (Griffiths and Duncan 1974). If loss of conduction is due to neuropraxic injury or primary demyelination, spontaneous potentials are absent as the axon remains structurally intact. These potentials may also be found in primary muscle diseases, but usually to a lesser extent (Griffiths and Duncan 1978). Electromyography is a sensitive indicator of

denervation and is particularly useful in cases where the effects of the nerve lesions may be sub-clinical. It therefore provides an accurate means of assessing the distribution of the lesion. Nerve root or spinal nerve lesions can be investigated by examining epaxial muscles (van Nes 1986). These muscles are supplied by dorsal branches of the spinal nerves which separate from the ventral branches at the level of the intervertebral foramen. Injuries proximal to the foramen affect both dorsal and ventral branches and denervation potentials can be recorded from the epaxial muscles. Lesions distal to this point spare the dorsal branches so that only limb muscles are affected. Neurogenic and disuse atrophy can be distinguished using EMG and the condition of muscles required for tendon relocation procedures can be assessed prior to surgery.

Electromyographic examination can provide prognostic information in traumatic nerve injuries (Steinberg 1979b) and may indicate the presence of reinnervation (Griffiths & Duncan 1974). Collateral axonal sprouting of intact nerve fibres to reinnervate denervated muscle effectively increases the size of the motor unit and therefore the amplitude of the motor unit potential. These motor unit potentials may also be polyphasic due to a reduced rate of conduction in the axonal sprouts (Griffiths & Duncan 1974).

Nerve conduction studies

Motor Nerve Conduction

Direct electrical stimulation of a peripheral nerve produces a muscle action potential described as an M wave, F wave or H wave depending upon the pathway involved in evoking the potential (Bowen 1987). Examination of the nerve conduction velocity and the amplitude, duration and character of evoked muscle action potentials provides information about the likely pathology of neural injury and an estimation of the proportion of fibres affected. In the forelimb the ulnar nerve is most commonly used to study motor nerve conduction as it is easily accessible. The radial and median nerves may also be examined (Walker and others 1979). Methods of examining motor nerve conduction and reference values for various peripheral nerves have been reported for the dog (Lee and Bowen 1970, Walker and others 1979, van Nes and van den Brom 1986) and cat (Malik and Ho 1989). Examination of nerve conduction is a useful aid to determining prognosis for traumatic injuries in particular. An estimation of the proportion of remaining functional fibres can be made and thus the potential for re-innervation by collateral axonal sprouting can be determined.

Evoked Muscle Action Potentials (EMAPs)

M Wave

The M wave is evoked by orthodromic, or normograde, transmission of nerve impulses from the site of stimulation to the muscle. Alterations in the latency, amplitude, duration and character of this potential are examined to assess the severity and pathological characteristics of the nerve lesion.

Latency

The latency of the M wave is used to calculate the motor nerve conduction velocity (Niederhauser and Holliday 1989). Conduction velocity is reduced in demyelinating disorders or with primary axonopathies (Niederhauser and Holliday 1989) and is not commonly observed in association with brachial plexus disease. If the dominant pathology is axonal degeneration then nerve conduction velocity usually remains normal if even a small proportion of functional fibres are retained. Nerve conduction velocity is influenced by age (Swallow and Griffiths 1977), body size (van Nes and van den Brom 1986) and tissue temperature (Lee and Bowen 1975).

Amplitude

The amplitude of the M wave is a function of the number of motor units contributing to the potential. If sufficient nerve fibres undergo degeneration the potential is abolished. In acute injuries the distal portion of the nerve will continue to conduct impulses until secondary axonal degeneration takes place (Griffiths and Duncan 1974). The EMAP progressively decreases in amplitude over 5 to 8 days then ceases. Partial degeneration of the nerve produces a potential of reduced amplitude (Griffiths and Duncan 1974).

Temporal dispersion

Temporal dispersion occurs principally as a consequence of demyelination and represents fibres conducting at variable rates depending on their degree of demyelination. Dispersion effectively reduces the amplitude and increases the duration of the potential.

F Wave

The F wave results from antidromic, or retrograde, depolarisation of the ventral horn cell which then transmits an impulse to the muscle in the normal orthodromic manner. F waves have a longer latency and smaller amplitude than M waves. Examination of the F wave may be used to obtain information about ventral nerve root function (Knecht and others 1983).

H Wave

The H, or Hoffman, reflex may be used to investigate both the ventral and dorsal nerve roots as it represents a true reflex arc (Knecht and Redding 1981, Sims and Selcer 1981). The H reflex may be evoked by submaximal stimulation of a mixed nerve such as the tibial or ulnar nerve (Knecht & Redding 1981, Sims & Selcer 1981). A method of recording H waves from the plantar muscles following stimulation of the caudal cutaneous sural nerve has recently been described (Malik & Ho 1991). Study of the H wave is still in its infancy in veterinary medicine, however it appears to have potential as a means of assessing nerve root function.

Sensory nerve conduction

Clinical evaluation of sensory function in animals is often very subjective, particularly in the case of partial lesions. Sensory nerve conduction studies provide a more accurate means of defining sensory nerve dysfunction. Methods of examining sensory nerve conduction and reference values have been described (Holliday & others 1977, Redding and others 1982, van Nes 1985).

Sensory nerve conduction studies may be applied in cases of brachial plexus trauma to determine whether the injury is proximal or distal to the spinal ganglia (van Nes 1986). Cutaneous nerves supplying clinically desensitised areas of skin continue to conduct action potentials in cases where the injury is proximal to the spinal ganglion. If the injury is distal to the spinal ganglion the sensory fibres degenerate and sensory potentials can no longer be recorded.

RADIOGRAPHIC EXAMINATION

Radiography is used principally for the evaluation of neoplastic, or occasionally vascular disease of the brachial nerves. It is of limited value in cases of traumatic brachial plexus disease and has no useful application to inflammatory disease. Radiographic techniques which have been used to evaluate brachial plexus disease include plain radiography, myelography, angiography and fluoroscopy.

Plain radiography

Brachial plexus neoplasia is associated with a number of potential radiographic abnormalities, although frequently radiography is unhelpful (Carmichael and Griffiths 1981). Enlargement of an intervertebral foramen due to pressure-induced bone lysis may

be seen with spinal nerve tumours which extend through the foramen (Bradley & others 1982). Uncommonly, a mineralised lesion may be observed with both nerve sheath and non-neural tumours (Targett and others 1993). Increased soft tissue density in the region of the brachial plexus may also indicate a non-neural tumour. Lytic, proliferative or reactive 'changes in the cervical vertebrae or proximal humerus may be seen with osteosarcoma, which may involve the plexus, or may represent secondary invasion of the bone by other tumours. Pulmonary metastatic disease may be demonstrated by thoracic radiographs. This is best evaluated by obtaining left and right inflated thoracic views (Suter and others 1974). False negative results may be obtained (Carmichael & Griffiths 1981). Enlargement of intra-thoracic or abdominal lymph nodes or a diffuse pulmonary infiltrate may be demonstrated radiographically in cases of lymphoma (Blackwood 1993). Fractures of the limb or first rib may support a presumptive diagnosis of traumatic nerve root avulsion or peripheral nerve injury (Chrisman 1991).

Myelography

Myelography may be performed via the cerebellomedullary or lumbar cistern. Techniques for both approaches have been described (Barber and others 1987, Lewis 1991). Lesions associated with brachial plexus disease rarely cause acute spinal cord swelling so the cerebellomedullary approach is usually selected. Myelography is indicated for the diagnosis of nerve root tumours which may be extradural (Luttgen & others 1980) or intradural-extramedullary (Bradley & others 1982). Tumours involving the vertebrae may also be associated with spinal cord compression but these are usually evident on plain radiography.

In man, myelography is reported to be of value in the diagnosis of nerve root avulsions and the characteristic changes have been described (Davies & others 1966, Yeoman 1968). In dogs, myelography may demonstrate a contrast outlined diverticulum following nerve root avulsion (Braund 1987), however this application appears to have limited potential in dogs (Wheeler & others 1986) and is rarely indicated.

Angiography

Arteriography has been used to successfully demonstrate partial occlusion of the subclavian artery causing brachial paralysis following trauma (MacCoy & Trotter 1977).

Fluoroscopy

Fluoroscopy may be used to examine the motility of the diaphragm in cases of cranial brachial plexus disease involving the fifth, sixth and seventh cervical nerve roots or

ventral branches. Brachial plexus lesions affecting these structures can cause hemiplegia or paralysis of the diaphragm in the absence of respiratory signs (Molenaar and others 1987).

OTHER IMAGING TECHNIQUES

In man, radiography is being superseded by computed axial tomography (CT) and magnetic resonance imaging (MRI) as a means of investigating brachial plexus disease. Roger & others (1988) reported an improved accuracy with both contrast enhanced CT and MRI over standard myelography for the evaluation of traumatic nerve root avulsion. MRI had the additional benefit of allowing visualisation of nerve roots distal to the intervertebral foramen. Marshall & De Silva (1986) compared the results of enhanced CT scans with surgical exploration of avulsed nerve roots following trauma and reported an accuracy of 100% based on gross CT abnormalities with a 25% rate of false positives due to overinterpretation of minor lesions on CT scanning. As these techniques become more widely available in veterinary medicine they will no doubt have similar benefits for the study of brachial plexus disease in animals.

CEREBROSPINAL FLUID EXAMINATION

Indications for CSF analysis in brachial plexus disease are limited to those cases where disease involving the nerve roots, meninges or spinal cord is suspected. Lesions distal to the nerve roots lie outwith the CSF pathway and therefore do not influence CSF composition. Methods of collection and analysis of cerebrospinal fluid (CSF) are detailed in the literature (Parker 1972, Mayhew and Beal 1980, Duncan and others 1987, Evans 1992). CSF may be obtained from either the cerebellomedullary or lumbar cistern. Samples collected caudal to the lesion are more likely to demonstrate abnormalities (Thomson & others 1990) therefore lumbar puncture is the preferred method in brachial plexus disease.

Pleocytosis is most commonly observed when the brachial nerve roots or meninges are infiltrated by lymphoma. The CSF white cell count may be markedly elevated by large numbers of lymphocytes which may or may not be malignant (Rosin 1982). Elevated protein levels in the absence of pleocytosis (albuminocytologic dissociation) may be demonstrated in cases of polyradiculoneuritis (Cummings & others 1982, Duncan & Griffiths 1984) or occasionally with nerve root neoplasia (Le Couteur 1989). Protein

levels may be moderately elevated in early cases of spinal cord infarction and occasionally the neutrophil count may be raised (de Lahunta and Alexander 1976).

SURGICAL EXPLORATION AND BIOPSY

Indications

The main indication for surgical exploration of the axilla is neoplastic disease involving the ventral nerve roots, common plexus bundle or proximal peripheral nerve trunks. Direct visualisation of primary nerve sheath tumours is the most accurate means of determining the true extent of the tumour and of assessing whether or not it is resectable. Examination of nerve roots must be performed by laminectomy. The two approaches may be combined in the case of extensive lesions. Surgical access to the brachial plexus may be indicated for biopsy of mass lesions or fascicular nerve biopsy in cases of suspected neuritis (Braund 1991). Biopsies of non-neural tumours may be obtained by fine needle aspirate, Tru-Cut¹ biopsy or wedge resection (Osborne 1974).

Surgical approaches to the brachial plexus

The brachial plexus may be exposed via a craniolateral, craniomedial or dorsal approach. The cranial approach described by Sharp (1988) is relatively atraumatic and provides good exposure of the plexus, particularly the proximal parts. The axillary vessels are avoided and the approach can easily be converted to forequarter amputation if indicated. Exposure of the C7, C8 and T1 ventral branches can be improved by sectioning the scalenus muscle cranial to the first rib. Examination of the proximal portion of the T1 ventral branch is facilitated by rib pivot thoracotomy (Schulman & Lippincott 1987).

The craniomedial approach (Knecht and Greene 1977) provides better exposure of the proximal peripheral nerve trunks than does the craniolateral approach. The main disadvantages of this approach is that the axillary artery must be negotiated during blunt dissection of fascia surrounding the plexus and exposure of nerves proximal to the plexus bundle is less satisfactory.

The dorsal approach reported by Steinberg (1988) involves extensive dissection of the muscle attachments to the scapula. It is questionable whether this approach offers any great advantage over the simpler craniolateral approach.

¹ Tru-Cut biopsy needle, Baxter Healthcare Corporation, Pharmaseal Division, Valencia, CA.

Surgical approaches to the nerve roots

Access to the spinal canal for investigation or resection of nerve root lesions is achieved by standard dorsal laminectomy (Sorjonen 1987). A lateral approach to the cervical spinal canal has also been described (Lipsitz and Bailey 1992) but due to anatomical constraints only lesions at C3/4 to C5/6 can be approached in this manner.

CLINICAL PATHOLOGY

Primary diseases of the brachial plexus are rarely associated with changes in the peripheral blood. Clinicopathological examination of blood is indicated where brachial neuropathy is part of a generalised or systemic disease process.

Haematological examination may demonstrate non-regenerative anaemia in cases of lymphoma, particularly in cats (Hardy 1981). Rarely, a leukaemic blood picture may be seen but this is the exception rather than the rule and blood parameters are frequently normal. Non-regenerative anaemia may also occur with metabolic causes of polyneuropathy such as hypothyroidism (Dunn 1989).

Blood chemistry evaluation is rarely helpful. If there is evidence of a generalised polyneuropathy, biochemical assays are indicated to exclude possible metabolic causes such as hypoglycaemia and hypothyroidism but these do not commonly present as brachial plexus disease. In doubtful cases, hormonal assays or endocrine function tests may be performed.

Serological examination may provide evidence of feline leukaemia virus (FeLV) infection in cases of feline lymphoma. The role of feline immunodeficiency virus (FIV) in the development of peripheral nerve disease has yet to be elucidated.

SECTION 1: PART 4

DISEASES OF THE BRACHIAL PLEXUS

The canine brachial plexus is subject to a variety of disease processes including traumatic nerve root avulsion and peripheral nerve injury, neoplasia, brachial plexus neuritis and idiopathic neuropathy. Rarely, brachial paralysis may be caused by vascular disturbances in the forelimb (MacCoy and Trotter 1977, Little 1992). In a review of twenty-two cases by Wheeler and others (1986) there were fifteen cases of nerve root avulsion, six of nerve sheath neoplasia and one peripheral nerve injury. In man, additional aetiologies, which have not yet been described in the dog, include thoracic outlet syndromes, damage following radiotherapy, hereditary disease and heroin addiction (Mumenthaler and others 1984).

This section reviews recognised primary disorders of the brachial plexus and conditions which may involve the plexus by secondary means. Generalised conditions which may present with signs referable to a brachial plexus lesion are also included. Specific clinical, diagnostic and pathological features are reviewed and the management of these conditions and factors affecting prognosis are discussed.

TRAUMA

Acute neurological dysfunction of a forelimb following trauma may be due to spinal nerve root avulsion or, less commonly, direct injury to a peripheral nerve trunk (Knecht 1976, Wheeler and others 1986). Any breed or age or either sex may be affected; however, traumatic lesions are most commonly seen in young animals. In fifteen cases of nerve root avulsion reviewed by Wheeler and others (1986) the age range was 4 months to 5 years with a mean of 19 months.

NERVE ROOT AVULSION

Traumatic nerve root avulsion is the commonest neurological condition affecting the canine forelimb (Griffiths and others 1974). The traction injury usually results from a road traffic accident (Griffiths 1974) and occurs when the limb is excessively abducted or rotated or when the shoulder is forcibly displaced (Steinberg 1988). Concurrent orthopaedic injuries or shock may mask signs of brachial paralysis, so neural function

should be specifically assessed in all cases presenting with forelimb injuries following road accidents.

Pathology

The neuropathology of traumatic brachial plexus injury has been described by Griffiths (1974), who recognised that intradural avulsion of the ventral and dorsal nerve roots from the spinal cord was the major primary lesion in these cases. Nerve roots are often completely avulsed but partial avulsions and root lesions of mixed severity may also occur, typically affecting nerve roots at the cranial and caudal extent of the injured segments. Postganglionic injury to nerve fibres in the ventral branches of the spinal nerves and plexus bundle is also recognised but gross disruption of these nerve trunks is rare. The major pathological changes in the ventral branches and peripheral nerves are those of Wallerian degeneration secondary to the nerve root lesion. Peripheral nerves distal to the ventral branches often retain a variable proportion of intact fibres. These comprise motor fibres originating from undamaged or partially affected nerve roots and sensory fibres which do not degenerate following preganglionic injuries as the axon remains confluent with the nerve cell body (Griffiths 1974).

The susceptibility of the nerve root to traction forces appears to be due to the lack of a supporting perineurium (Sunderland and Bradley 1961). The ventral roots are more susceptible than the dorsal and this may be reflected clinically when sensory deficits may not equate with those expected from the degree of motor dysfunction. Uncommonly, ventral root avulsion may be independent of dorsal root injury (Griffiths 1974).

Muscle denervation resulting from nerve root avulsion follows a segmental or myotomal pattern which means that the pathological and clinical effects vary in severity between muscles. The extent of denervation may also vary within an individual muscle for the same reason (Griffiths 1974).

Clinical Features

Griffiths (1977) described three types of clinical presentation based upon the distribution of nerve root lesions.

Avulsion of the complete plexus

Avulsion of nerve roots C6 to T1 results in complete paralysis of the limb. In some cases the proximal limb is advanced by the action of the trapezius and omotransversarius muscles which are innervated by the accessory nerve and the brachiocephalic muscle which is supplied by both the accessory and brachiocephalic nerves. The paralysed limb

appears longer than normal and hangs in the "dropped elbow" position with the dorsum of the paw contacting the ground. Tendon and nociceptive reflexes are absent and, in cases of more than two weeks duration, there is atrophy of affected muscles. The ipsilateral panniculus reflex is lost due to involvement of the C8 and T1 ventral roots. The consensual reflex is preserved, confirming the integrity of the sensory portion of the reflex. Damage to the T1 ventral root disrupts the sympathetic nerve supply to the pupil causing a partial Horner's syndrome with ipsilateral miosis in approximately half the cases of complete plexus avulsion (Griffiths 1977). In addition to miosis, a mild ptosis may be apparent in some animals. The pattern of cutaneous sensory loss shows some variation between individuals, however there is typically anaesthesia of the limb distal to the elbow. Sensation may also be lost over the distal two-thirds of the cranial brachium (Griffiths 1977, Bailey 1984).

Avulsion of the caudal plexus

This is the second most common type of injury accounting for thirty three percent of cases of traumatic nerve root avulsion (Griffiths 1977). The C8 and T1 nerve roots are predominantly affected resulting in paralysis of elbow and carpal extensor muscles. The limb is non-weightbearing but the distal limb may be carried off the ground by the action of elbow flexors which are largely innervated by fibres from C7. The ipsilateral panniculus reflex is absent and anisocoria with ipsilateral miosis occurs. Patterns of cutaneous sensory loss are less predictable with incomplete avulsions than with complete injuries and are often difficult to interpret. In the case of caudal avulsions involving C8 and T1 roots the desensitised area does not usually extend proximal to the elbow (Bailey 1984).

Avulsion of the cranial plexus

Injuries which principally involve the C6 and C7 nerve roots are the least common type of traumatic brachial plexus lesion. This injury causes the least disability as the action of elbow and carpal extensors is preserved and the limb can bear weight. Carpal flexion is also preserved. The most significant clinical deficits are loss of shoulder and elbow flexion and atrophy of the spinatus and biceps brachii muscles. The panniculus reflex and ocular sympathetic function are preserved. As with caudal plexus avulsions, the distribution of cutaneous sensory deficits is unpredictable. Patterns of desensitisation in partial avulsions are inconsistent due to variable degrees of individual nerve root injury and the presence of concomitant injury to sensory fibres in the plexus bundle or peripheral nerves. Deficits of cutaneous sensation in partial avulsion injuries have been described by

Griffiths and others (1974) and Bailey (1984). Other patterns of nerve root avulsion have been reported, such as C7 and C8 (Bailey 1984).

PERIPHERAL NERVE INJURY

Isolated injury of individual peripheral nerves is uncommon as they are generally well protected by overlying muscles and other soft tissues. Injury results from direct trauma and the radial nerve is the most likely to be involved (Wheeler and others 1986). Trauma may result from fractures, lacerations or compression of the nerve against underlying bone. In contrast to nerve root avulsions the effects of peripheral nerve injuries are confined to a specific nerve field and motor and sensory deficits are limited to the muscles and skin supplied by the injured nerve. The pathology of nerve injuries has been described in Part Two.

Radial nerve paralysis

Radial nerve injury may result from fractures of the humerus or first rib (Chrisman 1991). Superficially, the clinical presentation can resemble nerve root avulsion and many cases of complete or caudal nerve root avulsion are misdiagnosed as radial nerve paralysis (Wheeler and others 1986). The extensor muscles of the elbow and carpus are paralysed and the limb hangs in the "dropped elbow" position. If the injury is immediately above or distal to the elbow then branches to the triceps muscle group are spared and the limb may bear weight, although there is a tendency for the carpus to buckle. Animals may learn to compensate for the loss of carpal extension by flicking the foot forward during locomotion. Cutaneous sensory deficits are confined to the autonomous zone of the radial nerve which includes the cranial antebrachium and dorsal paw with sparing of the dorsolateral aspect of the fifth digit which is supplied by the ulnar nerve. In contrast to caudal plexus avulsions, panniculus reflex deficits and partial Horner's syndrome are not observed with radial nerve paralysis.

Other peripheral nerves

Isolated injuries to the other major peripheral nerves of the forelimb occur rarely and are not usually associated with significant functional deficits. The motor and sensory signs associated with individual peripheral nerve injury have been detailed by Knecht (1976) and Worthman (1957).

In dogs, uncomplicated suprascapular nerve transection causes no appreciable lameness as other muscles compensate for the paralysed shoulder extensor muscles (Worthman 1957). The major clinical finding is atrophy of the infra- and supraspinatus muscles.

Suprascapular nerve injury may be complicated by infraspinatus contracture leading to lameness and persistent abduction of the limb. Such cases may be successfully treated by partial tenotomy (Pettit and Slatter 1972).

Musculocutaneous nerve injury resembles cranial nerve root avulsion as loss of elbow flexion is the major sign in both conditions. These disorders can usually be differentiated clinically as cranial plexus avulsions are associated with other signs such as spinatus muscle atrophy indicating that the injury is not confined to the musculocutaneous nerve field.

The median and ulnar nerves together innervate the flexors of the carpus and digits and the skin of the palmar aspect of the paw. The ulnar nerve also supplies cutaneous sensation to the caudal antebrachium and lateral aspect of the fifth digit. If either of these nerves are injured in isolation then no clinical deficit is seen apart from loss of sensation in areas supplied only by the ulnar nerve. If both nerves are sectioned, which would be a rare natural injury, there is sinking of the weightbearing carpus due to paralysis of opposing carpal flexors (Worthman 1957). Sensation to the foot is only partially lost if the injury is proximal to the communicating branch between the musculocutaneous and median nerves.

INVESTIGATION OF TRAUMATIC INJURIES

Electrophysiological examination may help to confirm the site and severity of injuries. Examination should be delayed for a period of at least eight days following injury to allow degenerative changes to develop (Griffiths and Duncan 1974). Electromyography provides an objective method of assessing the distribution of denervation and is more sensitive than clinical examination alone. The pattern of denervation is indicative of the site of the lesion within the plexus. Nerve conduction studies may be used to assess the severity of nerve damage in terms of the number of injured fibres. If all the axons are damaged a muscle action potential cannot be evoked. Potentials of reduced amplitude but normal velocity are recorded from partially denervated muscles with the amplitude representing the approximate percentage of conducting fibres in the nerve (Griffiths and Duncan 1974). Serial electrophysiological examinations may be used to assess the progress of any subsequent reinnervation (Griffiths and Duncan 1978). Neuropraxic injuries cause loss of conduction across the injured site but conduction in the distal stump remains normal and denervation potentials are absent. Evidence of nerve root avulsion may be obtained from electromyography of the epaxial muscles and sensory nerve conduction studies (van Nes 1986). The use of electrodiagnostic techniques for

evaluation of nerve root injuries has been reported by Steinberg (1979b) and van Nes (1986).

Radiographic examination is frequently indicated in cases of nerve root avulsion to evaluate concurrent orthopaedic and thoracic injuries, however it provides no specific information regarding the nerve injury itself. Radiography may reveal fractures of the humerus or first rib in cases of radial nerve injury (Chrisman 1991). Myelography may demonstrate contrast filled diverticulae in cases of nerve root avulsion (Braund 1987) but results are inconsistent (Griffiths and others 1974) and this technique is rarely applied.

TREATMENT OF TRAUMATIC NERVE ROOT AND PERIPHERAL NERVE INJURY

The goal of therapy for brachial plexus and peripheral nerve injuries is return of adequate function to the limb. In animals this means that the limb should at least partially bear weight or have sufficient flexor function that the foot is not dragged. Treatment options include conservative therapy, surgical intervention to improve limb function and amputation.

Factors affecting treatment selection

Degree of disability

This is determined by which muscle groups are affected by the injury. Lesions affecting both elbow and carpal extensors cause the most severe disability as the limb cannot bear weight. These include complete and caudal nerve root avulsions and proximal radial nerve injuries. If only carpal extension is lost, as in distal radial nerve injuries, the animal may learn to compensate by flicking the foot forward during locomotion. Lesions involving the cranial plexus or other major nerve trunks do not affect these muscle groups and the gait is not markedly altered (Worthman 1957).

Degree of neural injury

The major factor affecting prognosis following nerve injury is the initial severity of the injury. First and second degree injuries have a good prognosis for spontaneous functional recovery. Recovery from first degree injuries is rapid and complete. The recovery period following second degree injuries is related to the distance over which the fibres must regenerate. Third degree injuries show some spontaneous reinnervation but this may be insufficient to restore adequate function. In partial lesions, the potential for recovery is related to the number of fibres affected, as collateral sprouting from surviving axons may

further improve function. Four and fifth degree injuries are indications for surgical repair but consideration must be given to the potential benefits of repair in terms of limb function.

Level of injury

Nerve root avulsions tend to affect several muscle groups as deficits usually involve several nerve fields. These injuries invariably have a poor prognosis as spontaneous recovery is unlikely and, at present, surgical repair of nerve roots remains an experimental procedure. The distance over which fibres must regenerate following injury also affects the prognosis. Greater distances are more likely to be associated with incomplete recovery (Braund 1987).

Complications associated with sensory loss

Many traumatic nerve root and peripheral nerve injuries result in some form of cutaneous sensory loss which may be associated with severe complications even if motor function can be restored. Restricted areas of sensory loss on the proximal limb do not usually lead to serious complications, however, desensitisation of the distal limb is often associated with severe traumatisation and self-mutilation which ultimately may necessitate amputation. Techniques to surgically adapt limb function are likely to be unsuccessful unless sensation on the palmar aspect of the foot is preserved. It could be speculated that paraesthesias associated with reinnervation may also lead to self-mutilation but this is difficult to determine in animals.

Other complications

Muscle fibrosis and contracture resulting from chronic denervation may further complicate management of nerve injuries. Some may be managed successfully by tenotomy of the affected muscle (Pettit and Slatter 1972).

Conservative Management

This is indicated where adequate limb function is preserved or in cases where there is a reasonable prognosis for spontaneous recovery. In acute cases, some deficit may be due to neuropraxic or second degree injury and surgical intervention is often delayed for at least a month in order to more accurately establish the severity of the injury and probable long term prognosis. Conservative therapy is mainly directed towards protection of the desensitised limb and management of any associated complications. This approach is generally only suitable for temporary management of severe nerve injuries.

Foot protection

This may be achieved by bandaging if wounds are present, or by the use of a canvas or leather boot. Rigid coaptation splints may be used to support the limb and minimise muscle contractures (Knecht 1976) but extreme care must be taken to avoid pressure sores.

Wound management

Traumatic ulceration and mutilation of the distal limb may be severe with associated osteomyelitis, necrosis and loss of digits. Aggressive wound management is indicated at an early stage with rigorous cleaning, dressing and appropriate antibiotic therapy. In many cases the prognosis for recovery of limb function is poor and amputation is indicated if serious wound complications arise.

Physiotherapy

Physical therapy such as passive manipulation, swimming, electrical stimulation and whirlpool baths may help to delay secondary problems such as muscle contractures (Braund 1987).

Surgery to Improve Limb Function

A number of different approaches have been used to improve limb function following traumatic injury including primary nerve repair, muscle and nerve translocations and joint arthrodesis. Careful clinical and electrodiagnostic assessment of each case is mandatory in order to select the most appropriate technique and to assess whether the degree of expected improvement following surgery is likely to benefit the patient in terms of useful limb function.

Primary nerve repair and nerve grafting

This is indicated in fourth and fifth degree injuries of nerve trunks. Techniques for repairing and grafting peripheral nerves have been described (Swaim 1972, Gourley and Snyder 1976, Rodkey 1993). Peripheral nerve repair is most successful if the injury is located a short distance from the denervated muscle (Rodkey 1993). Nerve grafts are used to repair postganglionic brachial plexus injuries in man (Birch and others 1988, Sedel 1988). This technique is rarely applicable to canine brachial plexus injury as significant preganglionic injury invariably occurs.

Tendon transposition

This technique involves transposing the tendon of a functioning muscle to a paralysed muscle in such a way that the transposed muscle functions in place of the paralysed one. The principal indication for this technique is radial nerve injury. Bennett and Vaughan (1976) described translocation of the tendon of origin of the biceps brachii to the medial olecranon to provide elbow extension and anastomosis of the flexor carpi radialis, or ulnaris, to the extensor carpi radialis to provide carpal extension. Hussein and Pettit (1967) described the same technique for elbow extension but transposed the flexor carpi radialis to the common digital extensor, as did Sterner and Moller (1960).

Although caudal plexus avulsions cause similar deficits to radial nerve injury, these techniques are rarely applicable to this type of injury. Sub-clinical denervation of the biceps brachii, which is often present with such injuries, means that there is insufficient muscle strength to function as an elbow extensor. Transposition of carpal flexors is not possible because the median and ulnar fields, which supply these muscles are also affected by caudal nerve root lesions. Sensory deficits are generally more extensive with avulsion injuries. Muscles should ideally be checked for evidence of sub-clinical denervation by electromyographic examination prior to transposition.

Carpal arthrodesis

Pancarpal arthrodesis to overcome loss of carpal extension has been described following distal radial nerve injury (Frost and Lumb 1966). This technique is only successful in cases where elbow extension has been preserved or can be restored by other means such as tendon relocation.

Nerve transfer

In man, nerve transfer has been used for the treatment of nerve root avulsions. The aim of the technique is to reinnervate distal stumps with fibres from the transferred nerve. The most frequently used techniques are transfer of an intercostal nerve to the musculocutaneous nerve and accessory nerve to the suprascapular nerve (Birch 1993). These techniques appear to restore limited function, which may be an asset in humans but may be inadequate to restore useful function in the dog. In dogs, experimental transfer of the musculocutaneous nerve to the radial nerve has been described (Knecht 1976). Improvement in motor function and cutaneous sensation was observed over a four month period but recovery was complicated by mutilation of digits.

Future trends

Reimplantation of nerve roots

Successful reimplantation of ventral nerve roots has been described experimentally in dogs (Jamieson and Eames 1980). While this technique may ultimately lead to some recovery of motor function the problems associated with proprioceptive and cutaneous sensory loss remain, as attempts to reimplant dorsal roots have so far been unsuccessful.

Muscle grafts

Freeze-thawed muscle grafts have been used experimentally in sheep to treat nerve root avulsion (Hems and Glasby 1992). The muscle provides a framework for regeneration of fibres from the avulsed root into the distal stump.

Nerve growth factor

Investigation into the use of exogenous nerve growth factor to enhance sensory nerve regeneration in peripheral nerve repair and reimplantation of dorsal nerve roots is being carried out currently in man (Anand and others 1993).

Amputation

In many cases of serious brachial plexus injury, notably complete and caudal nerve root avulsion, amputation of the affected limb is the treatment of choice. Prognosis for return of function is generally hopeless in cases of complete avulsion and these injuries are associated with severe, and occasionally life-threatening, complications related to desensitisation and subsequent traumatisation of the limb. As this is a radical procedure, surgery is usually delayed for at least four weeks if possible, to allow for any spontaneous recovery from neuropraxic or second degree injuries. If there is no clinical or electrophysiological evidence of improvement by this time, satisfactory recovery is unlikely. If the injury is confined to caudal nerve roots some innervation of paralysed muscles may persist via undamaged roots. These cases have the potential for a degree of recovery through collateral axonal sprouting of intact fibres so amputation is delayed for several months if complications do not supervene. Although this type of reinnervation may be limited, recovery may be sufficient to avoid amputation. Wheeler and others (1986) reported that only six of fifteen cases of nerve root avulsion required amputation or were euthanased, however it is unclear whether these were complete or restricted lesions.

NEOPLASIA

Tumours of the brachial plexus may be primary, arising from the nerve sheath, or secondary, involving the plexus by metastasis or local invasion or compression. In contrast to traumatic lesions, neoplastic disease involving the plexus most commonly affects dogs over five years of age (Bradley and others 1982, Targett and others 1993).

PRIMARY PERIPHERAL NERVE TUMOURS

Classification

A variety of terms have been used to describe nerve sheath tumours including Schwannoma, neurofibroma, neurofibrosarcoma and, less frequently, neurolemmoma, neurinoma and lemnocytoma. In man, the term neurofibromatosis is also used to describe multiple lesions which are usually associated with the hereditary disorder von Recklinghausen's disease (Urich 1984). The term neurofibroma implies a fibroblastic origin, however ultrastructural and tissue culture studies in man have confirmed that the Schwann cell is the primary neoplastic element in both Schwannomas and neurofibromas (Fisher & Vuzevski 1968, Cravioto & Lockwood 1969). The histiogenesis of canine nerve sheath tumours has not yet been established but it seems likely that, with certain rare exceptions (Vandevelde and others 1977), they also have a common origin. Histopathologically, nerve sheath tumours may show considerable variation in the appearance and arrangement of cells, the mitotic rate and the amount of collagen present and it is principally for this reason that many pathologists continue to differentiate between Schwannomas and neurofibromas. In man, Schwannomas are typically benign and well circumscribed and malignant transformation is rare (Brooks 1984). Canine nerve sheath tumours differ somewhat in that the majority are locally invasive resulting in destruction of nerve tissue and some may metastasise to the lungs or lymph nodes (Oliver and others 1965, Carmichael & Griffiths 1981, Bradley & others 1982, Le Couteur 1989, Targett and others 1993). These malignant forms are described as malignant Schwannomas or neurofibrosarcomas. Nerve sheath tumours may affect any nerve root, peripheral nerve or cranial nerve, however the brachial plexus is a main predilection site in the dog (Cordy 1990, Jubb and Huxtable 1993). The typical gross appearance of a primary brachial plexus tumour is illustrated in Figure 6. Less common forms of nerve sheath tumour have also been described in the dog including neurofibromatosis involving the cervical nerves (Goedegebuure 1975), malignant melanotic Schwannoma (Patnaik and others 1984) and central neurofibroma (Vandevelde and others 1977).

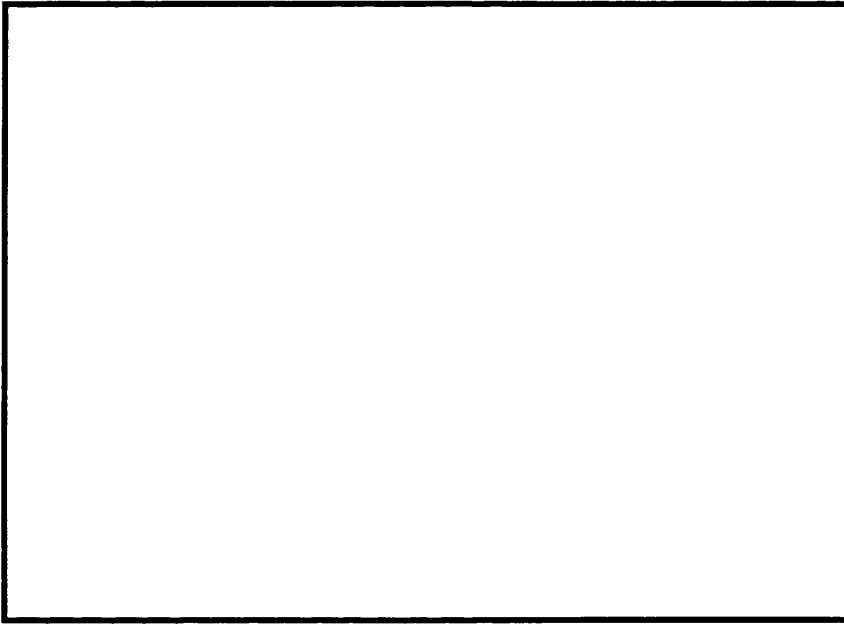


Figure 6

Typical gross appearance of a primary nerve sheath tumour involving several adjacent ventral branches as they emerge from beneath the scalenus muscle.

Incidence

Primary tumours of the brachial plexus nerves are uncommon in dogs (LeCouteur 1989) and are rare in cats (Zaki and Hurvitz 1976). A study by Hayes & others (1975) found that peripheral nerve sheath tumours at any site accounted for 26.6% of canine nervous system tumours. Nerve sheath tumours are most commonly diagnosed in adult dogs over five years of age but have been recognised in dogs as young as eight months old (Bradley & others 1982). A case of neurofibrosarcoma involving the brachial nerve roots was reported in a two and a half year old dog (Oliver & others 1965). Figure 7 illustrates the age incidence of forty six cases of primary brachial nerve tumours reported in the literature (Oliver and others 1965, Strafuss and others 1973, Chrisman 1975, Troy and others 1979, Wright and others 1979, Luttgen and others 1980, Carmichael and Griffiths 1981, Wright and Clayton Jones 1981, Bradley and others 1982, Bradney and Forsyth 1986, Wheeler and others 1986, Targett and others 1993). The age range in these cases was 2.5 to 13 years with a mean and median of 7 years. Seventy eight per cent of dogs were between five and twelve years of age which concurs with the age distribution reported by McGrath (1984) (cited by LeCouteur 1989). Hayes and others (1975) reported a bimodal incidence at two to three years and seven to eleven years.

Distribution

Primary brachial plexus tumours may be found anywhere from the nerve roots to the peripheral nerve trunks. A review of forty six cases reported in the literature (Oliver and others 1965, Strafuss and others 1973, Troy and others 1979, Wright and others 1979, Luttgen and others 1980, Carmichael and Griffiths 1981, Wright and Clayton Jones 1981, Bradley and others 1982, Bradney and Forsyth 1986, Wheeler and others 1986, Targett and others 1993) suggests a high incidence of tumours involving nerve tissue within the spinal canal. Tumour was present in the spinal canal in sixty five per cent of cases (30 of 46) and in twelve of these the spinal cord itself was involved. In at least fifty percent of cases with nerve root tumours (15 of 30), the tumour extended through the intervertebral foramen to involve nerves outwith the spinal canal. Tumours involving a single root and those affecting multiple roots were equally represented. The C6 to C8 nerve roots were most commonly affected followed by C5 then T1. Tumours which were confined to nerves distal to the intervertebral foramen accounted for less than thirty five per cent of cases.

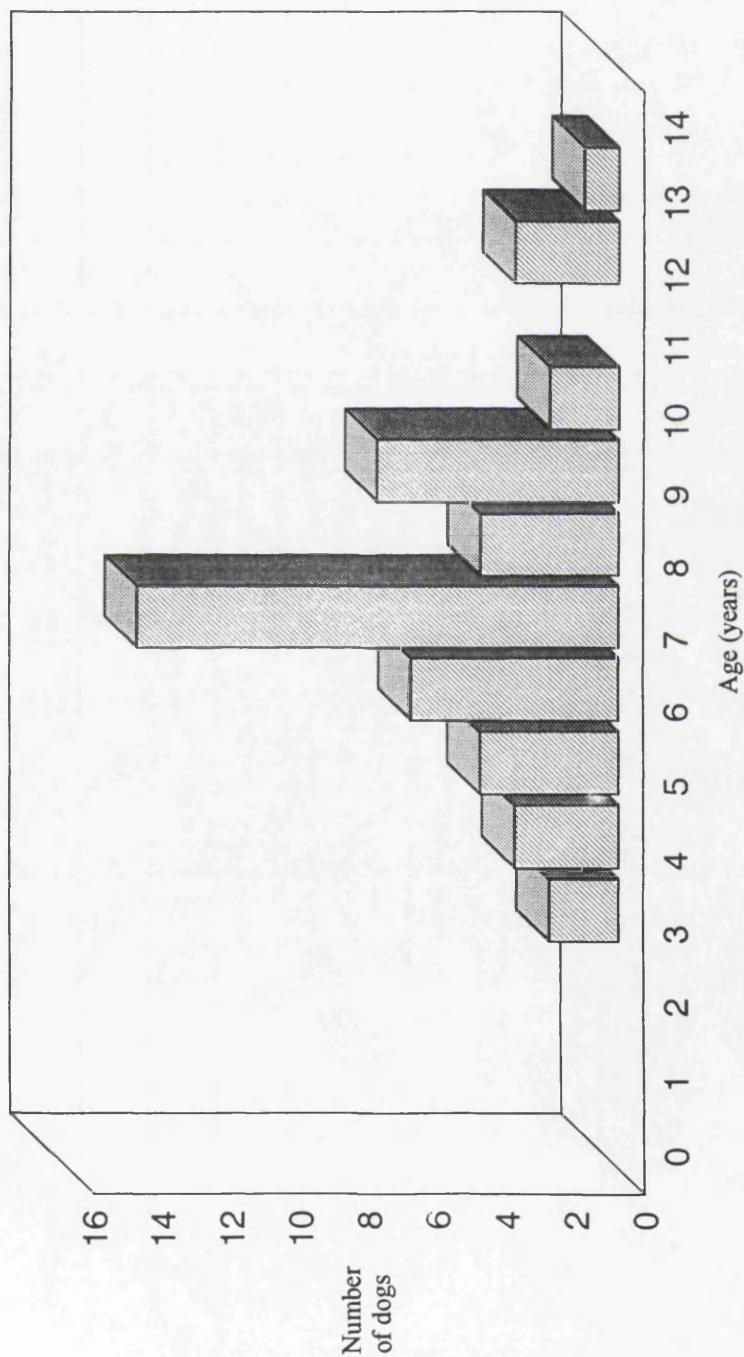


Figure 7

Age incidence of forty six cases of brachial nerve sheath tumours reported in the literature.

(Oliver and others 1965, Straffuss and others 1973, Chrisman 1975, Troy and others 1979, Wright and others 1979, Luttgen and others 1980, Carmichael and Griffiths 1981, Wright and Clayton Jones 1981, Bradley and others 1982, Bradney and Forsyth 1986, Wheeler and others 1986, Targett and others 1993).

Clinical Features

Primary brachial plexus tumours typically give rise to a slowly progressive, unilateral forelimb lameness (Carmichael & Griffiths 1981, Bradley & others 1982, Wheeler & others 1986), although tumours arising at the level of the nerve root may present with acute signs of spinal cord compression without preceding forelimb lameness (Targett and others 1993). The duration of clinical signs prior to presentation or diagnosis reported in the literature ranged from two to twelve months with a mean of seven months (Chrisman 1975, Carmichael and Griffiths 1981, Bradley and others 1982, Wheeler and others 1986, Wright and others 1986, Targett and others 1993). One case was referred after thirty six months (Targett and others 1993) but this was exceptional.

The clinical features of brachial plexus tumours have been reviewed by Sharp (1992). Muscle atrophy is the most consistent clinical finding (Carmichael and Griffiths 1981, Bradley & others 1982) occurring in about eighty eight percent of cases (Sharp 1992). The spinatus muscles overlying the scapula are commonly affected. Neurogenic and disuse atrophy are clinically indistinguishable in chronic cases. Discomfort on manipulation of the proximal limb or cervical region is a frequent finding but pain may be difficult to localise. Deep palpation of the axilla may be acutely painful. In some cases a cylindrical mass is palpable in the region of the first rib but this is an inconsistent finding (Carmichael & Griffiths 1981, Bradley & others 1982) and general anaesthesia may be required to facilitate palpation (Wheeler and others 1986). Specific neurological deficits in the limb are frequently absent or extremely subtle for several weeks or months. When present, these deficits vary depending upon the site of the lesion within the plexus but include paresis, proprioceptive deficits, a diminished pedal reflex and cutaneous sensory deficits. Lesions which involve the ventral roots or ventral branches of C8 or T1 result in loss of the ipsilateral and consensual panniculus reflex on the affected side. Miosis may be present if the T1 nerve root or spinal nerve is affected. Lesions distal to the ramus communicans spare the ocular sympathetic fibres and do not cause miosis. A full Horner's syndrome may occur if the tumour extends into the stellate ganglion (Sharp 1992). A single root or ventral branch may be affected but extension into adjacent roots and ventral branches has usually occurred by the time the animal is presented. Proximal extension of the tumour into the spinal canal leads to progressive hindlimb paresis (Troy and others 1979, Bradley and others 1982).

TUMOURS OF ADJACENT NON-NEURAL TISSUES

Non-neural tumours in the region of the caudal cervical vertebrae or axilla may involve the brachial plexus by invasion or entrapment and compression of adjacent nerves. Brachial plexus involvement has been associated with chondrosarcoma, osteosarcoma and an apocrine sweat gland tumour in dogs which were seven or eight years of age (Carmichael & Griffiths 1981, Targett and others 1993). These cases presented in an identical manner to primary tumours with intractable, progressive unilateral forelimb lameness of between one and forty eight months duration. The major clinical finding was spinatus muscle atrophy and a palpable axillary mass in two cases (Carmichael & Griffiths 1981). Only one case was reported to have specific neurological deficits, including a partial Horner's syndrome (Carmichael & Griffiths 1981). Braund (1984) also reported brachial plexus involvement with haemangiosarcoma. Axillary chondrosarcoma causing forelimb paralysis and Horner's syndrome has been reported in a cat (Shell and Sponenberg 1987).

METASTATIC TUMOURS OF THE BRACHIAL PLEXUS

Lymphoma

Approximately five per cent of generalised lymphomas in dogs and cats have secondary metastases to the nervous system (Cordy 1990). Epidural and CNS infiltration are most commonly recognised but involvement of cranial and spinal nerves, nerve roots and ganglia occasionally occurs (Zaki and Hurvitz 1976, Couto 1986, Cordy 1990). Lymphoma involving the brachial plexus or its nerve roots has been described in the dog and cat (Le Couteur 1989, Chrisman 1991). Metastasis to the brachial plexus from the alimentary tract has been recognised (Fox and Gutnick 1972) but any primary nodal or extra-nodal site could be implicated. Neural lesions occasionally represent a primary extra-nodal form of lymphoma (Rosin 1982, Couto 1986). Typical signs of brachial plexus disease are usually associated with diffuse invasion of the peripheral nerves by malignant lymphocytes (Fox and Gutnick 1972). Infiltration of the spinal cord or epidural space at the level of the C6 to T1 segments may also cause signs of brachial plexus disease in early stages (Chrisman 1975), however the subsequent development of hindlimb paresis indicates a spinal rather than peripheral lesion. Neural lymphoma involving the brachial plexus is infrequently reported in the literature and the incidence appears to be low. In a study of twenty eight cases of feline neural lymphoma, only one case demonstrated invasion of nerve roots supplying the forelimb (Zaki and Hurvitz

1976). In cats, seventy per cent of lymphoma cases demonstrate antibodies to feline leukaemia virus (FeLV) (Hardy 1981).

Lymphoma may develop from six months to fifteen years of age in both dogs (McEwan and Young 1989) and cats (Zaki and Hurvitz 1976). In dogs, the average age is six to seven years (McEwan and Young 1989). In cats, the age incidence is related to FeLV infection; infected cats develop lymphoma at an average of three years and FeLV negative cats are usually over seven years (Hardy 1981). The ages of animals with lymphoma of the brachial plexus reported in the literature were two and eleven years in dogs (Rosin 1982) and two years (in two cases) and ten years in cats (Fox and Gutnick 1972, Chrisman 1975, Zaki and Hurvitz 1976).

The clinical features of brachial plexus lymphoma are common to other forms of brachial plexus disease. Pain is not a characteristic feature of brachial plexus lymphoma (Holliday and Turrel 1987) but may be observed in some cases leading to confusion with primary neoplasia (Rosin 1982). Horner's syndrome due to invasion of the sympathetic trunk has been reported (Fox and Gutnick 1972). Systemic signs of lymphoma such as peripheral lymphadenopathy or palpable mesenteric nodes may be present in some cases (Chrisman 1975, Couto and others 1984) but the nervous signs may be the only indication of disease. The progression of clinical signs is typically more rapid than with local brachial plexus tumours but cases of up to 2 months duration have been described (Chrisman 1975).

INVESTIGATION OF NEOPLASTIC DISEASE

Electromyography is a valuable aid to the investigation and diagnosis of all types of brachial plexus tumour. In cases presenting with chronic lameness, the presence of spontaneous electrical activity confirms a neural rather than orthopaedic cause of the lameness and identifies the nature of associated muscle atrophy. The distribution of denervation suggests the level of the lesion and the structures involved. Denervation of paraspinal muscles indicates involvement of the spinal cord or intraforaminal nerve roots proximal to the dorsal spinal branch (Chrisman 1975, van Nes 1986).

Plain radiography of the cervical spine may demonstrate vertebral tumours or pressure-induced bone lysis and enlargement of the intervertebral foramen due to expanding nerve root tumours. This is best evaluated by oblique spinal views (Bradley & others 1982). Rarely, mineralisation of both nerve sheath and other tumours may be seen in the axillary region on thoracic views (Holliday and Turrel 1987, Targett and others 1993). Thoracic radiographs should be evaluated for the presence of pulmonary metastatic disease which

is common with non-neural tumours (Carmichael and Griffiths 1981). Oliver & others (1965) reported radiographic evidence of a focal lung metastasis in a case of neurofibrosarcoma. A normal radiographic appearance does not exclude the possibility of pulmonary metastases in cases of malignant nerve sheath tumours (Carmichael and Griffiths 1981, Targett and others 1993). In cases of neural lymphoma, radiography may demonstrate internal lymphadenopathy or pulmonary infiltration but negative findings are common.

Myelography is indicated for evaluation of nerve roots and is advisable prior to attempted surgical excision of brachial plexus tumours as sub-clinical invasion of the vertebral canal may occur in a significant number of cases. Bradley & others (1982) reported that only three out of six dogs with myelographic evidence of tumour within the spinal canal showed clinical evidence of spinal cord compression. Nerve root tumours may appear as extra-dural (Luttgen & others 1980) or intra-dural/extra-medullary mass lesions (Bradley & others 1982). Steinberg (1988) reported cases in which tumour tissue was present in the spinal canal in the absence of myelographic changes. Myelography may demonstrate spinal cord compression by expanding vertebral tumours, however this is rarely indicated if the diagnosis is evident on plain radiography. An extra-dural mass may be demonstrated in cases of epidural lymphoma.

Computed tomography (CT) allows excellent visualisation of nerve root tumours (Bagley and others 1993).

CSF examination is rarely beneficial in the diagnosis of nerve root tumours as changes in composition, when present, are non-specific. Albuminocytologic dissociation has been reported (Bradney and Forsyth 1986, Le Couteur 1989) and Luttgen and others (1980) described one case which showed both elevated protein (502 mg/l) and a mild, predominately polymorphonuclear pleocytosis. The collection site was not specified. CSF examination is of greatest value in cases of lymphoma involving the nerve roots or meninges, which may be associated with a marked pleocytosis consisting mainly of lymphocytes which may or may not be abnormal (Rosin 1982). Malignant lymphoblasts in CSF are diagnostic of lymphoma.

Haematological examination may occasionally demonstrate a non-regenerative anaemia, or rarely leukaemia, in cases of lymphoma (Hardy 1981). Blood chemistry assays may reveal abnormalities associated with neoplastic infiltration of the liver or kidneys.

Definitive diagnosis of brachial plexus tumours may require surgical exploration. Biopsy is indicated in cases where treatment is to be attempted in order to identify the tumour

type. This may be achieved by excision, wedge resection, punch biopsy or needle aspiration (Osborne 1974).

TREATMENT OF BRACHIAL PLEXUS TUMOURS

Surgical Excision

Resection of a local tumour may be attempted if it is in a suitable location, is not highly malignant, can be removed without causing destruction of important nervous structures and metastatic disease is absent. As nerve sheath tumours are highly invasive, it is rarely possible to adequately resect them without severely compromising limb function. In most cases, several ventral branches are affected and a wide margin of excision is necessary to prevent local recurrence. In a limited number of cases, the tumour may be confined to nerves which may be sacrificed without causing significant gait abnormalities, such as the thoracodorsal nerve (Steinberg 1988) or C5 and C6 ventral branches. In the majority of cases however, this type of approach is not feasible and, following exploration, the limb is amputated after the ventral branches have been sectioned as far proximally as possible (Holliday and Turrel 1987). At present this appears to be the most satisfactory method of treatment for most cases of primary brachial plexus tumour with survival times ranging from two months to two years (Holliday and Turrel 1987). Amputation is not curative if the tumour extends into the proximal ventral branches or nerve roots. Tumours which are located entirely within the spinal canal may be removed via dorsal cervical laminectomy. Successful surgical removal of a subdural neurofibrosarcoma with excision of the eighth cervical nerve root has been reported (Troy and others 1979). Limb function was not significantly impaired by the procedure.

Most non-neural tumours involving the plexus are also malignant and carry a poor prognosis. Tumours confined to the limb, as opposed to the spine, may be treated by amputation.

Conservative Management

In cases of local tumour which are not associated with significant pain, a conservative approach may be selected for a number of reasons. Owners may refuse to consider amputation as an acceptable option or the animal may suffer from concurrent disease such as orthopaedic problems in other limbs which would prevent successful rehabilitation following amputation. As most cases progress slowly over a number of months some owners may choose conservative management until the condition becomes painful and euthanasia is indicated. While there may be an initial response to analgesics or anti-

inflammatory drugs, long term control of pain associated with peripheral nerve tumours is rarely satisfactory.

Chemotherapy

Neural lymphoma may be treated in the same manner as other forms of lymphoma with a combination chemotherapy protocol. The combination most frequently used is cyclophosphamide, vincristine and prednisolone (COAP) (Cotter 1983a, b) but a number of protocols have been described (Madewell and Theilen 1987, MacEwan and Young 1989). Cotter (1983b) described treatment of feline epidural lymphoma with the COAP protocol and reported a remission period of up to fourteen months. Little is known about the effect of chemotherapy on cases with diffuse neural infiltration. Couto and others (1984) reported treatment of central nervous system lymphosarcoma with intrathecal cytosine arabinoside.

Chemotherapy may be of palliative benefit in some cases of nerve sheath tumours. A combined protocol using vincristine, adriamycin and cytoxan has been recommended (Holliday and Turrel 1987) but this type of therapy has yet to be fully evaluated in dogs.

Radiation Therapy

Radiation therapy for nerve sheath tumours has been suggested (Holliday and Turrel 1987, Johnston and others 1993) but the therapeutic benefits and potential complications have yet to be adequately investigated. Bagley and others (1993) indicated that results of radiation therapy following surgical resection of peripheral nerve tumours were not encouraging in a small series of cases. Treatment of solid lymphoma using radiotherapy has been reported (Elmslie and others 1991) but this is unlikely to be applicable to diffuse neural lesions. Brachial plexus damage resulting from radiotherapy for treatment of breast cancers and Hodgkin's disease is increasingly recognised in man (Mumenthaler and others 1984).

IMMUNE- MEDIATED AND IDIOPATHIC DISEASE

BRACHIAL PLEXUS NEURITIS

This is an uncommon condition which selectively affects the nerves of the forelimbs. The major clinical features closely resemble those of serum neuritis in man in which localised radicular pain progressing to upper limb weakness occurs seven to ten days after serum administration or prophylactic inoculation (Miller and Stanton 1954). A number of other neurological complications have been reported but brachial plexus neuritis is the most common, accounting for almost sixty per cent of cases (Miller and Stanton 1954). An identical syndrome, known as neuralgic amyotrophy, has been described following surgery, trauma or a variety of infections (Parsonage and Turner 1948). In a proportion of cases of both neuralgic amyotrophy and canine brachial plexus neuritis, no antecedent factor can be identified (Alexander and others 1974). In dogs, dietary equine or beef products have been implicated as a cause of brachial plexus neuritis (Cummings and others 1973, Steinberg 1988).

Clinical features

This condition typically presents with rapid onset bilateral forelimb paresis of varying severity (Cummings and others 1973, Alexander and others 1974, Sharp 1992). Motor deficits may be asymmetrical and unilateral cases may occur. Proximal muscles may be more severely affected (Sharp 1992). Sensory deficits, in the form of proprioceptive dysfunction and reduced pain sensation are typically present. Hindlimb function is normal. Facial paresis indicating VIIth cranial nerve involvement was reported by Cummings and others (1973). Brachial neuritis may be preceded by signs of a more general allergic reaction, including urticaria (Cummings and others 1973).

Investigation

Electromyography demonstrates an asymmetrical distribution of denervation which is confined to the forelimbs (Cummings and others 1973). CSF composition is normal (Cummings and others 1973, Steinberg 1988). Immunological testing suggested an anaphylactic hypersensitivity to horse serum in the case reported by Cummings and colleagues. Biopsies of mixed or sensory peripheral nerves demonstrate changes characteristic of axonal degeneration.

Pathology

Pathological findings were reported by Cummings and others (1973). Microscopy of affected nerves demonstrated Wallerian degeneration in the major peripheral nerve trunks with the exception of the axillary and subscapular nerves. These changes were present in both motor and sensory nerves. The proximal extent of the degeneration was found to be the ventral branches of spinal nerves with sparing of the nerve roots. The number of degenerating axons varied between fascicles. Many were only partially affected whilst others were completely degenerated or spared entirely. The pathogenesis of this condition is not clearly understood. The large number of mast cells which have been found in affected nerves (Cummings and others 1973) have prompted suggestions of nerve compression by immune-mediated perineurial oedema or alterations in the permeability of the vasa nervosum resulting from histamine release, however definitive proof for these theories has yet to be obtained.

Treatment

Treatment is predominantly supportive. Steinberg (1988) indicated that some dogs may show an apparent improvement following corticosteroid administration but a therapeutic basis for this has not been established. Corticosteroid therapy produced no improvement in the case of Cummings and others (1973) and spontaneous remission was not observed over a seven week period. Steinberg (1988) also reported that feeding a hypo-allergenic diet led to recovery followed by relapse if beef or equine products were reintroduced to the diet. Information regarding the prognosis for recovery of these cases is scarce and largely anecdotal. Recovery would have to take place by axonal regeneration from the proximal ventral branches therefore any return of function is likely to be prolonged. In human patients with brachial plexus neuritis, complete functional recovery may take up to three years or more (Tsairis and others 1972).

OTHER IDIOPATHIC BRACHIAL PLEXUS NEUROPATHIES

Duncan (1991) referred to a rare brachial plexus neuropathy of subacute or chronic onset which may affect one or both forelimbs in the dog. Whether this represents a specific entity or is an atypical presentation of a generalised type of polyneuropathy is unclear.

Brachial plexus neuropathy of unconfirmed aetiology has also been described in a cat (Bright and others 1978). This case differed from canine brachial plexus neuritis in that electrophysiological findings were suggestive of a demyelinating neuropathy. This was supported by a rapid rate of recovery which occurred within a month.

POLYRADICULONEURITIS

Acquired, generalised polyradiculoneuritides of both acute and chronic onset have been described in the dog and cat (Duncan 1980). These conditions characteristically present with flaccid tetraparesis or paraparesis but occasionally, atypical cases may present with signs of brachial plexus disease due to preferential forelimb involvement.

Acute polyradiculoneuritis following exposure to a racoon bite, known as Coonhound paralysis, has been well documented in the dog. Cummings and others (1982) described a case in which signs of paresis were first observed in the forelimbs. In addition to flaccid paresis, cranial nerves may be affected, particularly the seventh, and the bark is usually weak or absent (Duncan 1980, Cummings and others 1982, Duncan and Griffiths 1984). Electromyography shows evidence of moderate to severe denervation and nerve conduction velocities may be reduced. Increased F wave latency and dispersion has also been reported with Coonhound paralysis (Duncan 1991). CSF obtained from the lumbar cistern may have elevated protein levels but white blood cell counts are typically normal. Cummings and others (1982) described the pathology of Coonhound paralysis. The pathological changes tended to be concentrated in the ventral nerve roots and spinal nerves in which segmental demyelination, axonal degeneration and an inflammatory cell infiltrate comprising monocytic cells, macrophages, lymphocytes and plasma cells were observed. The precise pathogenesis remains obscure but some animals may have a genetic susceptibility to the disease (Holmes and deLahunta 1974). Acute idiopathic polyradiculoneuritis with identical clinical features to Coonhound paralysis but with no known antecedent factor has also been described (Northington and others 1981). Nerve biopsies from these cases were either normal or showed evidence of fibre degeneration. Corticosteroids do not appear to influence the outcome in cases of acute polyradiculoneuritis and treatment is palliative. The prognosis is guarded but many cases will make a satisfactory recovery. An uncommon chronic progressive form of polyradiculoneuritis involving both motor and sensory fibres has been described in dogs over six years of age (Cummings and de Lahunta 1974) and in the cat (Flecknell and Lucke 1978). Clinical signs, which may initially affect one limb, develop over a number of months. In dogs, cranial nerve deficits involving the seventh or tenth nerves may be present. Electrophysiological examination and nerve biopsy help to establish a diagnosis of polyneuritis in mildly affected cases. CSF may show albuminocytologic dissociation. A variety of pathological changes were observed suggesting that diverse pathogenetic processes were involved.

VASCULAR DISEASE

Vascular disturbances in the proximal limb or caudal cervical cord may give rise to signs of brachial plexus disease. These may result from coagulation disorders or thromboembolism.

COAGULATION DISORDERS

A case of brachial paralysis following a bite wound to the proximal brachium was diagnosed in a cat (Little 1992). Unilateral forelimb paralysis developed over several hours. A large haematoma was present in the axilla and medial brachium. Coagulation tests revealed that the cat had a clotting factor IX deficiency (haemophilia B, Christmas disease) (Brooks and Dodds 1989) although it had previously been asymptomatic. Following resolution of the haematoma, limb function improved over a period of several weeks resulting in complete recovery.

VASCULAR OCCLUSION

Brachial paralysis following thrombus formation in the sub-clavian artery has been reported in the dog (MacCoy and Trotter 1977). Thrombosis occurred six days after a road traffic accident and brachial paralysis developed over an eight hour period. The thrombosed vessel was identified by angiography and the affected portion of the right sub-clavian artery was replaced by a Dacron¹ graft. Neurological function was restored over a period of several weeks, however limb function was impaired by ischaemic contracture of the triceps muscles.

FIBROCARILAGENOUS THROMBOEMBOLISM

This condition may affect the grey matter of the caudal cervical cord segments supplying the brachial plexus resulting in acute flaccid forelimb paresis (Zaki and Prata 1976). Hindlimb paresis due to adjacent white matter damage is usually present in the early stages but may take several hours to develop (de Lahunta and Alexander 1976). Hindlimb deficits may resolve so that in later stages the signs may also resemble brachial plexus disease. Extensive grey matter infarction at this level is associated with a poor prognosis for return of limb function (Braund, Brewer and Mayhew 1987).

¹ DeBakey Prosthesis of Dacron, Pilling Co., Fort Washington, PA.

SECTION 2

CLINICAL CASES

SECTION 2: PART 1

MATERIALS AND METHODS

CASE SELECTION

The thirteen cases presented here were selected from those referred to the University of Glasgow Veterinary School (GUVS) for investigation of a forelimb gait abnormality during the period October 1990 to June 1993. All cases were presented to the neurology clinic, with the exception of case 7, which was referred for orthopaedic investigation. All cases were examined by the author, but cases 2, 7, 11 and 12 were the primary responsibility of other clinicians as acknowledged. Cases of forelimb paralysis due to primary spinal cord disease were not included in the study, with the exception of case 8 in which the initial presenting signs were suggestive of brachial plexus disease.

CLINICAL DETAILS

A full case history was obtained from the owner and referring veterinary surgeon and the relevant details were recorded. All cases underwent full systemic examination and only significant abnormal findings are described.

All cases received a complete neurological examination as detailed by Oliver and Mayhew (1987). Mentation and posture were noted and the owners questioned about any change in behaviour or attitude. The gait was evaluated, with assistance if necessary, for lameness, co-ordination and weakness. Conscious proprioception and motor function were assessed by paw position or tactile placing reactions, reflex stepping, sway test, wheelbarrowing, hopping tests and hemiwalking. Local spinal reflexes were assessed in each limb with the dog in lateral recumbency. Muscle tone was examined by passive flexion and extension of the limb. The patellar reflex was evaluated but myotactic reflexes were not routinely tested in the forelimb, as these were found to be inconsistent in animals with normal forelimb function. The pedal reflex was tested to evaluate strength of flexor muscle groups and to assess cutaneous sensory fields in the distal limb. The presence or absence of conscious pain perception was also noted. Muscle bulk and symmetry were assessed by palpation and the joints were examined for the presence of musculoskeletal disease. The panniculus reflex was tested on each side and the presence or absence of a direct and consensual reflex noted. Bladder and bowel function was evaluated by questioning the owner, observation of hospitalised cases, bladder palpation and examination of the perineal reflex.

Cranial nerves were routinely tested as described by Oliver and Mayhew (1987). In these cases, particular note was made of ocular sympathetic function. The pupils were assessed for size and symmetry under normal lighting conditions using distant ophthalmoscopy. Direct and consensual photomotor reflexes were tested in each eye and fundoscopy was performed. The eyes were observed for ptosis, enophthalmos and protrusion of the membrana nictitans.

Based on these findings, an attempt was made to localise the lesion to the cervical spinal cord, the brachial plexus or a peripheral nerve trunk. In the case of brachial plexus lesions, the proximal extent of the lesion and the cranial and caudal distribution were estimated where possible.

ANCILLARY INVESTIGATIONS

In most cases, further diagnostic procedures were carried out in order to further define the extent and severity of the lesion, investigate the aetiology and obtain information regarding prognosis. The relevant tests are detailed with individual case reports.

Routine haematological and biochemical evaluation was performed in several cases to investigate the possibility of systemic disease or to evaluate general health prior to anaesthesia. Red blood cell count, haematocrit, haemoglobin concentration, mean corpuscular volume, mean cell haemoglobin, platelet count and total and differential white blood cell count were determined. Plasma concentrations of urea, creatinine, sodium, potassium, chloride, calcium, phosphate, glucose, cholesterol, bilirubin, alkaline phosphatase, alanine transferase (ALT), aspartate transferase (AST), total protein, albumin and globulin were analysed. Creatine kinase levels were also determined in case 13. Results of these tests were compared to reference ranges of GUVS laboratories.

Blood samples from case 8 were submitted to the Feline Virus Unit at GUVS and examined for antibodies to feline leukaemia virus (FeLV), feline immunodeficiency virus (FIV) and feline coronavirus (FIP).

Thyroid and adrenal function were evaluated in case 13. A TSH stimulation test was performed by determining plasma T4 values prior to, and six hours after, the intravenous administration of 0.1 units/kg of bovine thyroid stimulating hormone (Thyrotropic Hormone, Sigma Chemical Co., St. Louis, USA) (Feldman and Nelson 1987). Adrenal function was assessed by a low dose dexamethasone suppression test (Mack and Feldman 1990). Serum cortisol values were determined before, and at three and eight hours after,

intravenous administration of 0.01mg/kg dexamethasone (Azium, Schering Plough Animal Health).

Electrophysiological, radiographic and myelographic examinations and CSF sampling were performed under general inhalational anaesthesia. A variety of anaesthetic regimes were used depending upon the procedure and individual patient requirements.

The majority of cases underwent electrophysiological examination using a Neuromatic 2000M electromyograph (Dantec Elektronik, Denmark) and recordings of spontaneous and evoked muscle action potentials were made. Electromyography was performed, using a concentric bipolar needle electrode, as described by Bowen (1987). Motor nerve conduction studies were carried out on the ulnar nerve as detailed by Bowen (1987). The latency, amplitude and duration of M waves were recorded and the nerve conduction velocity calculated as described by Niederhauser and Holliday (1989). Values were compared to reference values given by Walker and others (1979). Values were corrected for age where applicable (Swallow and Griffiths 1977). Tissue temperature was not recorded but examination was performed in a warm room shortly after induction of anaesthesia. The presence or absence of an F wave was noted. H reflexes were not examined in this study. Sensory nerve conduction studies were performed on the lateral cutaneous radial nerves in cases 3 and 11 as described by van Nes (1985).

Plain radiography of the cervical spine or proximal forelimb was performed in a number of cases. In cases with suspected neoplasia, left and right inflated views of the thorax were obtained to evaluate the lung field for metastatic disease (Suter and others 1974). Myelography was carried out in cases 5 and 6 by injection of 0.3mls/kg iopamidol (Niopalm 300mg iodine/ml, Merck Pharmaceuticals) into the cisterna magna using the same protocol as described for CSF sampling.

CSF samples were obtained from a number of cases, from either the cerebellomedullary or lumbar cistern or both. The collection site was clipped and aseptically prepared. Cisterna magna samples were collected using a 21g 1" or 1.5" hypodermic needle according to patient size. The technique used is described by Evans (1992) [Method 1]. Lumbar samples were obtained from cases 8 and 13 via the L5/L6 interarcuate space as described by Lewis (1991). A 3.5" 20g spinal needle (Monoject 220 Spinal Needle, Sherwood Medical Industries, St. Louis, U.S.A.) was used for case 13 and 1.5" 22g spinal needle for case 8 which was a cat. Samples were inspected for colour, consistency and turbidity. The cell count and total protein concentration were determined and compared to reference values given by Bailey and Higgins (1985). If the white blood cell

count exceeded 5 cells/ul in the cisterna magna or 8 cells/ul in the lumbar cistern, a differential count was determined following cytopspin.

An anticholinesterase test was performed in case 13. 0.25 ml of edrophonium chloride (Tensilon, Roche Products Ltd.) was administered by intravenous injection and the animal was exercised one to two minutes later. Exercise tolerance was compared before and after injection.

From the history, clinical findings and results of ancillary investigations, a diagnosis was made and treatment instigated where appropriate. In cases where the outcome was unsuccessful post-mortem examination was performed with the owner's permission.

SECTION 2: PART 2

CASE SUMMARIES

The following cases are grouped according to aetiology into traumatic, neoplastic and inflammatory or idiopathic conditions. Patient details, presenting signs and the clinical or pathological diagnoses of all the cases are summarised in Table 2.

CASE	BREED	AGE	SEX	PRESENTING SIGN(S)	DURATION OF SIGNS	DIAGNOSIS
1 (121429)	Rhodesian ridgeback	2 yrs	M	Paralysis RF	4 wks	Traumatic nerve root avulsion [C/P]
2 (121614)	Labrador retriever	6 yrs	M	Paralysis RF	30 mins	Traumatic nerve root avulsion [C]
3 (118011)	Rottweiler	4 yrs	M	LF lameness	8 wks	Distal radial nerve injury [C]
4 (118563)	Cairn terrier	9 yrs	M	Progressive RF lameness	5 wks	Neurofibrosarcoma [C/P]
5 (118712)	Irish setter cross	5 yrs	FN	LF lameness to quadriparesis	9 wks	Malignant Schwannoma [C/P]
6 (121966)	Flat coated retriever	7 yrs	M	Progressive LF lameness	5 wks	Nerve sheath tumour [C]
7 (119826)	Old English sheepdog	11 yrs	MN	Progressive LF lameness	8 wks	Nerve sheath tumour [C]
8 (120381)	Domestic short haired cat	7 yrs	MN	LF paresis to quadriparesis	2 wks	Neural lymphoma [P]
9 (120399)	Shetland sheepdog	9 yrs	MN	Progressive LF lameness	8 wks	Vertebral osteosarcoma [P]
10 (119200)	Doberman	10 yrs	FN	Progressive LF lameness	8 wks	Undifferentiated sarcoma [C/P]
11 (118068)	Tibetan terrier	2.5 yrs	FN	Bilateral FL paresis	8 wks	Brachial plexus neuritis [C]
12 (116124)	Cairn terrier	10 yrs	M	Paresis LF	6 wks	Polyneuritis [C]
13 (120714)	English springer spaniel	8 yrs	M	Bilateral FL paresis & seizures	2 wks	Brachial neuropathy [C] Insulinoma [C/P]

Table 2
Summary of patient details.
[C] indicates clinical diagnosis; [P] indicates pathological diagnosis.

Case 1: No. 121429

Signalment: "Nico", a 2 years old male Rhodesian ridgeback

Weight: 42 kg.

Diagnosis: Avulsion of dorsal and ventral nerve roots C6 to T1.

Case Summary

One month before presentation the dog was struck by a car. The right forelimb had not been used since.

Significant findings were confined to the right forelimb which was paralysed and hung in a "dropped elbow" position with the dorsum of the foot contacting the ground (Figure 8). Severe muscle atrophy involving all intrinsic muscles of the limb was apparent on visual inspection. The limb was flaccid, with complete loss of muscle tone. The pedal reflex was absent and there was anaesthesia of the limb distal to the elbow and over the distal craniolateral brachium. The panniculus reflex was altered; stimulation of the right flank produced a consensual response on the left side but no ipsilateral response. Stimulation of the left flank produced an ipsilateral response only. There was miosis of the right pupil which was responsive to light. No other features of Horner's syndrome were noted. In addition to the neurological deficits, the toes and dorsal aspect of the right foot were abraded and the medial carpus had been severely mutilated. The first digit was missing leaving the phalanx exposed in the centre of a large necrotic wound (Figure 9). The right prescapular lymph node was palpably enlarged.

The clinical findings indicated that all the major peripheral nerve fields of the right fore were affected. This was consistent with a lesion within, or proximal to, the plexus bundle. Loss of the efferent portion of the panniculus reflex on the right side indicated a lesion affecting C8 and T1 fibres at the level of the nerve roots or ventral branches. The positive consensual response confirmed that the sensory portion of the reflex was intact. Ipsilateral miosis confirmed a lesion of the ventral nerve root of T1. Cutaneous sensory loss involved multiple nerve fields and corresponded to the motor deficits. On the basis of the clinical findings and known history of trauma a diagnosis of avulsion of the dorsal and ventral nerve roots of C6 to T1 was made.

Electromyography demonstrated fibrillation potentials and positive sharp waves in all the intrinsic muscle groups of the right forelimb and in the cutaneous trunci muscle (Figure 10). Stimulation of the right ulnar nerve failed to elicit an evoked muscle action potential.

The lack of nerve conduction in the ulnar nerve one month after injury indicated that the prognosis for recovery of limb function was poor. The situation was further complicated by severe self-mutilation and trauma to the distal limb. Lymphadenopathy suggested the presence of infection and immediate amputation of the limb was recommended. The owners would not consider amputation and requested that the dog be euthanased.

At post-mortem examination, inspection of the cervical spinal cord revealed complete avulsion of the sixth, seventh and eighth dorsal and ventral nerve roots from the spinal cord on the right side (Figure 11). The first thoracic nerve appeared discoloured but was grossly intact and there was adhesion of the dura mater to the wall of the spinal canal at the level of the C7 nerve root (Figure 12). The paravertebral muscles, right thoracic wall and ventrum showed evidence of previous contusion. As an incidental finding, three small healing splits were noted in the liver and one in the spleen. These were presumably related to the original trauma.

Microscopy of the spinal cord at segments C6, C7, and C8 demonstrated compression of the right side of the cord with coarse vacuolation of the dorsal and ventral white matter which was presumed to result from cord compression due to haemorrhage at the time of injury. Nerve roots were absent on the right side. Neuroma formation was evident at the site of the ventral root avulsion (Figure 13). Nerve roots on the left side were normal. Examination of the plexus bundle and peripheral nerves revealed Wallerian-type degeneration and vascularisation (Figure 14).



Figure 8

Case 1 demonstrates the typical appearance of a complete brachial nerve root avulsion injury with knuckling of the foot, dropped elbow and prominence of the spine of the scapula due to atrophy of the spinatus muscles.

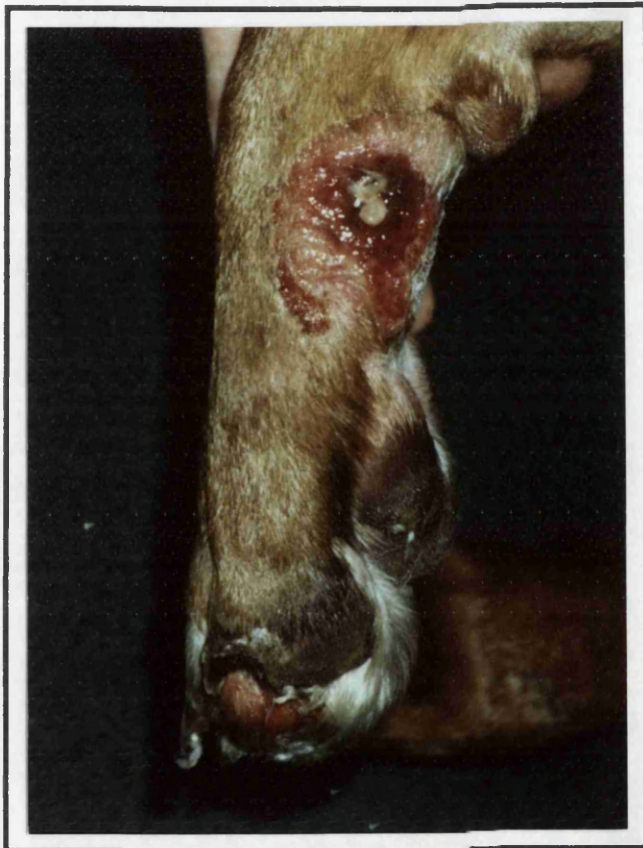


Figure 9

Tauma and self-mutilation of the distal limb in Case 1 following complete brachial plexus root avulsion with loss of cutaneous sensation.

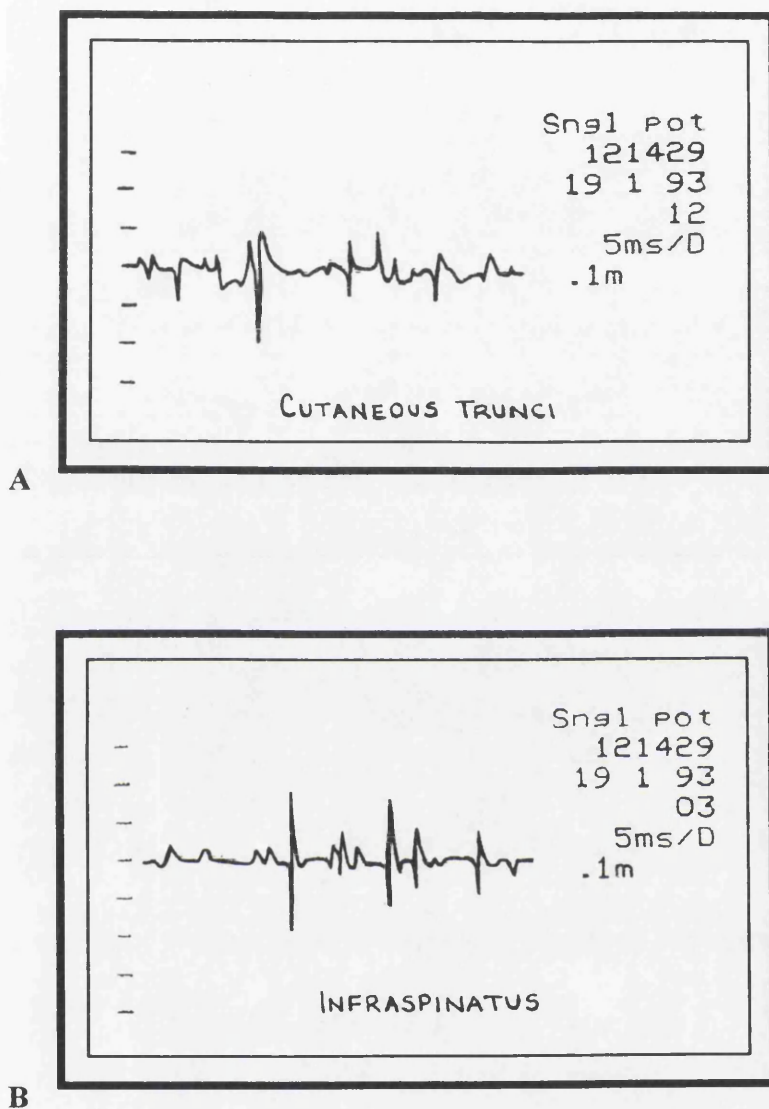


Figure 10

Electromyographs obtained from the cutaneous trunci muscle (A) and the infraspinatus muscle (B) in Case 1. The presence of fibrillation potentials and positive sharp waves indicates denervation of these muscles. The distribution of spontaneous electrical activity confirms the cranial and caudal extent of brachial nerve root injury.

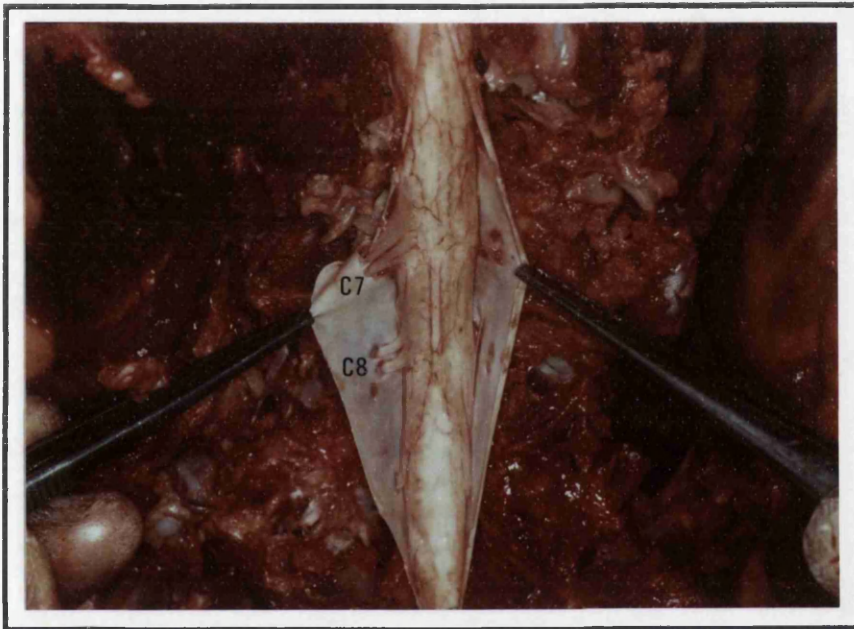
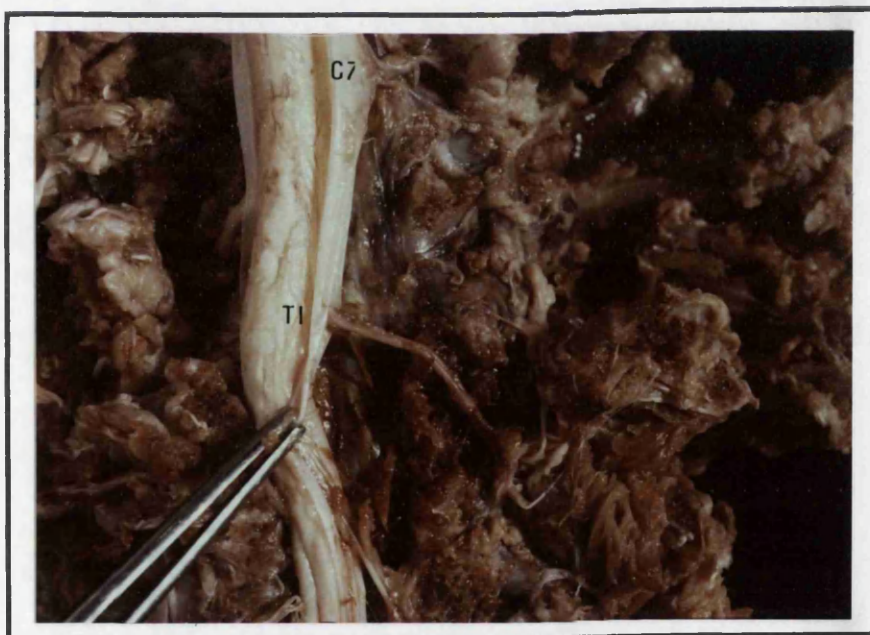


Figure 11

Case 1. Dorsal view of the caudal cervical spinal cord at post mortem showing intradural avulsion of the C7 and C8 nerve roots from the spinal cord on the right side. The dura has been incised and reflected.



A



B

Figure 12

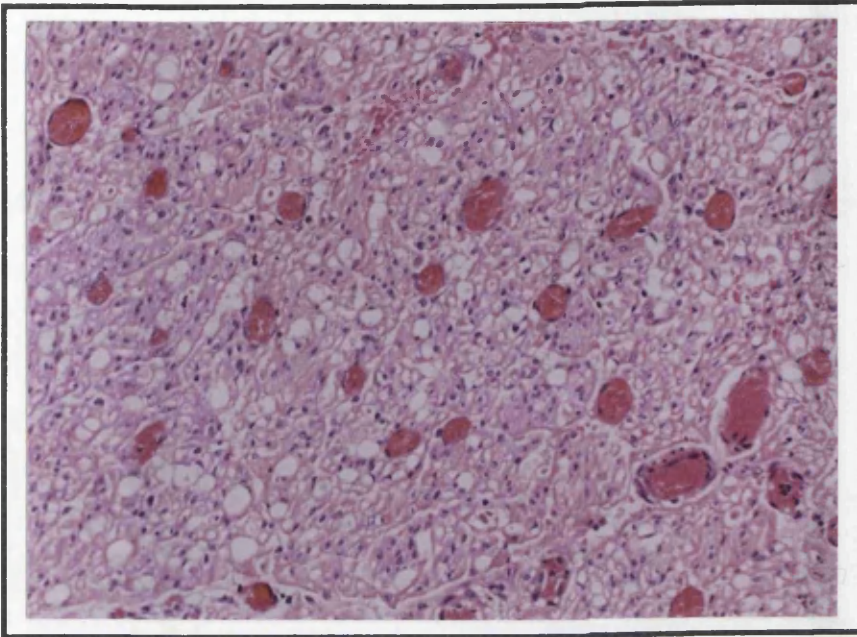
Case 1. Fixed post mortem specimen of the caudal cervical spinal cord comparing the normal left side (A) to the affected right side (B). On the affected side only the T1 nerve root, which is traumatised and discoloured, is visible. There is adhesion of the dura mater to the wall of the vertebral canal at the level of C7.



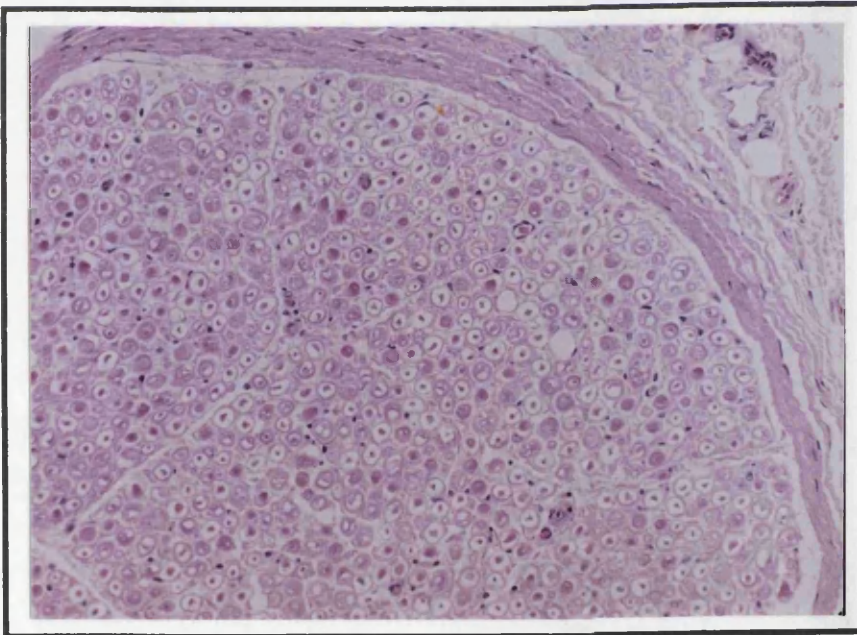
H & E x 7.5

Figure 13

Case 1. Transverse section through the spinal cord at the level of the seventh cervical segment. Nerve roots are not visible on the right side in contrast to the normal left side (open arrow). There is neuroma formation at the site of the ventral nerve root avulsion (closed arrow) and there is distortion of the spinal cord on the right.



A x 60



B x 30

Figure 14

Case 1. Figure A shows degeneration of a mixed peripheral nerve four weeks after complete brachial nerve root avulsion with loss of axons, vascularisation and infiltration of the nerve by macrophages. Figure B illustrates a normal nerve from the non-affected limb of the same animal for comparison. H & E

Case 2: No. 121614

Signalment: "Ben", a 6 years old male Labrador retriever

Weight: 32 kg.

Diagnosis: Avulsion of ventral and dorsal nerve roots C6 to T1.

Case Summary

The dog was admitted to the hospital immediately after being struck by a car. He was ambulatory, but dragged the right forelimb which was non-weightbearing. Haemorrhage from the oral cavity was also noted.

A degree of cardiovascular shock was evident on systemic examination. The oral haemorrhage was caused by a full-thickness lingual wound and a mandibular degloving injury. Tachypnoea and harsh lung sounds suggested possible thoracic trauma but radiography of the thorax demonstrated no significant abnormality. The right carpus was swollen but there was no instability or crepitus on manipulation of the joint.

Treatment for shock was instigated and a padded dressing applied to the carpus. When the dog's general condition stabilised a more extensive examination was performed. The right forelimb was paralysed and hung in the "dropped elbow" position with the carpus knuckled, as in case 1. The limb was atonic and a pedal reflex could not be elicited. Cutaneous sensation was absent distal to the elbow and over the craniolateral aspect of the distal half of the brachium. The panniculus reflex was abnormal in that stimulation of either flank resulted in a positive reflex on the left side only. There was miosis of the right pupil, which was responsive to light, indicating a partial Horner's syndrome. The left forelimb and hindlimbs were normal.

The clinical signs indicated involvement of all the nerve roots or ventral branches contributing to the plexus, namely C6 to T1. The panniculus deficit and ocular sympathetic deficit suggested a lesion at the level of the nerve roots. Cutaneous sensory loss was compatible with the degree of motor loss, indicating involvement of both dorsal and ventral roots. The history and obvious traumatic nature of the injury led to a clinical diagnosis of avulsion of the dorsal and ventral nerve roots from C6 to T1.

Radiographs of the thorax and abdomen were obtained. No rib fractures or pulmonary lesions were evident. The swollen right carpus was radiographed but, with the exception of soft tissue swelling, no abnormalities were seen. Electrophysiological studies were not indicated at this time because the injury had only been present for a short period.

When the dog's general condition was satisfactory the facial injuries were repaired. The paralysed limb was supported in an Velpeau-type sling to protect the foot and the dog was discharged. A poor prognosis for return of limb function was given.

The dog was re-examined ten days later. The facial wounds had healed but limb signs were unchanged except for early neurogenic atrophy of all major muscle groups. The Ehmer sling had been removed as it seemed uncomfortable and the foot was protected by a dressing. Amputation of the limb was discussed with the owners who elected to wait a further two weeks before making a final decision. One week later the dog was returned to the hospital having been unwell for the previous two days. Examination of the paralysed limb revealed malodorous, necrotic wounds on the distal part of the limb. In view of the hopeless prognosis for return of limb function and the potentially serious complications of wound infection and necrosis, amoxycillin/clavulanic acid 375mg BID (Synulox, SmithKline Beecham Animal Health) was prescribed and the limb was amputated two days later.

Five weeks after amputation the dog was reported to be coping well and was managing to walk up to two miles.

Case 3: No. 118011

Signalment: "Satan", a 4 years old male Rottweiler

Weight: 45 kg.

Diagnosis: Distal radial nerve injury.

Case Summary

This dog was presented with a left forelimb lameness of two months duration following an incident where the dog had jumped off a bed and collided with a wall-mounted radiator. The owner had witnessed the incident and thought that the left forelimb had been trapped between the wall and the radiator as the dog landed. For four to five days following this episode the dog would squeal when rising from a prone position. There had since been a gradual improvement in the lameness. Rest, exercise or non-steroidal anti-inflammatory drugs had little effect on the severity of the lameness.

Gait assessment demonstrated a 2/5 lameness of the left forelimb. Significant findings were confined to this limb. There was audible scuffing of the nails as the foot was advanced and the centre nails were severely worn. If the dog sat for a few minutes the left carpus consistently began to flex and tremble. When asked to "give a paw", extension of the left carpus appeared weaker than the right. Paw position sense appeared slow when compared to other limbs. The limb could support weight during hopping tests and local limb reflexes were intact. Muscle bulk was comparable with other limbs. The panniculus reflex and ocular sympathetic function were normal and cutaneous sensation was intact. There was no clinical evidence of musculoskeletal disease.

The gait deficit appeared to be due to weakness of the carpal extensor muscles which are innervated by the radial nerve. Other muscles innervated by proximal parts of the radial nerve, notably elbow extensors, were unaffected and cutaneous sensation was preserved indicating that the lesion was distal to the point at which the cutaneous sensory branches leave the main nerve trunk proximal to the elbow. The nature of the accident preceding the clinical signs suggested that the radial nerve may have been subject to a compression injury.

Electromyography demonstrated spontaneous electrical activity in the carpal extensor group of the left fore. No other muscle groups, including the left triceps, were affected. Sensory nerve conduction studies were performed on the left lateral cutaneous radial nerve which was found to be conducting normally.

Radiographs of the left elbow and distal humerus were obtained but no abnormalities were present.

In view of the duration of the signs and relatively innocuous nature of the injury no treatment was undertaken.

At follow-up examination six weeks later the gait deficit had improved. The dog was no longer lame but still scuffed the nails. Paw position sense was normal. The carpus still tended to flex and shake as the dog sat but the foot position was spontaneously corrected.

CASE	TUMOUR	LIMB DEFICITS	ATROPHY	PAIN	CUTANEOUS SENSATION	IPSI LATERAL PANNICULUS	IPSI LATERAL MIOSIS	PALPABLE MASS
4 (118563)	Neurofibrosarcoma	LF lameness	Minimal triceps	Axilla / cervical	Intact	Absent	Yes	No
5 (118712)	Mal. Schwannoma	LF lameness to quadriparesis	Moderate triceps	Cervical / proximal LF	Intact	Absent	Yes	No
6 (121966)	Nerve sheath tumour	LF lameness Poor hopping LF	Moderate triceps	No	Intact	Present	No	No
7 (119826)	Nerve sheath tumour	LF lameness	All muscle groups	Axilla / cervical	Intact	Absent	Yes	No
8 (120381)	Neural lymphoma	LF paresis to quadriparesis	No	No	Intact	Present	No	No
9 (120399)	Vertebral osteosarcoma	LF lameness	Moderate triceps Minimal spinatus	Cervical / proximal LF	Intact	Present	No	No
10 (119200)	Undifferentiated sarcoma	LF lameness	Moderate spinatus	Proximal brachium	Intact	Present	No	Yes

Table 3
Summary of clinical findings in cases of primary and secondary neoplasia involving the brachial plexus.

CASE	TUMOUR TYPE	NERVE(S) INVOLVED	SPINAL CANAL INVOLVED	METASTASES
4 (118563) [P]	Neurofibrosarcoma	C8 nerve roots/ventral branch T1 ventral branch and spinal nerve	Yes	No
5 (118712) [P]	Malignant Schwannoma	C8 & T1 ventral branches, nerve roots & epidural mass	Yes	Yes
6 (121966) [C]	Nerve sheath tumour	Radial nerve	No	Unknown
7 (119826) [C]	Nerve sheath tumour	C8 & T1 nerve roots / ventral branches	No	Unknown
8 (120381) [P]	Neural lymphoma	Cervical nerve roots and spinal cord	Yes	Also found in kidneys & thoracic muscles
9 (120399) [P]	Vertebral osteosarcoma	Compression of C8 spinal nerve	Yes	No
10 (119200) [C]	Undifferentiated sarcoma	Suprascapular	No	Unknown

Table 4
Summary of tumour distribution in cases of brachial plexus neoplasia.
[C] indicates clinical localisation only; [P] indicates pathological examination.

Case 4: No. 118563

Signalment: "Hamish", a 9 years old male Cairn terrier

Weight: 12 kg.

Diagnosis: Neurofibrosarcoma involving ventral branches and nerve roots of C8 and T1.

Case Summary

Five weeks before presentation the owner had observed a mild right foreleg lameness. This had progressed to a stiff, hunched forelimb gait associated with pain and the dog cried if touched or lifted. He had become very dull and reluctant to move and was uncharacteristically aggressive if approached. Treatment with mefenamic acid (Ponstan, Parke, Davies and Company) and prednoleucotropin (PLT, C-Vet Ltd.) prior to presentation at GUVS had failed to alleviate the lameness.

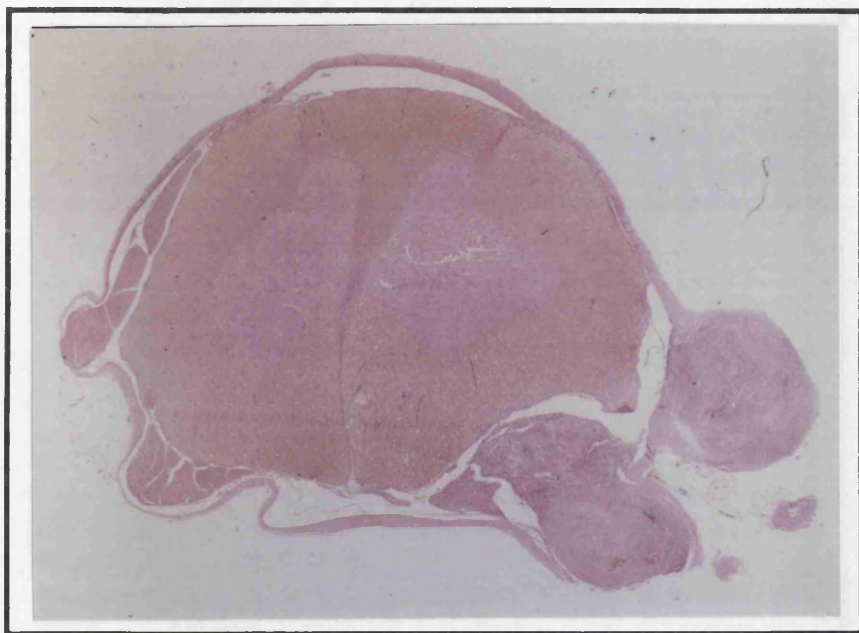
Gait assessment revealed a short, stilted forelimb gait. A limited neurological examination was carried out because of the degree of pain. Paw position sense was normal and local spinal reflexes were intact in all limbs. The right triceps muscle group was mildly atrophied. There was miosis of the right pupil with an intact photomotor reflex. Bilateral stimulation of the panniculus reflex resulted in a motor response from the left cutaneous trunci muscle only. An axillary mass was not palpable but there was marked pain if the limb or neck was manipulated. Cutaneous sensation appeared to be intact.

The significant abnormalities in this case were the panniculus deficit, partial Horner's syndrome and triceps atrophy. The first of these signs indicates involvement of the nerve roots or ventral branches of C8 and T1. The pupillary abnormality confirms involvement of the T1 nerve root or spinal nerve. A lesion at this site could also cause extensor weakness which might have been demonstrated by hopping tests. In view of the duration of the lameness it was not possible to determine clinically whether the triceps muscle atrophy was due to denervation or disuse. On the basis of the clinical findings and history of progressive, painful lameness in a dog of this age, a tentative diagnosis of a nerve sheath tumour involving the ventral root of T1 and the root or ventral branch of C8 was made.

In view of the rapid progression of signs, painful nature of the condition and poor prognosis the owner requested that no further investigations be undertaken and the dog was euthanased.

Pathological examination revealed gross thickening of the roots of the eighth cervical nerve, particularly the ventral root. This was accompanied by slight swelling and discolouration of the spinal cord. The C8 ventral branch was thickened distally to the level of the common plexus bundle. At the point of union of C8 and T1 the T1 ventral branch was found to be similarly thickened. This swelling extended proximally to the level of the intervertebral foramen.

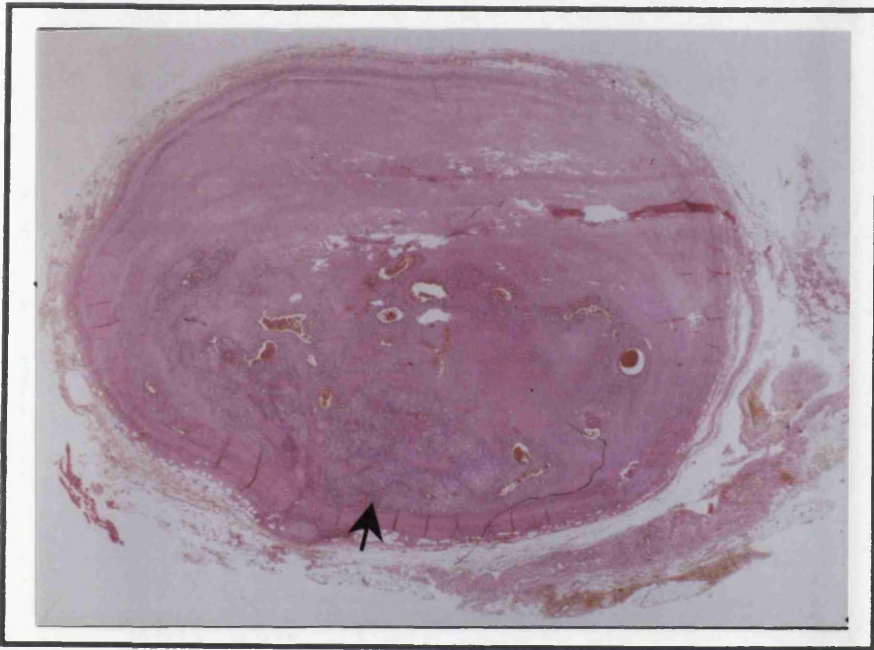
Microscopy of the spinal cord showed cord compression resulting from enlargement of the nerve roots (Figure 15). Microscopy of the affected nerve roots revealed almost complete infiltration by neoplastic tissue (Figure 16). At the level of the C8 root the tumour could be seen invading the spinal cord. The tumour was composed of a mixture of plump spindle cells arranged in swathes or bundles (Figure 17). Cell and nuclear size was variable with frequent mitoses. Special staining methods demonstrated the presence of collagen and reticulin fibres (Figure 18). This tumour was classified in the pathologist's report as a neurofibrosarcoma based upon "the large amounts of collagen present, the mitotic rate and the atypical appearance of cells and nuclei".



H & E x 7.5

Figure 15

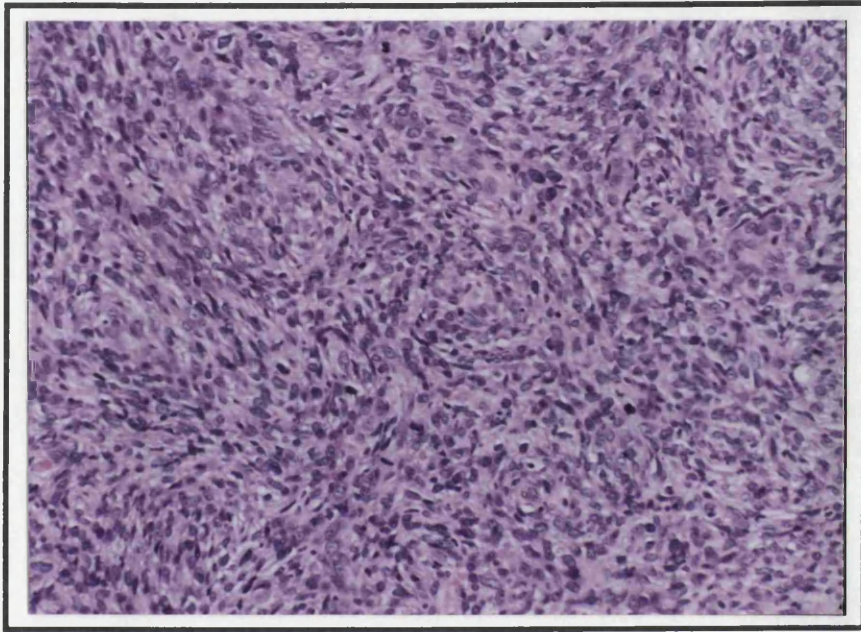
Case 4. Nerve root tumour. Transverse section through the spinal cord at the level of the eighth cervical segment. The dorsal and ventral nerve roots on the right are neoplastic and grossly thickened in comparison to the normal left side. Enlargement of the ventral root has resulted in compression of the ventrolateral aspect of the spinal cord with coarse vacuolation of the adjacent white matter.



H & E x 10

Figure 16

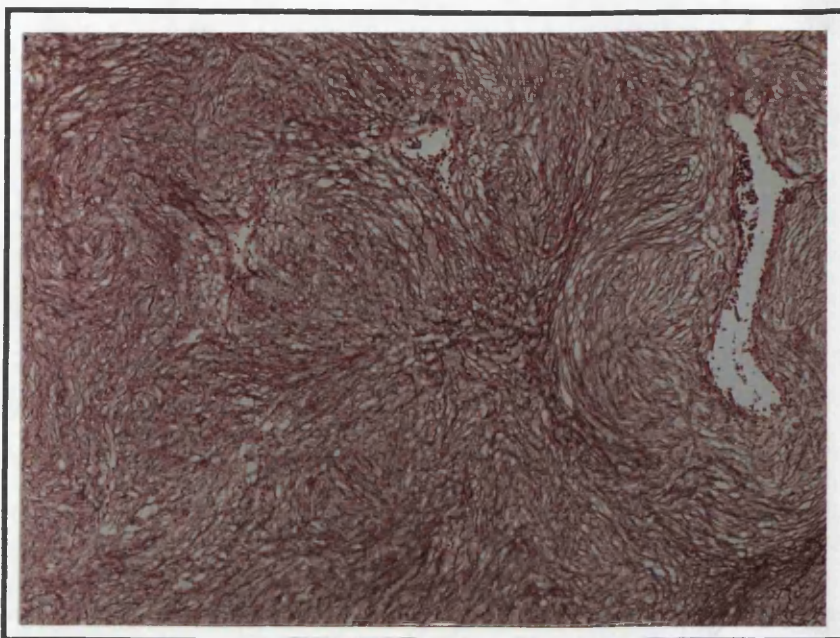
Microscopy of neoplastic nerve root from Case 4. Transverse section through the affected nerve root showing extensive infiltration of the nerve by the tumour with only small areas of recognisable nerve tissue remaining in the lower half of the section (arrow).



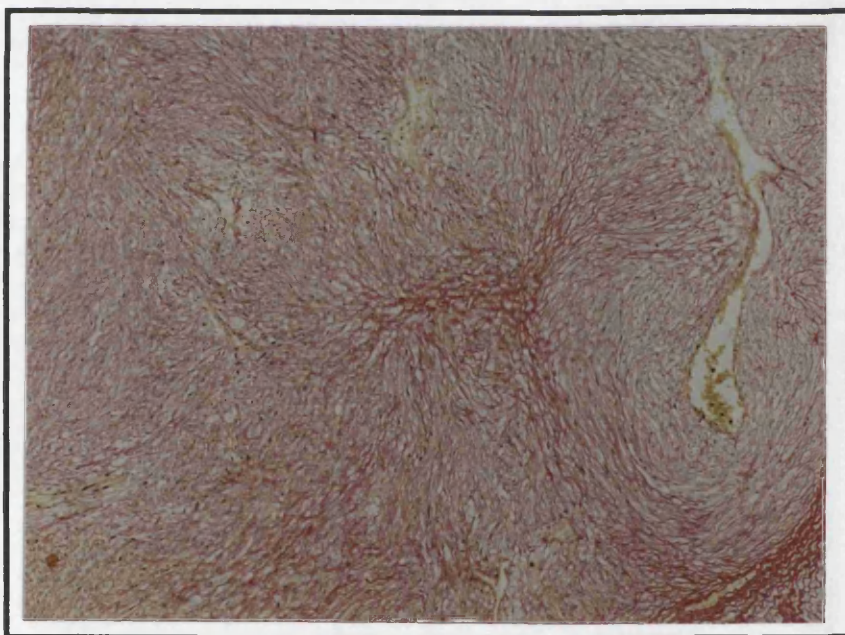
H & E x 60

Figure 17

Microscopy of neoplastic nerve root from Case 4 showing plump spindle cells arranged in a combination of loose swathes and bundles.



A Gordon & Sweet's method x 30



B Sirius red x 30

Figure 18

Sections of the nerve root tumour from Case 4 stained to show the presence of (A) reticulin (black) and (B) collagen (red) which are typically associated with nerve sheath tumours in dogs.

Case 5: No. 118712

Signalment: "Rusty", a 5 years old neutered female Irish setter cross

Weight: 23 kg

Diagnosis: Malignant Schwannoma invading the C8 and T1 nerve roots and epidural space.

Case Summary

This dog was initially presented with a three week history of apparent neck pain. The signs had appeared suddenly and had remained static. There was no history of trauma. The owners reported that the dog had difficulty lowering her head to eat and frequently yelped when attempting to do so. She would squeal occasionally when rising or as she lay down.

Assessment of the gait revealed a minimal left foreleg lameness. No deficits were found on neurological examination and there was no clinical evidence of musculoskeletal disease. There was a good range of voluntary neck movement but manipulation of the neck was resisted. On one occasion the dog yelped when the head was pushed to the right side.

The main differential diagnoses considered at this time were mild degenerative cervical disc disease, discospondylitis, a vertebral tumour or a peripheral nerve tumour. Plain radiographs of the cervical spine were obtained but no abnormalities were seen.

The dog was discharged and the owners were instructed to limit exercise to the lead for toilet purposes only. Piroxicam (Feldene, Pfizer Ltd.) was prescribed at a dose of 10 mg. every 48 hours. Three weeks after discharge the owner reported by telephone that the dog had returned to normal and showed no further evidence of pain.

Six weeks after initial presentation the dog was re-examined because the neck pain and left foreleg lameness had recurred. The lameness had worsened significantly over a ten day period. Treatment with piroxicam and aspirin by the referring veterinary surgeon had not alleviated the lameness or cervical pain.

There was a 4/5 lameness of the left foreleg. The left triceps group was moderately atrophied. Paw position sense was normal and the pedal reflex was satisfactory. There was marked pain on manipulation of the proximal left fore and neck and on palpation of the axilla, but a mass was not identified. There was loss of the panniculus reflex on the left side on both ipsilateral and contralateral stimulation. There was miosis of the left

pupil which was light responsive, but no other signs of Horner's syndrome were present. Systemic examination was unremarkable.

The most useful localising signs were the panniculus deficit and the partial Horner's syndrome indicating a proximal lesion involving the C8 and T1 spinal nerves. This would also account for the atrophy detected in the triceps muscles. These signs, associated with intractable progressive lameness in this age of dog were consistent with a diagnosis of nerve sheath tumour.

Electromyography was performed and spontaneous electrical activity was detected in the left forelimb, involving the triceps muscles and all muscle groups distal to the elbow. Left and right lateral thoracic radiographs were obtained with the lungs inflated. These showed no evidence of pulmonary metastatic disease. Plain lateral views of the cervical vertebrae were unremarkable and myelography was performed. Lateral and dorsoventral views of the cervical spine following the administration of iopamidol (Niopam 300, E. Merck Pharmaceuticals) by cerebellomedullary puncture demonstrated an extradural mass to the left of the spinal cord at the level of the seventh cervical vertebra. (Figure 19). Cerebrospinal fluid obtained prior to myelography contained no cells and 360 mg/l of protein¹.

These findings supported the diagnosis of an extra-dural nerve sheath tumour.

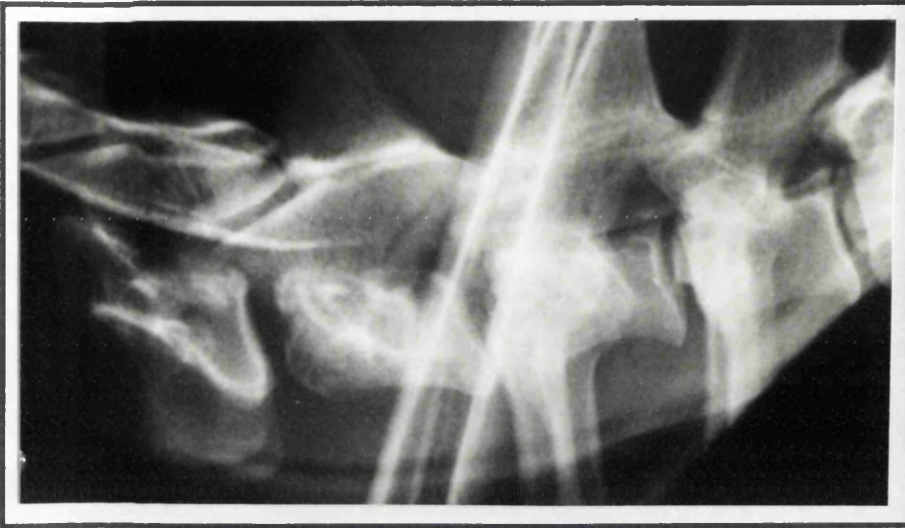
Exploratory dorsal laminectomy was performed seven days later. During the intervening period the dog developed progressive paraparesis. Neurological examination identified an upper motor neurone lesion compatible with spinal cord compression at the site of the suspected tumour. The approach to the caudal cervical spinal cord was carried out as described by Sorjonen (1987). A pink, fleshy mass was visualised between the dura mater and the vertebral wall on the left side. This mass enveloped the roots of C8 and T1 which were grossly thickened. The bulk of the mass was excised and submitted for pathological examination. Further exploration revealed that the mass extended through the intervertebral foraminae of C8 and T1. In view of the extensive nature of the tumour and the likelihood of local recurrence it was decided not to proceed further and the dog was euthanased.

At necropsy the C8 and T1 spinal nerves were grossly thickened and white. Firm, white tissue extended distally through the foramen and along the ventral branches and

¹ Normal value < 250 mg/l (Bailey and Higgins 1985)

proximally into the epidural space. Multiple, small, nodular lesions were scattered throughout the lung lobes.

Microscopy of the abnormal nerve tissue demonstrated a tumour composed of tightly packed spindle cells arranged in streams and bundles (Figure 20). There was a moderate rate of mitosis. Collagen and reticulin fibres associated with the tumour were demonstrated by special staining methods (Figure 21). Similar tissue was identified in the pulmonary lesions. On the basis of the histological appearance and pulmonary metastases the tumour was classified as a malignant Schwannoma.



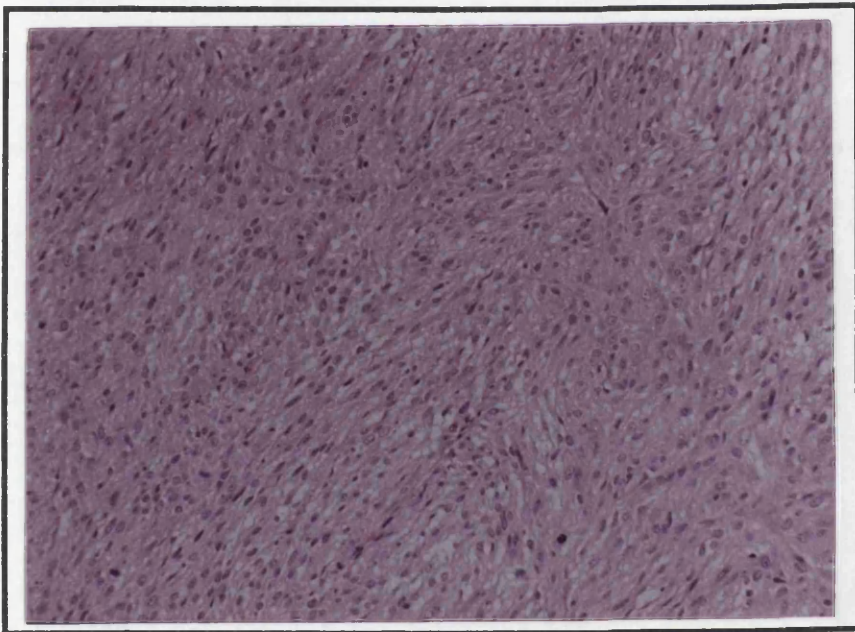
A



B

Figure 19

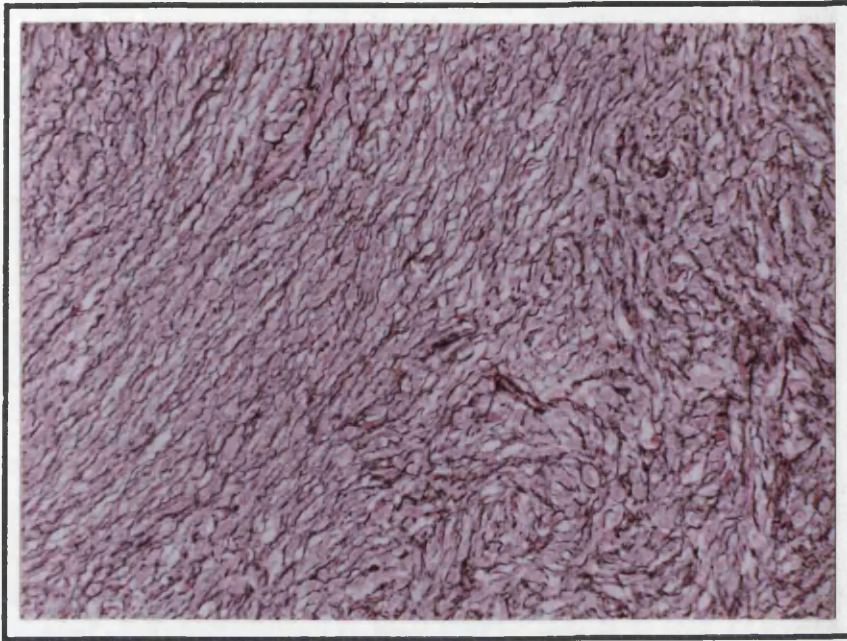
Radiographs of the caudal cervical spine from Case 5 following myelography. The lateral view (A) shows a filling defect in the ventral contrast column overlying the C7 vertebra with thinning of the dorsal column. The dorsoventral view (B) shows that the contrast column on the left has been displaced medially by an extradural mass at the same site (arrows). The mass was a malignant Schwannoma involving the C8 nerve root.



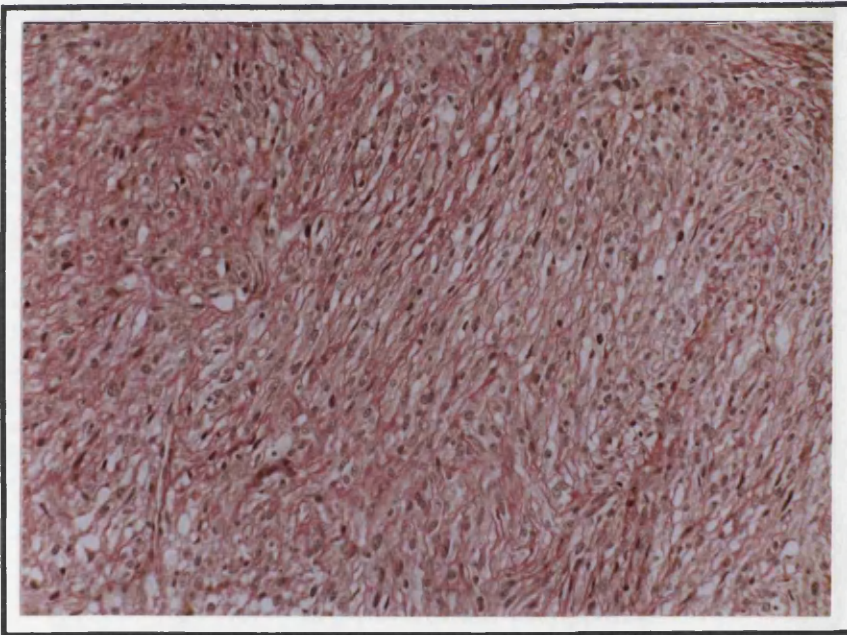
H & E x 60

Figure 20

Microscopy of the Schwannoma in Case 5. The spindle shaped cells are arranged in streams and occasional bundles.



A Gordon & Sweet's method



B Sirius red

Figure 21

Specially stained sections of the Schwannoma from Case 5 showing the presence of (A) reticulin (black) and (B) collagen fibres (red). x 60

Case 6: No. 121966

Signalment: "Ranza", a 7 years old male Flat coated retriever

Weight: 33.5 kg.

Diagnosis: Presumed nerve sheath tumour.

Case Summary

The dog was presented with a history of progressive left foreleg lameness of five weeks duration. The attending veterinary surgeon found no evidence of musculoskeletal disease and no abnormalities were seen on radiography of the limb. The lameness, which appeared to worsen with exercise, failed to respond to either prednoleucotropin (PLT, C-Vet Ltd.) or prednisolone.

Assessment of the gait revealed a moderate left fore lameness and the limb was held up at rest. The dog was unable to perform hopping tests on the left fore. Paw position sense and local spinal reflexes were normal. Tone in the left triceps group seemed reduced on elbow flexion and this muscle was also moderately atrophied. There was no Horner's syndrome or panniculus deficit. There was no pain on manipulation of the left fore and no axillary mass was palpable. There were no cutaneous sensory deficits. The right fore and the hindlimbs were normal.

The predominant findings were lameness and paresis of the left fore. The decreased tone and triceps atrophy suggested a lesion involving the C8 or T1 ventral branches or radial nerve. Preservation of elbow flexion indicated that the musculocutaneous nerve and its origins were not involved. Sparing of the panniculus reflex and ocular sympathetic function suggested that the ventral branches of C8 and T1 and the T1 nerve root and spinal nerve were intact. Based upon the age of the dog, the course of the disease and the clinical findings a presumptive diagnosis of nerve sheath tumour was made.

Electromyography demonstrated a patchy distribution of fibrillation potentials and positive sharp waves in the left triceps and carpal extensor muscles (Figure 22). Nerve conduction studies were not performed.

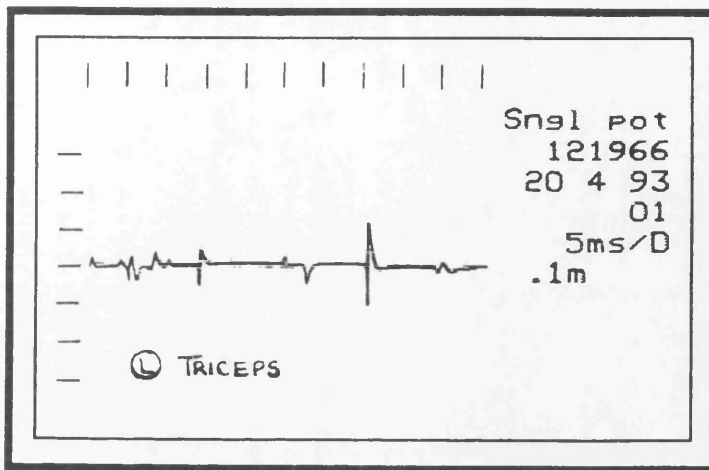
The clinical and electromyographic findings suggested that the site of the tumour was most probably the radial nerve trunk. The majority of fibres contributing to this nerve arise from the C8 and T1 nerve roots. The median and ulnar nerves also originate from these segments, so a lesion affecting the roots or ventral branches would affect muscles

supplied by these nerves, which was not evident on clinical or electromyographic examination.

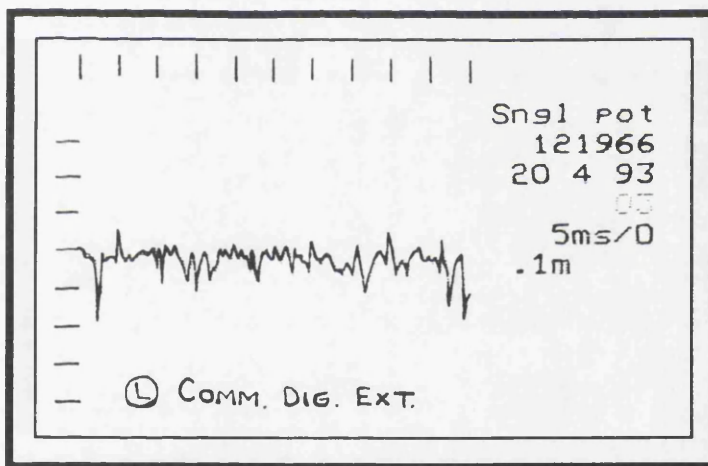
With a view to possible exploratory surgery, plain radiography and myelography of the cervical spine were performed and no significant abnormalities were seen. This was done to exclude intraforaminal lesions although there was no clinical evidence of this. Lateral views of the thorax did not show evidence of pulmonary metastases.

The owners were advised that surgical exploration of the brachial plexus to confirm the diagnosis and determine the extent of nerve involvement was appropriate in this case; however, it was likely that amputation of the limb would be indicated. The owners were unwilling to permit surgery and elected to manage the dog conservatively as there was reasonable limb function and the dog did not appear to be in appreciable pain.

Four months after presentation the owners reported that the lameness had continued to progress and the limb was carried when the dog exercised. In the last two weeks there appeared to be discomfort associated with manipulation of the limb. Surgery was again declined.



A



B

Figure 22

Electromyographs obtained from the left triceps muscle (A) and left common digital extensor muscle (B) in Case 6. Fibrillation potentials and positive sharp waves confirmed the presence of denervation and indicated that the changes were more advanced in the common digital extensor.

Case 7: No. 119826

Signalment: "Toby", an 11 years old neutered male Old English sheepdog

Weight: 35kg.

Diagnosis: Presumed nerve root tumour involving the C8 and T1 nerve roots.

Case Summary

Two months before presentation the owners reported foreleg stiffness and discomfort on rising associated with the forelimb/neck region. One week later a sudden onset left forelimb lameness was noted. The site of pain could not be localised by the attending veterinary surgeon but there was reported to be marked crepitus of the left elbow. A tentative diagnosis of osteoarthritis was made and the dog was treated with prednoleucotropin (PLT, C-Vet Ltd.). There was initial improvement, but the signs recurred on cessation of treatment one week later. Further therapy with phenylbutazone and an increased dosage of prednoleucotropin failed to prevent further deterioration. Subsequent radiographs of the elbow revealed no evidence of osteoarthritis and the dog was referred for investigation. Dullness and excessive panting were also reported. Latterly, the owners had noticed that the dog persistently licked the left carpus.

On examination there was a 4/5 left forelimb lameness. When standing, the foot was rested lightly on the ground in a normal position. The elbow appeared to be dropped. There was marked pain on manipulation of the proximal limb but the pain could not be localised to a specific site. The intrinsic muscles of the left fore were atrophied. Paw position sense was normal in all limbs. The pedal reflex was intact although there was reluctance to withdraw the limb. There was no efferent panniculus reflex on the left flank. There was anisocoria with a small, light responsive left pupil. No axillary mass could be palpated but attempts to examine this region caused considerable discomfort.

The neurological deficits indicated a lesion affecting the T1 ventral nerve root and C8 root or ventral branch. A tentative diagnosis of nerve sheath tumour was made on the basis of the age and history.

Further investigation in the form of myelography, electrodiagnostic studies and exploratory surgery were discussed with the owner but in view of the unfavourable prognosis they declined further investigation and requested that the dog be discharged. He was subsequently euthanased by the referring veterinary surgeon.

Case 8: No. 120381

Signalment: "Oliver", a 7 years old neutered male Domestic short haired cat

Weight: 5 kg

Diagnosis: Neural lymphoma.

Case Summary

Two weeks prior to presentation the owners became aware that the left forelimb was abnormal. The cat appeared to have difficulty placing the paw and tended to knuckle onto the carpus. The attending veterinary surgeon diagnosed possible radial nerve damage as the cat had fallen from a window ledge the previous day. The forelimb weakness progressed to paralysis over the following three days by which time there was paresis of the left hindleg. Over the next twenty four hours this progressed to severe paraparesis with urinary and faecal retention. Corticosteroids were administered which resulted in a partial improvement to the extent that some voluntary movement returned to the left fore and the cat was able to walk a few steps before falling. There was no history of systemic illness prior to the onset of neurological signs. The cat had not urinated for twenty four hours before presentation.

On examination the cat was paraplegic apart from a degree of hip flexion in the left hind. No deficits were found in the forelegs at this time apart from reduced elbow flexion. In the hind limbs muscle tone was increased. Pedal reflexes were present and were accompanied by crossed extensor reflexes. Conscious pain perception was normal. The panniculus reflex was intact and there were no cranial nerve deficits. The bladder was full. General systemic examination revealed no other significant abnormalities.

The history and clinical findings were indicative of a diffuse cervical myelopathy. The partial response to corticosteroid therapy indicated that this was likely to be due to either an inflammatory or neoplastic process such as lymphoma.

Haematological examination demonstrated a slight reduction in the haematocrit (27.4%) and haemoglobin concentration (9 g/dl) but the red blood cell count was within normal limits ($6.31 \times 10^{12}/l$). Mild lymphopaenia was also present ($1.32 \times 10^9/l$). Biochemical analysis revealed elevated serum levels of alkaline phosphatase (65 u/l) and ALT (88 u/l) which may have been secondary to corticosteroid therapy. Antibody titres to FeLV, FIV and FIP were negative. CSF obtained from the lumbar cistern demonstrated an elevated

leukocyte count of >200 cells/ μ l¹. Cytological examination showed that these cells were predominantly mature lymphocytes (90%) with 8% macrophages and 2% neutrophils. No abnormal lymphocytes were seen. There was insufficient sample for protein analysis.

The marked increase in lymphocyte numbers in the CSF was suggestive of lymphoma but, as no abnormal cells were present, meningomyelitis could not be excluded.

Prednisolone (Prednicare, Animalcare Ltd.) therapy was continued at a dose of 1 mg/kg daily for five days then 0.5 mg/kg daily. Ampicillin (Amfipen, Mycofarm UK Ltd.) was administered at 50 mg B.I.D. in view of the urinary retention. The bladder was expressed three times daily. On several occasions bladder expression was difficult due to marked sphincter tone and the bladder was emptied by catheterisation. Despite some improvement in hindlimb and tail function there was an overall slow deterioration over a two week period although the signs fluctuated from day to day. During this period anisocoria developed. The photomotor response was normal indicating a sympathetic lesion affecting the smaller right pupil. Weakness developed in the left fore followed by the right fore. The pedal reflexes were present but depressed. The cat became dull, inappetent and ultimately stuporous. Over a thirty six hour period there was rapid deterioration to virtual quadriplegia, with only slight movement present in the right fore leg, and loss of conscious pain sensation in the hindlimbs. A right facial nerve palsy developed and loss of sensation over the ophthalmic and maxillary nerve fields on the right side of the face indicated fifth cranial nerve involvement. There was negative tear production in the right eye. The cat was euthanased.

Post-mortem examination revealed the characteristic gross appearance of feline lymphosarcoma. There was diffuse involvement of the spinal cord and thickening of the nerve roots which was particularly evident in the cervical region and cranial cervical enlargement. There were also multinodular lesions in both kidneys and infiltration of thoracic muscles. Microscopy was not performed.

¹ Normal value < 10 WBC/ μ l (Parker 1972)

Case 9: No. 120399

Signalment: "Sam", a 9 years old neutered male Shetland sheepdog

Weight: 12 kg.

Diagnosis: Osteosarcoma of the seventh cervical vertebra resulting in secondary nerve root and spinal cord compression.

Case Summary

This dog was presented with a progressive forelimb lameness of two months duration. At the time of onset, a swelling was noted over the left carpus which did not appear to be painful. Treatment with prednoleucotropin (PLT, C-Vet, Ltd.) and phenylbutazone did not improve the lameness. Radiographs of the carpus and shoulder of the affected limb showed no abnormality. Treatment with betamethasone (Betsolan, Pitman-Moore Ltd.) resulted in a satisfactory, but temporary, improvement. As the lameness progressed the dog developed cervical pain and was unable to lower his head to a feeding bowl. The gait became very hunched with a short forelimb stride. Betamethasone injections partially alleviated the discomfort for about two days.

On examination there was a 3/5 left forelimb lameness. The forelimb gait was generally stilted and hunched. Paw position reactions were normal and tendon and nociceptive reflexes were intact. There was atrophy of the left triceps muscles and, to a lesser extent, the spinatus muscles. The panniculus reflex was normal and there was no Horner's syndrome. No axillary mass was palpable but manipulation of the proximal limb caused considerable discomfort. No other significant clinical abnormalities were found.

Neuromuscular function appeared normal apart from the muscle atrophy. Disuse atrophy of the triceps and shoulder muscles could not be excluded because of the chronic history.

Electromyography was performed to confirm the nature of the muscle atrophy. Sporadic denervation potentials were found in flexor and extensor muscles of the carpus and in the interosseous muscles. Motor conduction velocity and compound evoked muscle action potentials were normal in the left ulnar nerve. Radiographs of the cervical vertebrae were obtained. No vertebral abnormalities were demonstrated. Manipulation of the affected limb under a light plane of anaesthesia appeared to cause pain, suggested by a marked increase in the respiratory rate, particularly if the limb was drawn cranially. The axilla was palpated under anaesthesia but a mass was not present.

Haematological examination demonstrated mild anaemia (5.23×10^{12} RBCs/l; haematocrit 34.6%) and neutropaenia (1.344×10^9 /l). Blood chemistry evaluation was unremarkable.

The age of the dog and the history of intractable, progressive forelimb lameness associated with denervation were thought to be suggestive of a brachial nerve sheath tumour. Further investigative procedures, namely myelography and possible exploratory surgery, were discussed with the owners, however further studies were declined and euthanasia was requested.

Pathological examination of the spinal column showed that the body of the seventh cervical vertebra was distorted, with thickening of the left lateral wall which bulged into the spinal canal (Figure 23). This resulted in compression of the eight cervical nerve and spinal cord. The mass was composed of hard grey tissue which extended laterally into surrounding muscle. A solitary 0.5 cm white nodule was found in the liver.

Microscopic examination of the abnormal tissue revealed spicules and trabeculae of new bone surrounded by plump spindle cells with variable mitoses. This tissue could be seen in close proximity to the adjacent nerve root (Figure 24). A diagnosis of a well-differentiated low grade osteosarcoma was made. The hepatic nodule was found to be a metastasis composed of the same tissue.

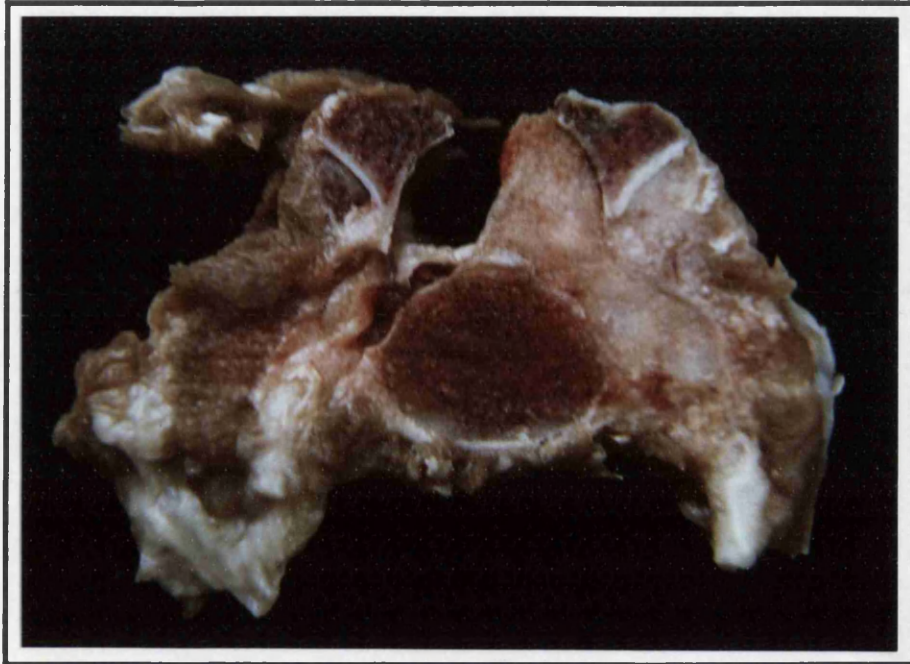
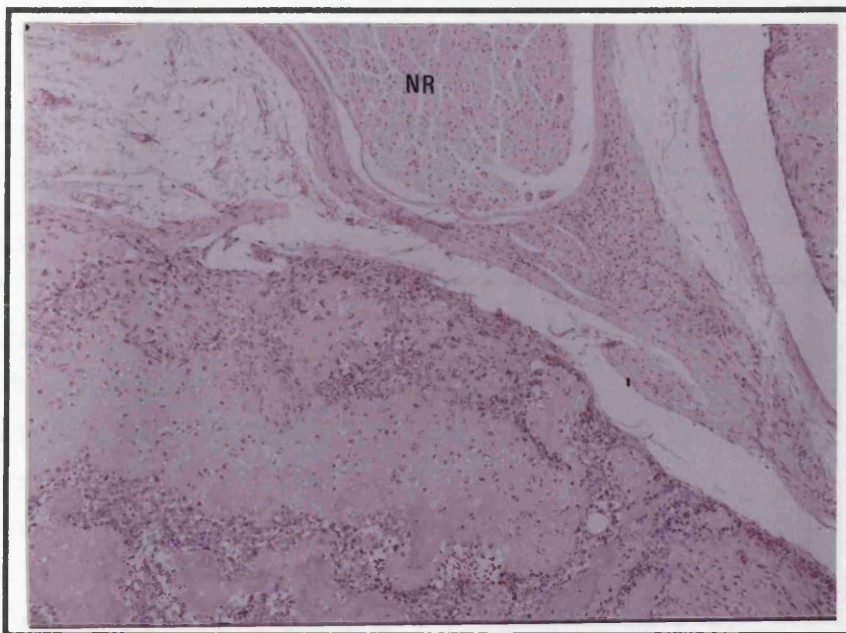


Figure 23

Case 9. Cranial view of a transverse section through the seventh cervical vertebra demonstrating a neoplastic mass (osteosarcoma) extending from the lateral wall of the vertebra into the lumen of the vertebral canal medially and the cervical musculature laterally on the left side.



H & E x 30

Figure 24

Case 9. Section through the caudal part of the seventh cervical vertebra demonstrating the proximity of the vertebral osteosarcoma to the adjacent nerve root (NR).

Case 10: No. 119200

Signalment: "Sheema", a 10 years old neutered female Dobermann

Weight: 25 kg.

Diagnosis: Undifferentiated soft tissue sarcoma of the proximomedial brachium and caudal cervical spondylopathy.

Case Summary

The dog was presented with a history of sudden onset, progressive lameness of two months duration. Treatment with phenylbutazone resolved the lameness for two weeks, after which there was a progressive deterioration. By the time of presentation the dog was reported to occasionally cry out as she lay down. Apart from some weight loss she appeared otherwise well.

Gait assessment demonstrated a 4/5 lameness of the left foreleg and moderate hindlimb ataxia. Conscious proprioceptive reactions were delayed in the hindlimbs and normal in the forelimbs. Due to the severity of the lameness hopping tests were not carried out on the left fore. Local spinal reflexes were normal in the hindlimbs and right fore. The pedal reflex was present, but reduced, in the left fore; however, this was considered to be due to voluntary suppression of the reflex as flexion of the proximal limb caused considerable discomfort. There was atrophy of the infra- and supraspinatus muscles with prominence of the scapular spine. The panniculus reflex was intact and there was no Horner's syndrome. There were no cutaneous sensory deficits.

A large, firm, non-mobile mass was palpable, extending from the proximal third of the medial left humerus into the axilla. The left suprascapular lymph node was palpably enlarged. A grade III systolic murmur was audible on auscultation. There were no other significant clinical findings.

The forelimb lameness was due to a painful mass on the proximal brachium. It was unclear from the neurological examination whether there was any involvement of nervous structures although the spinatus atrophy was quite marked in comparison to other muscle groups in the affected limb. The hindlimb ataxia appeared to be of spinal origin but could not be localised. In view of the age and breed, caudal cervical spondylopathy was considered the most likely cause of the hindlimb deficits.

Following induction of anaesthesia, radiographs of the proximal left humerus were obtained. These demonstrated that the mass was confined to soft tissue structures with no bone involvement. Left and right thoracic views showed no evidence of metastatic

disease. Lateral and dorsoventral radiographs of the cervical spine demonstrated narrowing of the C7/T1 intervertebral disc space with dorsal tipping of the cranial aspect of C7 resulting in narrowing of the vertebral canal. In view of the potentially poor prognosis associated with the forelimb tumour, myelography was not performed. Electromyography demonstrated spontaneous electrical activity in the infra- and supraspinatus muscles. This indicated that nerve involvement was confined to the suprascapular nerve. The craniomedial extent of the mass extended deep into the cranial axilla and possibly compressed the suprascapular nerve as it crossed the medial surface of the supraspinatus muscle. A wedge biopsy of the forelimb mass was obtained. The mass was considered to be non-resectable so no further action was taken until the results of the biopsy were available.

Four days later the dog presented as an emergency with gastric dilatation and volvulus and was euthanased.

Examination of the biopsy specimen showed an undifferentiated, highly malignant sarcoma.

INFLAMMATORY AND IDIOPATHIC CONDITIONS

Case 11: No. 118068

Signalment: "Cher", a 2.5 years old neutered female Tibetan terrier

Weight: 7.5 kg.

Diagnosis: Presumed brachial plexus neuritis.

Case Summary

Two months before presentation at GUVS the dog was noticed to be unwell. She was lethargic and inappetent and unable to bark. She also began coughing up saliva and water when drinking. She was treated for a suspected respiratory infection with amoxycillin, flunixin and intravenous fluids and showed a temporary improvement; however, two weeks later the dog was re-presented to the attending veterinary surgeon with recurrence of the previous symptoms and an abnormal gait. She could only walk a few steps before lying down. The forelimbs were weak and ataxic, with crossing of the legs and knuckling onto the carpi. She also appeared to pant excessively. There had been a progressive deterioration in the gait and at the time of presentation she was unable to bear weight on the front legs. Hindlimb function had remained normal.

On clinical examination there was marked paresis of both forelimbs, especially the extensor muscles. There was a degree of voluntary elbow flexion. The dog was unable to wheelbarrow or hop on the front legs but the hindlimbs were normal. Paw position sense and placing reactions were normal. The forelimbs were hypotonic and the pedal reflexes were markedly reduced with only a moderate degree of elbow flexion. There was general atrophy of both forelimbs. Pain sensation was patchy in the distal limbs. The panniculus reflex was absent bilaterally. The right pupil was smaller than the left but both responded normally to light. No cranial nerve abnormalities were found but the dog's temperament precluded examination of the gag reflex. There were no significant findings on general systemic examination.

The forelimb paresis was due to lower motor neurone disease and the lack of hindlimb abnormalities suggested that the lesion was peripheral. There were combined motor and sensory deficits. The problems associated with drinking and loss of bark suggested a possible tenth cranial nerve lesion. The significance of the sympathetic lesion of the right pupil was unclear as this may have been due to a concurrent idiopathic Horner's syndrome. On the basis of the clinical signs a tentative diagnosis of brachial plexus neuritis was reached.

Electromyographic examination revealed sporadic fibrillation potentials and positive sharp waves in a number of muscles in both forelimbs. There appeared to be no distinct pattern and the distribution of spontaneous activity was not symmetrical. No abnormalities were present in the hindlimbs. An evoked muscle action potential could not be elicited by stimulation of the right ulnar nerve. The left was not tested. Conduction in the left tibial nerve was of normal amplitude and velocity. The potential recorded from the left lateral cutaneous radial nerve was of markedly decreased amplitude (+2.8 uV)¹ (Figure 25). Plain radiographs of the lateral thorax were obtained to check for megaesophagus in view of the possible tenth cranial nerve deficit, but the oesophagus appeared normal. Normal cerebrospinal fluid was obtained from the cisterna magna and haematology and serum chemistry, including creatine kinase, were unremarkable.

Prednisolone (Prednicare, Animalcare Ltd.) was prescribed at an initial dose of 5mg daily. This was reduced to 3mg/day then 1mg/day at ten day intervals.

One month later the owners reported a subjective improvement in the gait. The neurological findings were unchanged apart from the degree of muscle atrophy, which had advanced, and there was now complete loss of cutaneous sensation in the forepaws.

After a further six weeks the degree of voluntary movement had continued to improve in the proximal muscles. Objectively, there was good elbow flexion when the pedal reflex was examined and there was positive pain sensation in the medial digit of the left fore. The proximal muscles were now relatively less atrophied than the distal muscles. Electrodiagnostic studies were repeated at this time. Conduction was absent from the left and right ulnar nerves and the left lateral cutaneous radial nerve.

At re-examination six months later (nine months after first presentation) there was considerable improvement. Proximal limb function was good but the dog walked on the dorsal aspect of the carpi. Triceps function appeared normal. Pain sensation in the feet had returned to normal. Anisocoria was still present but was less severe. The carpi could only be extended to within twenty degrees of normal indicating early contracture of the flexor muscles. The owners were instructed to carry out daily physiotherapy in the form of passive manipulation in an attempt to minimise the degree of carpal contracture. Protection of the carpi was also advised although some protective callous had developed.

¹ Normal value > 8 uV (Redding and others 1982)

Sixteen months later there had been further gradual improvement although the dog continued to walk on the dorsum of the carpi (Figure 26). Some voluntary carpal extension was now present however. Shoulder and elbow function appeared normal and there were no cutaneous sensory deficits. A degree of miosis remained and the dog was reported to still cough when drinking water. The owners had been padding the carpii which had prevented trauma. Daily physiotherapy had been maintained and the mild carpal contractures had not worsened.

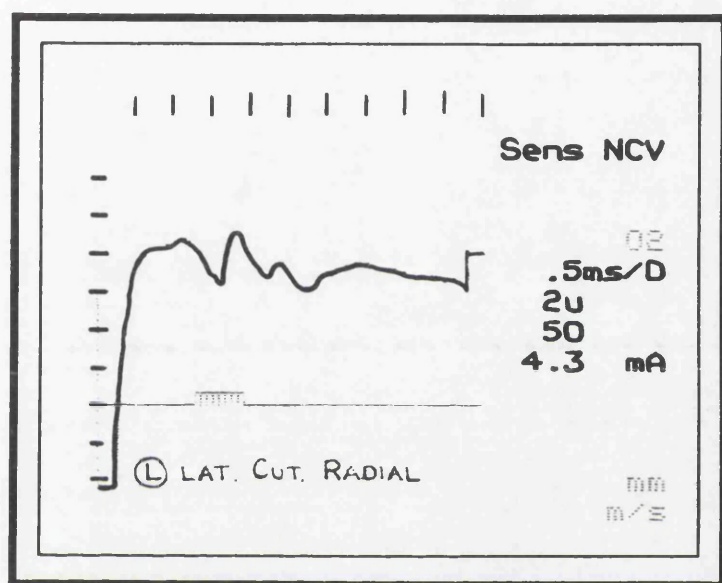


Figure 25

Sensory evoked potential recorded from the lateral cutaneous branch of the left radial nerve in Case 11. The amplitude of this potential (2.8 uV) is reduced in comparison to normal values of 11.8 ± 3.82 uV reported by Redding and others (1982).



Figure 26

Case 11. Brachial plexus neuritis. Sixteen months after the onset of forelimb paresis proximal limb strength had returned but the dog walked on the dorsum of the carpi because of weakness of the carpal extensor muscles.

Case 12: No. 116124

Signalment: "Sandy", a 10 years old male Cairn terrier

Weight: 7.5 kg.

Diagnosis: Polyradiculoneuritis.

Case Summary

Six weeks before presentation the dog was reported to have an undiagnosed left hindleg lameness which resolved within a few days of unspecified treatment. One week later the left foreleg became suddenly lame, which the owner related to falling on a slippery floor. Lameness progressed over a two week period until the limb was no longer weight bearing and was held in a dropped elbow position with the carpus knuckled. In the three weeks prior to presentation the owner felt that the lameness was static and did not appear to be associated with significant pain. Radiographs of the limb demonstrated no significant abnormalities. The attending veterinary surgeon made a tentative diagnosis of brachial plexus tumour and the dog was referred for investigation.

The left forelimb was virtually paralysed, apart from slight elbow and shoulder flexion. This limb was atonic and areflexic, with atrophy of all the major muscle groups. Hopping tests demonstrated a degree of weakness in the right foreleg, but local spinal reflexes were intact. Paw position sense was absent from the left hind and there was poor hock flexion when the limb was withdrawn. The patellar reflex was brisk. The right hind was clinically normal. Pain sensation was present in all limbs, including the paralysed left fore. The panniculus reflex was intact and there was no Horner's syndrome.

The major features of the examination were a lower motor neurone paralysis of the left forelimb and loss of paw position sense in the left hind. The reduced hopping on the right fore was equivocal and the weak hock flexion of the left hind was also mild and not considered to be, in itself, conclusive evidence of a lower motor neurone deficit. If all the signs were genuine then they indicated a polyneuropathy. If the hind limb problem was actually of upper motor neurone origin the most likely cause would be an asymmetric caudal cervical spinal cord lesion.

Electromyography was performed to confirm the nature of the motor deficits in the right fore and left hind. There was marked spontaneous electrical activity in all major intrinsic

muscle groups in the left fore and in the muscles below the stifle in the left hind. The carpal flexors and interosseous muscles of the right fore were also affected. Smaller numbers of potentials were recorded from the right hind distal to the hock and from the left gluteals. Stimulation of the left ulnar nerve failed to elicit an action potential. An evoked compound muscle potential recorded from the left plantar muscles following stimulation of the tibial component of the sciatic nerve was of markedly reduced amplitude. The maximum amplitude recorded was $<1\text{mV}^1$. The nerve conduction velocity was also reduced at 37 metres/second² and there was some dispersion of the potential. No F waves were recorded. Plain radiographs of the cervical vertebrae were obtained. There was bridging spondylosis ventrally at C3/C4, C4/C5 and C5/C6. This was not thought to be clinically significant. CSF was collected from the cerebellomedullary cistern. The protein level was mildly elevated at 380mg/l^3 . No cells were seen on cytological examination. Blood was submitted to haematology and biochemistry but the results were unremarkable. Adrenal and thyroid function tests were performed to exclude a metabolic polyneuropathy. Resting cortisol was within the normal reference range at 81.5nmols/l and following a low-dose dexamethasone suppression test values were $<27\text{nmols/l}$ at three and eight hours which indicated normal adrenal function. Serum T4 values rose from 17.6nmol/l to 36.6nmol/l after administration of TSH, indicating normal thyroid function.

The electrophysiological findings indicated a polyneuropathy. There was evidence of both axonal degeneration and demyelination. The mild CSF changes suggested nerve root involvement, probably of an inflammatory nature, and a tentative diagnosis of polyradiculoneuritis was made. Neural lymphoma was also considered but it was thought likely that this would have shown more progression over the three week period prior to presentation.

A course of prednisolone (Prednicare, Animalcare Ltd.) was prescribed starting at a dose of 5mg. daily. This was progressively reduced over a period of three weeks.

¹ Normal value 22mV (Walker and others 1979)

² Normal value (for age) $> 42\text{ m/s}$ (Swallow and Griffiths 1977)

³ Normal value $< 250\text{ mg/l}$ (Bailey and Higgins 1985)

The dog was re-examined five weeks after the start of treatment. The owner reported an obvious improvement two days after starting therapy, however the signs appeared to stabilise after this. At the time of examination the dog had been off steroid therapy for two weeks with no deterioration. On examination there was still a degree of left fore lameness but otherwise the gait was normal. There were no significant neurological abnormalities found, other than weak hopping on the left fore. Muscle atrophy had resolved. No further treatment was prescribed and the dog was allowed home. No further follow-up was available.

Case 13: No. 120714

Signalment: "Ben", an eight years old male English springer spaniel

Weight: 24 kg.

Diagnosis: Brachial neuropathy and insulinoma.

Case Summary

Two weeks prior to presentation the dog suddenly became ataxic and began stumbling whilst out on a walk. The pupils were dilated and he bumped into obstacles. He was carried home and within fifteen minutes appeared normal. Subsequently, the owner noticed an apparent forelimb weakness which presented as a hunched gait with a shortened forelimb stride. The gait had progressively deteriorated and eight days before presentation the dog had suffered a severe, generalised tonic-clonic seizure. There was also a recent history of dysuria and difficulty passing faeces.

On examination the dog's stance was abnormal. He tended to crouch with the hocks resting on the ground (Figure 27), although the hocks could be extended normally when he attempted to walk. The gait was stiff and stilted but not obviously ataxic, although he preferred to lean against a wall when walking. He was able to walk only a few steps before resting and the gait appeared to deteriorate with exercise. Wheelbarrow and hopping tests demonstrated forelimb weakness. Paw position sense was normal. Muscle tone was reduced in the forelimbs but muscle bulk appeared normal when compared to the hindlimbs. The forelimb pedal reflexes were present but weak. The panniculus reflex was intact and Horner's syndrome was not present. No abnormalities of the hindlimbs or cranial nerves were present. In addition to the neurological signs, the prostate was palpably enlarged but not painful. The remainder of the systemic examination was normal.

The abnormal stance appeared to represent an attempt to decrease the weight load on the forelimbs. Weakness and hypotonia of both extensor and flexor muscles and the reduced pedal reflex suggested a lower motor lesion involving the C6 to T1 spinal nerve fields. In addition to brachial polyneuropathy, the main differentials in this case were generalised musculoskeletal diseases associated with joint or muscle pain, particularly polyarthritis and polymyositis, but no pain or joint swelling was evident. Myasthenia gravis was considered because exercise appeared to exacerbate the limb weakness, however the fact that weakness was localised to the forelimbs made this an unlikely possibility.

There was no clinical evidence of organic forebrain disease to account for the seizures. Primary epilepsy was discounted due to the age of the dog at the time the seizures commenced. Metabolic disease, in particular hypoglycaemia secondary to insulinoma, was considered to be the most likely possibility.

On admission, the blood glucose level was 3.4 mmol/l. Following a twelve hour fast the blood glucose level progressively dropped to 1.8 mmol/l. This was consistent with an insulinoma.

Nerve conduction studies were performed on the left ulnar nerve. Motor nerve conduction velocity was normal at 76.1 m/s. Compound evoked muscle action potentials were of normal shape and duration, however the amplitude of both the proximal and distal potentials were significantly decreased (Figure 28). F waves of normal latency were observed on stimulation of both proximal and distal sites. Electromyography demonstrated an asymmetrical distribution of spontaneous electrical activity in both forelimbs. In the left fore there were large numbers of fibrillation potentials and positive sharp waves in all muscle groups. In the right fore a similar degree of spontaneous electrical activity was observed in muscles distal to the elbow but proximal muscles showed some sporadic activity. CSF samples obtained by lumbar and sub-occipital puncture both showed elevated protein levels but no nucleated cells. The lumbar sample contained 1140 mg/l¹ protein and the cisterna magna sample 580 mg/l². Serum creatine kinase levels were assayed to check for evidence of muscle damage but the results were normal (188 u/l). Haematological examination was unremarkable. Administration of 2.5mg of edrophonium chloride (Tensilon, Roche Products Ltd.) intravenously did not improve the gait.

Examination of a urine sample demonstrated protein (13mg/100ml), urea (9.25mmol/l), pH 6.5, specific gravity 1.019, small quantity of blood pigments, neutrophils, epithelial cells and large numbers of bacteria. Lateral radiographs of the abdomen revealed smooth enlargement of the prostate consistent with benign prostatic hyperplasia. Contrast radiography (pneumocystogram and retrograde urethrogram) demonstrated narrowing of the urethra as it passed through the prostate. This indicated that dysuria was due to benign prostatic disease.

¹ Normal value < 400 mg/l (Bailey and Higgins 1985)

² Normal value < 250 mg/l (Bailey and Higgins 1985)

Treatment with ampicillin 250mg BID (Amfipen, Mycofarm UK Ltd.) resulted in resolution of the dysuria within two days. The forelimb weakness worsened and atrophy of the forelimb muscles became evident. There was also slowing of the forelimb paw position reactions. Exploratory laparotomy was advised with a view to removing the insulinoma but permission was refused. Medical treatment of the condition with steroids and diazoxide was also discussed but the owner requested euthanasia.

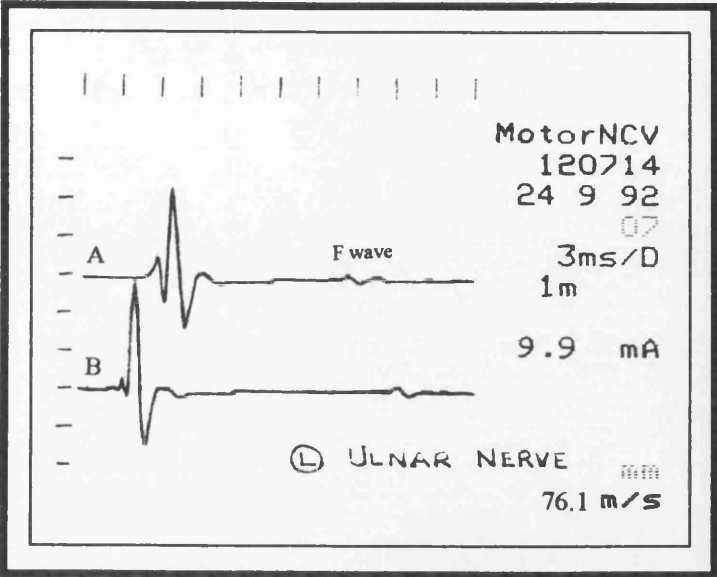
At post-mortem examination a solitary grey/blue nodule was present on the left limb of the pancreas. Microscopy confirmed this to be an insulinoma. No gross metastatic lesions were visible in the liver or surrounding tissue. In addition to the pancreatic changes, benign prostatic hyperplasia, mild mitral endocardiosis and a small adrenal adenoma were present.

Light microscopy of brachial nerve roots, proximal peripheral nerves and spinal cord did not demonstrate significant morphologic abnormalities. Distal nerves and muscle were not examined.



Figure 27

Case 13. Abnormal crouching hindlimb posture associated with bilateral forelimb weakness in a dog with an insulinoma.



L Ulnar nerve	Stimulation site		Normal values ¹	
M wave	Proximal (A)	Distal (B)	Proximal	Distal
Amplitude	3.76 mV	4.44 mV	20.7 mV	23.2 mV
Duration	5.40 ms	5.40 ms	4.6 ms	4.6 ms
F wave latency	19.8 ms	24.0 ms	*	*

¹Walker and others (1979)

Figure 28

Compound evoked muscle action potentials recorded from the interosseous muscles following stimulation of the left ulnar nerve at the level of the elbow (A) and the carpus (B) in Case 13. The amplitude of both potentials is reduced but the shape of the potentials and the nerve conduction velocity are normal.

DISCUSSION

GENERAL COMMENTS

The thirteen cases presented here demonstrate the broad range of clinical abnormalities which may be associated with brachial plexus disease; from mild lameness with minimal neurological deficits to complete paralysis of the forelimb. The manner of presentation is dependent largely upon the aetiology but factors such as the level and distribution of the lesion within the plexus and the severity of nerve damage also significantly affect the clinical signs.

The cases in this series fall into three main groups, according to the aetiology which was traumatic in three cases (cases 1, 2 and 3), neoplastic in seven cases (cases 4 to 10) and inflammatory or idiopathic in three cases (cases 11, 12 and 13). In six cases the diagnosis was confirmed by post mortem examination or biopsy (cases 1, 4, 5, 8, 9 and 10) and in seven cases the diagnosis was based on clinical and ancillary findings (cases 2, 3, 6, 7, 11, 12 and 13). Post mortem examination was performed on case 13 but a definitive cause of the brachial neuropathy was not established.

Deficits were restricted to one forelimb in eight cases (1, 2, 3, 4, 6, 7, 9 and 10), both forelimbs were affected in two cases (11 and 13) and all four limbs became involved in three cases. Cases with a traumatic or neoplastic aetiology involved one limb, as would be expected, with the exception of two cases of neoplasia which had invaded the spinal cord leading to quadriplegia (cases 5 and 8). Multiple limbs were affected in all cases of inflammatory or idiopathic disease (11, 12 and 13).

In the cases of traumatic, inflammatory or idiopathic neuropathy and diffuse neoplasia, significant neurological deficits were present in the affected limb(s) at presentation (apart from case 3 which had a very mild traumatic neuropathy). This differed from cases of focal neoplasia which presented with lameness and minimal neurological deficits. The most valuable clinical findings in the latter group were partial Horner's syndrome and a unilateral panniculus deficit as these confirmed the presence of a neural (rather than orthopaedic) lesion and indicated both the caudal and proximal level of the lesion. In many cases, both the location and severity of the lesion could be accurately assessed by careful clinical examination and in all of the cases, (with the exception of case 8), the aetiological diagnosis was reached on the basis of the clinical findings, signalment and history rather than ancillary investigations. In general, electrophysiological examination was the single most useful ancillary test. Although the findings were not helpful in terms of establishing a definite aetiology they provided an accurate assessment of the pattern of denervation, differentiated between disuse and neurogenic atrophy (which was

particularly helpful in the case of local tumours), helped to define the severity of nerve damage and provided information about the pathological nature of the neuropathy. In previous studies, EMG has also been used to differentiate lesions proximal and distal to the spinal nerve (Chrisman 1975, van Nes 1986) but this application was not used in the present series. Radiographic examination was helpful only in case 5, where a nerve root tumour was identified within the spinal canal on myelography. The pulmonary metastases identified at post mortem in this case were not detected radiographically, presumably due to the small size of the lesions (Kealy 1987). CSF examination may be diagnostic in some cases of nerve root, meningeal or spinal lymphoma if malignant lymphocytes are found (Vandevelde and Spano 1977) and haematological and serological findings may support the diagnosis. In case 8, which had lymphoma involving the cervical nerve roots and spinal cord, the CSF white cell count was significantly elevated. In case 13, serum chemistry analysis identified a concurrent pancreatic islet cell tumour.

BRACHIAL NEUROPATHY DUE TO TRAUMA

This group included two cases of nerve root avulsion (cases 1 and 2) and one peripheral nerve injury (case 3).

The history and clinical findings in cases 1 and 2 were typical of those previously described with C6 to T1 avulsion injuries (Griffiths 1977). The area of cutaneous sensory loss may vary with this type of injury (Griffiths 1977); the desensitised area may include part of the craniolateral brachium or may be restricted to skin distal to the elbow. The more extensive pattern of desensitisation was identified in both these cases. Bailey (1984) predicted that complete nerve root avulsion would also result in desensitisation of the autonomous zone of the dorsal cutaneous branch of C6, on the dorsum of the neck. This area was not specifically tested in the cases reported here. Superficially, the limb posture in cases 1 and 2 resembled proximal radial nerve injury (Worthman 1957, Knecht 1976) which is a common misdiagnosis in cases of complete or caudal cervical nerve root avulsion (Wheeler and others 1986). These types of injury can be readily differentiated by clinical examination. Findings such as spinatus muscle atrophy, loss of elbow and carpal flexion and the pattern of cutaneous sensory loss indicate that the lesion is not confined to the radial nerve field and the panniculus deficit and miosis which occur with caudal and complete avulsions indicate the proximal level of the injury. In man, much emphasis is placed upon the distinction between pre-ganglionic and post-ganglionic brachial plexus injuries as the prognosis and indications for surgical repair are largely determined by the level of injury (Birch 1993). A number of techniques have been used

to evaluate the level of damage including myelography (Yeoman 1968), CT and MRI imaging (Marshall and De Silva 1986, Roger and others 1988), axon reflex testing (Bonney 1954), sensory nerve conduction studies (Bonney and Gilliat 1958), somato-sensory-evoked potentials (Jones 1979) and surgical exploration (Marshall and De Silva 1986). In the dog, isolated post-ganglionic lesions associated with traction injuries appear to be exceptional so this type of ancillary investigation is of limited value.

Cases 1 and 2 both suffered significant complications associated with cutaneous sensory loss. Abrasion and self-mutilation of the distal limb occurred within 3 weeks of injury and both animals were systemically ill. Limb amputation was indicated within a week of abrasions first being noticed. In these particular cases, this complication hastened, rather than altered, the final outcome but they demonstrate the need for committed limb management in cases where motor injury is less extensive and some recovery may be possible. Abrasions and self-mutilation may also hinder attempts to improve limb function by surgical means such as tendon transposition, joint arthrodesis and nerve transfer in cases where the distal limb is desensitised (Frost and Lumb 1966, Knecht 1976).

In case 1, electromyography contributed little additional information that was not available from the clinical examination. Examination of cervical epaxial muscles may be used to confirm the presence of a preganglionic lesion (van Ness 1986) but was not performed in this case. Electrodiagnostic techniques may provide useful information regarding the prognosis of traumatic nerve root injuries (Steinberg 1979b). In case 1, absence of conduction in the ulnar nerve indicated extensive or total degeneration of motor fibres, confirming that the prognosis for recovery via collateral axonal sprouting was extremely poor. In partial injuries, where some conduction persists, the potential for reinnervation by collateral axonal sprouting is indicated by the amplitude of the evoked potential (Gilliat and Hjorth 1972, Griffiths and Duncan 1974). Electrophysiological examination was not applicable to Case 2 on first examination as the injury was of insufficient duration for secondary degenerative changes to have developed (Griffiths and Duncan 1974).

The prognosis for return of useful limb function following avulsion of all roots contributing to the brachial plexus is generally regarded as hopeless (Griffiths 1977) as conditions are unfavourable for fibre regeneration. Avulsions injuries occur a short distance from the cell body and are therefore associated with significant permanent neuronal loss due to irreversible chromatolysis. Regeneration of surviving neurones is adversely affected by the severity of nerve injury, which is typically grade four or five,

and the distance over which fibres would have to regenerate to reach the distal muscles. The widespread nature of the injury also means that these cases are not suitable candidates for surgical intervention. The prognosis for lesions restricted to the caudal nerve roots is more favourable as collateral sprouting of neurones from intact cranial roots may result in partial recovery which may be sufficient to avoid amputation (Wheeler and others 1986).

The pathological changes found in Case 1 corresponded to those previously described by Griffiths (1974). The T1 nerve root was not grossly avulsed from the cord but was atrophied and discoloured. Failure of the ulnar nerve to conduct indicated that few, if any, motor fibres from T1 (or C8) remained functionally intact. Griffiths (1974) reported that significant numbers of viable axons may persist in the peripheral nerves following nerve root avulsion. A proportion of these axons are thought to be sensory neurones which remain viable if the injury is proximal to the spinal ganglion (Griffiths 1974). Microscopy of the ventral branches and mixed peripheral nerves in Case 1 showed fibrosis and vascularisation of the nerve with few recognisable axons. This suggests that significant postganglionic damage, with subsequent degeneration of sensory axons, had also occurred in this case demonstrating the diffuse pre- and post ganglionic axonal damage which results from traction injuries.

Case 3 demonstrated an unusual peripheral nerve injury. Paresis was confined to the carpal extensor muscles which are innervated by the radial nerve, therefore injury must have occurred distal to branches of this nerve supplying the triceps muscles and skin. Electromyography was very useful as a means of confirming the presence and distribution of denervation in this case, as the neurological deficits were relatively subtle. Sensory nerve conduction studies confirmed that the superficial branch of the radial nerve was not affected. Examination of radial nerve conduction, recording from the carpal extensor muscles, may have helped to confirm the diagnosis and determine the severity of the lesion but was not carried out in this case. The most likely site of radial nerve injury in this case would be at the level of the lateral distal humerus where the nerve bifurcates into superficial and deep branches. Injuries proximal to this point would involve the muscular branch to the triceps muscles and distally the nerve is well protected by the extensor carpii radialis, common digital extensor and supinator muscles (Evans 1993). Injury at this level might be expected to involve the superficial cutaneous branch, however cutaneous sensory nerves are composed largely of smaller diameter, thinly myelinated or unmyelinated fibres which are less susceptible to crush injury than larger, heavily

myelinated motor fibres (Thomas and Holdorff 1984), so preferential sparing of these fibres is possible.

Information regarding the grade of injury was obtained from the history and electromyographic examination. The duration of signs prior to presentation (two months) and the slowly progressive rate of recovery indicated that this was not principally a neuropraxic injury as confirmed by the presence of spontaneous electrical activity in the affected muscles. The rate of recovery was consistent with axonal regeneration suggesting that the majority of fibres were affected by a Grade 2 injury. If so, complete functional recovery would be expected as the pattern of innervation is preserved by intact nerve sheaths (Sunderland 1951). Residual weakness was present fourteen weeks after injury; however, as regenerating fibres advance at approximately one to two millimeters per day (Duncan 1980), complete recovery of all parts of the carpal extensor muscles would be expected to take several months in a large dog.

The delayed correction of paw position observed in this case was probably related to carpal extensor weakness rather than a true proprioceptive deficit as the digital joints are supplied by the palmar proper digital branches of the ulnar nerve which were unaffected by the injury.

In case 3, no specific treatment was indicated as the dog was not incapacitated by the injury and the prognosis for satisfactory recovery was good. Even grade 4 or 5 injuries at this site may not require treatment as many dogs adapt to the injury by passively flicking the carpus forward during locomotion (Worthman 1957, Knecht 1976). Dogs which do not compensate adequately are ideal candidates for carpal arthrodesis or carpal flexor translocation to maintain carpal extension (Frost and Lumb 1966, Bennet and Vaughan 1976), as elbow function and cutaneous sensation are preserved.

BRACHIAL NEUROPATHY DUE TO NEOPLASIA

In the present series, neoplastic disease involving the brachial plexus was identified in six dogs and one cat. A primary nerve sheath tumour was diagnosed in four cases (cases 4, 5, 6 and 7), a local non-neural tumour in two cases (cases 9 and 10) and diffuse neoplastic infiltration of the cranial brachial nerve roots in one case (case 8). Diagnosis was confirmed by necropsy or biopsy with the exception of cases 6 and 7 which were presumptively diagnosed on the basis of clinical and ancillary findings.

In this study the terms neurofibrosarcoma and Schwannoma have been used to imply different histological characteristics between the nerve sheath tumours in cases 4 and 5. The validity of this distinction between Schwannomas and neurofibromas is controversial as it has been shown in man that both types originate from Schwann cells (Fisher and Vuzevski 1968). For this reason, many investigators favour discarding terms such as neurofibroma in favour of Schwannoma or the more general nerve sheath tumour to avoid confusion with neurofibromatosis or neuroma (Cordy 1990). The nerve sheath tumours in cases 4 and 5 both contained significant amounts of collagen and reticulin. The presence of collagen in nerve sheath tumours has been attributed to production of collagen, or collagen precursors by neoplastic Schwann cells or to a non-neoplastic fibroblast response to nerve damage (Cordy 1990). It has also been suggested that malignant Schwann cells and fibroblasts may both arise from the same neoplastic stem cell (Conley and others 1976). Reticulin is a component of basal lamina and is therefore associated with Schwann cells. A feature of some neurofibromas reported in the literature is the absence of reticulin (Vandeveld and others 1977, Lantos 1992) and on this basis it could be argued that the tumour found in case 4, which was classified as a neurofibrosarcoma, might be more correctly classified as a malignant Schwannoma. As the cellular origins of canine nerve sheath tumours have not yet been elucidated the argument remains one of semantics; however, as canine nerve sheath tumours demonstrate similar, if not identical, biological behaviour regardless of histological classification it would seem likely that they are variants of the same tumour. The occurrence and behaviour of nerve sheath tumours varies between species (Johnson 1990). In man, solitary Schwannomas are benign growths which rarely destroy the nerve (Brooks 1984). Malignant transformation is rare although isolated malignant forms do occur (Urich 1984). In dogs, nerve sheath tumours typically exhibit extensive local invasion with destruction of affected nerves but have been reported as having little tendency to metastasise (Cordy 1991). Pulmonary metastasis of both neurofibrosarcoma and Schwannoma has been reported by several authors (Oliver and others 1965, Carmichael and Griffiths 1981, Bradley and others 1982, Targett and others 1993). Metastasis to lymph nodes and tonsil have also been reported (Carmichael and Griffiths 1981). Pulmonary metastases from a malignant Schwannoma were present in case 5 after only nine weeks of lameness indicating the potential for early metastasis.

Tumours of non-neural origin which were seen in this series included osteosarcoma, originating in a cervical vertebra (case 9), undifferentiated sarcoma (case 10) and lymphoma (case 8), all of which have been reported previously in association with

brachial plexus neoplasia (Zaki and Hurvitz 1976, Carmichael and Griffiths 1981, Rosin 1982, Targett and others 1993).

Brachial plexus neoplasia, including both primary and secondary forms, is typically, although not exclusively, recognised in dogs over five years of age (Carmichael and Griffiths 1981, McGrath 1984 [cited LeCouter 1989], Targett and others 1993). This is reflected in the present study in which the age range was five to eleven years. Multicentric and other forms of lymphoma are also most common in dogs over five years of age (McEwan and Young 1989) although the few cases of brachial plexus lymphoma reported in the literature ranged from two to eleven years of age. In cats, age incidence is related to the epidemiology of FeLV infection (Hardy 1981). Cats which are FeLV negative tend to be affected from seven years of age, as in case 8.

Neoplasia may affect the brachial nerves anywhere along their length. The nerve roots were affected in five out of seven cases (cases 4, 5, 7, 8 and 9), although clinical signs indicating a nerve root lesion were observed only in three of these cases, all of which were primary tumours (cases 4, 5 and 7). In forty six cases of primary nerve sheath tumours reported previously in the literature tumours were most commonly located proximal to the plexus with the nerve roots and/or ventral branches being affected in at least sixty five per cent of cases. The C6 to C8 nerve roots were most frequently involved. Three out of four cases of primary neoplasia in the current series involved the nerve roots (cases 4, 5 and 7) but in all cases the C8 and T1 roots were affected. The fourth case appeared clinically to affect the radial nerve (case 6). In contrast to non-neural tumours reported by Carmichael and Griffiths (1981) and Targett and others (1993), which typically caused extensive involvement of the plexus, the two cases of local non-neural neoplasia in this series caused isolated lesions. In case 9, the eighth cervical nerve roots and spinal nerve were compressed by a vertebral osteosarcoma and in case 10, the suprascapular nerve was affected by an undifferentiated sarcoma extending into the cranial axilla. Invasion or compression of the spinal cord was present in the three cases which were examined at post mortem (cases 4, 5 and 9). Clinical signs of a spinal cord lesion were observed only in case 5. Sub-clinical cord compression may be associated with slowly expanding lesions (Vandevelde 1981). Case 8 demonstrated the typical distribution of lymphoma with multiple cervical nerve root involvement (Fox and Gutnick 1972, Chrisman 1975, Zaki and Hurvitz 1976). Lesions were also present in the kidneys and thoracic muscles. Neural and renal forms of lymphoma are usually considered to be metastatic (Weller and Stann 1983) but both may occur occasionally as

a primary extra-nodal lesion (Couto 1986). A primary lesion at a more typical site could not be identified in this case.

All the cases in the present study presented with progressive, unilateral lameness which is the typical presenting sign of brachial plexus neoplasia (Carmichael and Griffiths 1981, Bradley and others 1982, Wheeler and others 1986). The duration of clinical signs prior to presentation or diagnosis relates largely to the site at which the tumour develops. The mean duration in cases of primary tumours uncomplicated by intraforaminal lesions in a series of reported cases (Chrisman 1975, Carmichael and Griffiths 1981, Bradley and others 1982, Wheeler and others 1986, Wright and others 1979, Targett and others 1993) was seven months. Animals with tumours arising in the nerve root are presented typically within a month of onset (Targett and others 1993) and may present with signs of a compressive myelopathy without preceding foreleg lameness. Alternatively, compressive myelopathy may develop as early as five days (Troy and others 1979) or as late as one year (Bradley and others 1982) after forelimb lameness is first noted and typically progresses rapidly (Troy and others 1979, Wright and others 1979) as in case 5. Non-neural tumours may be presented between one to forty-eight months after the onset of lameness (Carmichael and others 1981, Targett and others 1993). In the present study all cases were referred early in the course of disease. The most rapid progression of signs was seen with lymphoma (case 8) which progressed from forelimb weakness to quadriparesis within forty eight hours. Three cases with local tumours were referred after eight weeks of lameness (cases 7, 9 and 10), two after five weeks (cases 4 and 6) and one case had two separate episodes of lameness nine and two weeks before diagnosis (case 5). With the exception of cases 6 and 8, referral was prompted by obvious limb or cervical pain rather than neurological dysfunction.

In forty two cases of primary brachial plexus neoplasia reviewed by Sharp (1992), the most common clinical signs in addition to lameness were muscle atrophy (88%), an axillary mass (69%) and axillary pain (60%). Muscle atrophy was present in all cases of primary neoplasia in this study but was frequently minimal and could not be distinguished from disuse atrophy on examination. This is probably related to the short duration of lameness in these cases which all presented within five weeks of onset. In case 7, which was examined two months after onset, atrophy of all the major muscle groups, with the exception of the biceps, could be readily appreciated. Mild to moderate atrophy was detected in three cases (cases 4, 5 and 6) and in these cases the triceps group was principally involved. Both cases with local secondary tumours also showed a similar degree of atrophy. An axillary mass was not palpable in any of the four primary cases

reported here, even under anaesthesia, although in three cases (4, 5 and 7) attempts to palpate the axilla caused a marked pain reaction in the conscious animal. Pain was a major sign in three of the four primary tumours and in both secondary tumours which is consistent with previous reports (Carmichael and Griffiths 1981, Wheeler and others 1986, Targett and others 1993) although in a study by Bradley and others (1982) only four out of twelve cases demonstrated pain. Pain may be associated with the limb or cervical region but is often difficult to localise. It would seem logical that cases involving nerve roots would be more likely to show cervical pain and this tendency is apparent among reported cases (Troy and others 1979, Targett and others 1993); however, the site of pain is not a reliable indicator of the site of the lesion (Carmichael and Griffiths 1981, Targett and others 1993). Four of the six cases of local neoplasia reported here had tumours involving the nerve roots (cases 4, 5 7 and 9) and all showed spontaneous cervical pain and severe pain on manipulation of the affected limb. A notable feature in these cases was the lack of satisfactory or sustained response to analgesics. In twenty five per cent of cases with primary tumours clinical signs are restricted to lameness and muscle atrophy (Sharp 1992), however most cases show more specific evidence of neurological disease such as proprioceptive or cutaneous sensory deficits in the affected limb, loss of the ipsilateral panniculus reflex and partial or complete Horner's syndrome. In addition to muscle atrophy, three out of four cases of primary tumour in this series had specific neurological deficits which were panniculus reflex loss and ipsilateral miosis in all cases. These signs were of useful diagnostic value as they confirmed the presence of neurological disease and gave an accurate indication of the level of the lesion. In case 8, which had lymphoma, the predominant signs were of a cervical myelopathy, with only reduced pedal reflexes indicating a possible lower motor neurone deficit. Interestingly, cutaneous sensory loss was not detected in any of the current cases, in contrast to previous reports. This may be related to the duration of disease, which ranged from three to nine months in reported cases (Chrisman 1975, Wheeler and others 1986) and two to eight weeks in the present series, as some cutaneous sensation would be preserved until the majority of fibres in the nerve were destroyed. In addition, tumours involving the nerve roots or ventral branches would result in a dermatomal pattern of sensory loss which might be difficult to detect clinically unless several adjacent dermatomes were affected. Case 7, which had a suspected nerve sheath tumour, was noted to persistently lick the left carpus. This might have been associated with paraesthesia as no local cause of irritation could be defined.

Electromyography was the most valuable ancillary procedure in this group, particularly in the absence of specific neurological deficits as in cases 6 and 10. EMG confirmed that muscle atrophy was due to denervation rather than disuse which was often not possible clinically. The pattern of denervation suggested the level and extent of plexus invasion and therefore helped to determine the likely effects of tumour resection on limb function. Electromyographic examination of paraspinal muscles has been used to investigate nerve root involvement in cases of feline brachial plexus lymphoma (Chrisman 1975) but was not performed in this series. Plain radiography yielded little diagnostic information in these cases. Previously reported abnormalities, including enlargement of the intervertebral foramen (Bradley and others 1982) and mineralisation of an axillary mass (Targett and others 1993), were not noted. In case 9, the primary vertebral osteosarcoma could not be visualised on plain radiography, even retrospectively. CSF examination was performed in one case of a nerve root tumour (case 5) and one case of lymphoma (case 8). Normal CSF was obtained from case 5 which would be expected as the lesion was extradural. Albuminocytologic dissociation and, rarely, mild pleocytosis have been reported with some nerve root tumours (Luttgen and others 1980, Le Couteur 1989). CSF is the most valuable aid to diagnosis in cases of intradural lymphoma and is diagnostic if malignant lymphoblasts are found (Vandeveld and Spano 1977). In case 8, the CSF white blood cell count was elevated but all cells were mature lymphocytes so an inflammatory myelopathy could not be excluded. Haematological examination may reveal leukaemia or non-regenerative anaemia in a minority of cases with feline lymphoma (Hardy 1981) but was normal in case 8.

Most authors agree that the most successful treatment for primary brachial plexus tumours is radical excision by amputation of the limb and section of the most proximal extent of the ventral branches (Holliday and Turrel 1987). Tumours located entirely within the spinal canal may be resected via laminectomy (Troy and others 1979). Tumour resection was attempted in only one case of local neoplasia in this series (case 5) and this proved unsuccessful due to the extent of tumour invasion. Case 6, which appeared to have a more distal lesion, was the most suitable candidate for resection, however the owners were unwilling to permit amputation. Cases 4 and 7 were given an unfavourable prognosis for resection. As these cases had clinical signs of C8 and T1 spinal nerve invasion and were over four weeks duration it was thought likely that both intra- and extraforaminal structures would be affected. Resection would have entailed amputation, rib pivot thoracotomy (to access T1) and laminectomy and in many of these cases the intraspinal portion of the tumour cannot be adequately resected (Holliday and Turrel

1987). Amputation was not advised in case 10 due to the highly malignant nature of the tumour which was an undifferentiated sarcoma. Case 9 had an unresectable primary vertebral osteosarcoma which was not identified prior to post mortem examination. A poor prognosis had been given on the assumption that this case had a primary brachial plexus tumour.

Chemotherapeutic treatment of neural lymphoma adopts the same protocol as used for treatment of multicentric forms (Cotter 1983a,b). Cats with epidural forms may respond well providing the cord is not irreversibly damaged (Cotter 1983) but information concerning the response and prognosis of brachial plexus lymphoma is scarce. Initially there may be some response to corticosteroids as in case 8. Chemotherapy was not undertaken in case 8 as lymphoma was not confirmed in life.

BRACHIAL NEUROPATHY DUE TO INFLAMMATORY AND IDIOPATHIC DISEASE

The brachial plexus may be selectively affected by inflammatory or idiopathic disease or may be the dominant clinical target of some generalised polyneuropathies. In this group of three cases, neuropathy was confined to the forelimbs in one case (Case 13). One case also showed cranial nerve signs (Case 11) and one case had a generalised polyneuropathy (Case 12).

Case 11 demonstrated a number of features of canine brachial plexus neuritis, a condition resembling serum neuritis and neuralgic amyotrophy in man (Cummings and others 1973). In the human disease, symptoms typically occur three to fourteen days after surgery, trauma, a variety of infections, serum administration or prophylactic inoculation (Parsonage and Turner 1948, Miller and Stanton 1954). A proportion of cases appear to be spontaneous in that no preceding factor is recognised. In canine brachial plexus neuritis, ingestion of horsemeat products has been identified as an antecedent factor (Cummings and others 1973, Steinberg 1988).

In case 11 a predisposing factor was not clearly identified. The dog was treated for a suspected respiratory tract infection two weeks before the onset of paresis, based upon a history of malaise, inappetence, coughing and loss of bark. While the demeanour and appetite improved following treatment, coughing and dysphonia persisted and a partial tenth cranial nerve lesion was suspected. It is therefore unclear whether the initial signs were due to respiratory disease or were an early manifestation of the neuropathy itself.

In man, radicular pain is consistently the earliest sign of both serum neuritis and neuralgic amyotrophy (Parsonage and Turner 1948, Miller and Stanton 1954). This has not been an obvious feature of the canine disease but neuralgia is difficult to identify in the dog. It could be speculated that the early malaise and inappetance observed in this case may have been due to discomfort. The onset of signs in this case differs from previous reports of both the human and canine disease. Typically, the progression of signs is very rapid, reaching maximum severity within hours to a few days (Parsonage and Turner 1948, Miller and Stanton 1954, Cummings and others 1973). In Case 11, the signs progressed from mild to very severe paresis over a period of six weeks and cutaneous sensory loss continued to progress for a further four weeks. The motor and sensory deficits equated with previous reports of canine brachial plexus neuritis (Cummings and others 1973). In addition to the forelimb deficits there was subjective evidence of a tenth cranial nerve lesion. In the case reported by Cummings and others (1973) unilateral facial paresis was observed and there was pathological evidence of degeneration in the hypoglossal nerve. Case 11 also had a unilateral partial Horner's syndrome which has not previously been reported in either the human or canine diseases. The possibility of a concurrent idiopathic Horner's syndrome could not be ruled out.

Pathological changes in brachial plexus neuritis are typically those of Wallerian degeneration (Cummings and others 1973). Lesions were confined to the ventral branches and peripheral nerves with sparing of the nerve roots and proper spinal nerves. Motor and sensory fibres were affected. In case 11, electrodiagnostic examination provided evidence of axonal degeneration. The distribution of fibrillation potentials and positive sharp waves in this case was patchy and asymmetrical which is consistent with the findings of Cummings and others (1973) who noted an asymmetric pattern of muscle wasting between and within muscle groups. Sensory nerve conduction studies also confirmed axonal degeneration in the lateral cutaneous radial nerve as recorded potentials were of significantly reduced amplitude.

The pathogenesis of brachial plexus neuritis remains obscure. It is generally accepted that there is an immune-mediated basis, and in the case of serum neuritis and some cases of canine brachial plexus neuritis a hypersensitivity reaction has been demonstrated. The mechanisms by which this type of reaction leads to neuropathy however is unknown. Potential pathogenetic mechanisms have been reviewed by Cummings and others (1973).

Generalised polyneuropathy due to inflammatory, degenerative, neoplastic and metabolic disease are now well recognised in dogs (Duncan 1980, Duncan 1991). Usually the neuropathy is symmetrical or the hindlimbs are more severely affected but occasionally forelimb signs may predominate and the disease presents as a brachial neuropathy. In case 12, the major presenting signs indicated unilateral brachial plexus disease, however careful examination, supported by electrophysiological examination, demonstrated the generalised nature of the condition. Information regarding the pathology of the lesion was obtained from ancillary investigations. Electrodiagnostic examination indicated axonal degeneration in the right ulnar nerve and both axonal degeneration and demyelination in the tibial nerve. The absence of F waves on electroneurography was suggestive of ventral root disease. The elevated CSF protein level was suggestive of polyradiculoneuritis. The classical animal model of polyradiculoneuritis is Coonhound paralysis (CHP) in which flaccid tetraplegia develops acutely within seven to ten days following a racoon bite. Coonhound paralysis appears to be analogous to Guillain-Barre syndrome (GBS) in man where an acute inflammatory demyelinating polyradiculoneuropathy may develop following an antecedent illness, in particular viral infections, although other factors including bacterial and mycoplasma infections, surgery and rabies immunisation (Arnason 1984) may be implicated. Approximately thirty percent of cases however have no obvious antecedent factor (Arnason 1984). In both CHP and GBS the inflammatory response is believed to be immune-mediated and the prominent pathological findings are mononuclear cell infiltration, segmental demyelination and axonal degeneration of peripheral nerve tissue. In the dog these changes are concentrated predominantly in the ventral roots and spinal nerves (Cummings and others 1982). Acute idiopathic polyradiculoneuritis has also been described in the dog in the absence of exposure to racoons (Northington and others 1981) and a chronic relapsing form of polyradiculoneuritis of unknown aetiology affecting older dogs has been reported (Cummings and de Lahunta 1974).

The presenting signs of case 12 were atypical of polyradiculoneuritis in that paresis affected the forelimbs to a significantly greater degree than the hindlimbs. Typically, paresis is noted first in the hindlimbs progressing to tetraparesis or tetraplegia within forty-eight hours although cases presenting initially with forelimb weakness have previously been reported (Cummings and others 1982). Case 12 showed a sub-acute onset over two weeks which again is not typical of acute polyradiculoneuritis. Other possible causes of polyneuropathy which were considered at the time of examination in this case included distal denervating disease, endocrine neuropathy and paraneoplastic

neuropathy. The electrodiagnostic and CSF findings did not support a diagnosis of distal denervating disease where degeneration is localised to the terminal motor fibres (Duncan 1980). Polyneuropathy has also been reported in dogs with diabetes mellitus, insulinoma and hypothyroidism although the relationship between these conditions remains unclear (Duncan 1991). While reports of the pathology vary, the lesion is basically degenerative and therefore the CSF changes observed in this case would not be expected. As the rise in CSF protein in this case was minimal, biochemical and hormonal assays were performed to exclude these conditions. No evidence of neoplastic disease was found on examination.

An interesting feature of this case was the rapid recovery following steroid administration. It would seem unlikely that this was co-incidental as the signs had been progressive and then static for five weeks prior to presentation. The initial rapid recovery over two days followed by a slower rate of improvement would suggest that i) there was a significant reversible component to the lesion and ii) there was an ongoing active inflammatory process. As electrophysiology identified both axonal degeneration and demyelination in this dog, it would seem likely that early recovery would be due to remyelination. Axonal regeneration could also lead to rapid recovery if degeneration was restricted to the most terminal parts of the nerve fibre. Cummings and others (1973) reported a case of CHP which showed an rapid recovery over 18 days.

In case 13 deficits were restricted to the forelimbs. At initial examination, paresis in the absence of proprioceptive deficits suggested a predominantly motor problem. Later development of proprioceptive abnormalities showed that sensory fibres were also affected. Atrophy of the forelimb muscles indicated the presence of axonal degeneration and this was confirmed by electromyography. Spontaneous electrical activity was most prevalent in muscles distal to the elbow, particularly the interosseous muscles. Nerve conduction studies demonstrated evoked muscle potentials of reduced amplitude due to loss of motor fibres. The normal nerve conduction velocity and lack of temporal dispersion suggested that demyelination was not a significant pathological feature in this case. The presence of F waves indicated some conduction through the ventral roots. Increased CSF protein levels suggested polyradiculoneuropathy. Protein levels of the lumbar sample were significantly higher than those from the cisterna magna demonstrating the value of obtaining samples caudal to the site of the lesion (Thomson and others 1990). Elevated CSF protein levels are often seen with polyradiculoneuritis but, in contrast to case 13, demyelination of the nerve roots, especially the ventral root, is a significant pathological finding in some forms of the disease (Cummings and de Lahunta

1977, Northington and others 1981, Cummings and others 1982). Axonal degeneration is the major pathological abnormality in brachial plexus neuritis which may present in the manner of case 13. However, Cummings and others (1973) reported that lesions did not extend proximal to the ventral branches, therefore alterations in CSF composition would not be expected.

Case 13 was complicated by a co-existing insulinoma with secondary hypoglycaemia. The effects of hypoglycaemia on the central nervous system are well recognised. In contrast to normal peripheral nerves, the capacity of central neural tissue to utilise energy sources other than glucose is very limited (Jaspan and others 1982) and signs of cerebral dysfunction are the most common manifestation of hypoglycaemia. A distal sensorimotor polyneuropathy is occasionally recognised in human patients with insulinoma (Mulder and others 1956, Jaspan and others 1982) and three similar cases have been reported in the dog (Shahar and others 1985, Chrisman 1980, Schrauwen 1991). The distribution of deficits in case 13 differs from other cases reported in dogs where the hindlimbs were more frequently, or more severely, affected than the forelimbs. Cases in which the upper limbs were predominantly, or exclusively, affected have been described in man (Mulder and others 1956). In humans, onset or exacerbation of the neuropathy may be preceded by a hypoglycaemic crisis and it is interesting to note that in case 13, forelimb weakness was noticed within a few days of the first major episode of cerebral disturbance.

The pathology of hypoglycaemic neuropathy has not been clearly defined, however studies in man have demonstrated that the neurone, rather than the myelin sheath, is the primary site of injury (Jaspan and others 1982). It remains a point of contention whether the principal site of injury is the axon itself or the ventral horn cells, nerve roots and spinal ganglia (Jaspan and others 1982). The major site may vary between individuals and, as there is clinical and experimental evidence for lesions involving each of these areas, it has been suggested that the condition is best described as a neuronopathy (Mulder and others 1956). It has been postulated that this condition may represent a "dying-back" neuropathy in which the most distal parts of the nerve are deprived of essential factors and degenerate secondary to an abnormality within the cell body (Jaspan and others 1982). Interestingly, pathological examination of the spinal cord, nerve roots or peripheral nerves at the level of the brachial plexus failed to demonstrate any morphological abnormality in case 13, suggesting that morphological changes may have been confined to distal parts of the nerves which were not examined. Clinical and electrodiagnostic findings reported in dogs with clinical neuropathy and insulinoma indicated that axonal degeneration was the primary pathological abnormality, as in case

13. Braund, Steiss and others (1987) described a sub-clinical, predominantly demyelinating, polyneuropathy in two dogs with insulinoma and suggested that the dominant pathology may be related to the severity of the polyneuropathy, with demyelination being the principal finding in sub-clinical cases and axonal degeneration predominating in clinically affected dogs. Electrodiagnostic examination of both clinical and sub-clinical cases supported a more distal distribution of the neuropathy (Shahar and others 1985; Braund, Steiss and others 1987) and this was also suggested in case 13.

An interesting feature of case 13 was the raised CSF protein level. Elevated CSF protein levels have been reported in some humans with hypoglycaemic neuropathy (Jaspan and others 1982) but the reason for this has not been clearly identified. In view of the varied pathological findings in man, it is possible that increased protein levels may be found in cases where lesions of the spinal ganglia or nerve roots predominate and normal protein levels in cases where the peripheral axons are principally affected, however this is entirely speculative as no such correlation has been demonstrated. There is little information regarding CSF composition in neuropathy associated with canine insulinoma. Chrisman (1980) reported normal CSF values in a quadriparetic dog with concurrent insulinoma; however CSF was obtained from the cisterna magna which is a less sensitive means of examining nerve root abnormalities than a lumbar sample (Thomson and others 1990).

The pathogenesis of hypoglycaemic polyneuropathy remains speculative. It has been postulated that in some individuals there is an inherent inability of the peripheral nerves to utilise amino acids and fats as an alternative energy source in the face of hypoglycaemia (Jaspan and others 1982) but this theory remains unproven. Polyneuropathy has also been recognised as a paraneoplastic syndrome in dogs (Sorjonen and others 1982, Braund, McGuire and others 1987). Nerve lesions were characterised by a combination of axonal degeneration and demyelination/remyelination (Braund, McGuire and others 1987). Proposed mechanisms for this effect include the production of a substance by the tumour which is harmful to the nerve or renders it susceptible to hypoglycaemia or an immune-mediated mechanism wherein antigenic similarity between the tumour and peripheral nerve triggers an immune response against the nerve (Zweifel and Albers 1980) but conclusive evidence for these theories has yet to be obtained.

It has been recognised in man that correction of the underlying hypoglycaemia by excision of the insulinoma may lead to improvement or resolution of the neuropathy (Jaspan and others, 1982). The same probably applies to dogs but much of the evidence for this is anecdotal. In the dog, partial improvement has been described following

medical management using corticosteroids and diazoxide to elevate blood glucose levels (Schrauwen 1991).

Circumstantial and electrophysiological evidence would suggest that, in case 13, the neuropathy was related to the insulinoma. It would have been interesting to determine if excision of the insulinoma altered the progression of the neuropathy, but unfortunately permission for laparotomy was refused in this case. Treatment was limited to dietary management for a period of two weeks, which resulted in resolution of the cerebral disturbances but the neuropathy continued to deteriorate.

GENERAL CONCLUSIONS

Brachial plexus disease usually falls into one of three syndromes based on the underlying cause; trauma, neoplasia or inflammatory and idiopathic neuropathies. Vascular disease is less frequently recognised.

Trauma is typically associated with significant neurological deficits, of acute onset, which affect one limb. Despite the common term "brachial plexus avulsion" the major lesion in traction injuries is avulsion of the nerve roots from the spinal cord, therefore the prognosis for recovery of avulsed nerve fibres is hopeless. The site and severity of the nerve root injury are the main factors which determine the outcome in these cases. Secondary complications associated with paralysis and desensitisation of the limb are a major factor in the management of nerve root and some peripheral nerve injuries.

Neoplasia typically causes a progressive unilateral lameness in dogs over five years of age. Significant neurological deficits are commonly absent from the affected limb. In cases with minimal neurological deficits, the presence of a partial Horner's syndrome or absence of the ipsilateral panniculus reflex are valuable localising signs and confirm a neurologic rather than orthopaedic cause of the lameness. Quadriparesis may be seen with tumours involving the spinal canal. Over half the cases of nerve sheath tumours have lesions involving the nerve roots or spinal nerves, making them unsuitable candidates for amputation, which is regarded as the treatment of choice. Nerve sheath tumours are capable of early metastasis.

Cases of inflammatory or idiopathic disease usually present with neurological deficits in more than one limb, however, the severity of the deficits may vary between affected limbs and may be sub-clinical. There may be cranial nerve involvement. The inciting cause in these cases is not commonly identified. The presence of a concurrent insulinoma in one case suggests that metabolic disease may be an additional possible cause of brachial plexus neuropathy.

In most cases the diagnosis was reached on the basis of history and clinical findings but ancillary investigations were beneficial in several cases. In general, electrophysiological examination provided the most useful information regarding the distribution and pathological changes associated with brachial plexus disease. Contrast radiography, CSF examination and clinical pathology were also helpful in specific cases.

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