NERVE DISTRIBUTION OF THE FETAL BOVINE MANUS

by

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DEDICATION

To my wife, Marlene,

and to my son,

José Alberto.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The innervation of bovine manus has been studied by many investigators (13, 17, 18, 51). Most of the work has been done by gross dissections of adult forelimbs. This approach is usually limited to a description of the route and distribution of the major nerves and their larger, superficial branches. The smaller, deeper branches of these major nerves have been somewhat neglected or overlooked since they are difficult to identify and/or follow grossly, are almost indistinguishable from the surrounding connective tissue, and are easily torn. This is especially true when attempting to follow the smaller nerves of the metacarpal and digital area, where many heavy tendons and ligaments are found.

The nerve supply to equine carpus, metacarpus and digit has been studied using serial sections of fetal limbs (51); to our knowledge no such studies have been done on bovine fetal limbs. Yet, the structures innervated by the smaller and deeper nerves of the carpus, metacarpus and digits are very important if diagnostic and surgical nerve blocks of the larger, superficial nerves are to be properly performed. Further, diseases of this region of livestock often impair the animal's utility, thus causing economic loss. Finally, knowledge of the sensory innervation of the manus is important

since lameness diagnosis and surgery of this region is very common and generally performed under local anesthesia (13, 18).

We therefore undertook to determine the feasibility of using fetal forelimbs for gross and microscopic studies of the nerves of the manus. The microscopic study was done from serial transverse sections. Attempts were made to follow the smaller nerves to the structures innervated. All findings were correlated with gross dissections of the adult manus. The results of this study provide the first detailed description of the innervation of the bovine manus. In addition, we have demonstrated the value of the combined technique of gross dissection and study of serial transverse section of fetal material to effectively study the nerve supply to the bovine manus. The information gained on our study adds significantly to our knowledge and understanding of bovine anatomy.

LITERATURE REVIEW

The Development, Morphology and Distribution of the Brachial Plexus:

The term "brachial plexus" is used to denote a network of nerve fibers formed by the convergence and subsequent joining of ventral rami of a variable number of spinal nerves which serve the forelimb or wings of animals. The differentiation, number and the pattern of the nerves which form the brachial plexus is species specific and is dependent upon the development and specialization of the limbs. The primary development occurs during the early period of embryonic growth (3). In birds (49) the plexus primoridum is recognizable at 82-84 h. of incubation, and it is definitively constituted by 120 hrs. By the eleventh day of incubation the peripheral nerve distribution is similar to that of the adult. Embryologically, the brachial plexus has been studied in aves (3, 6, 42, 50), pisces, amphibians, reptiles, pigs, cats, mice, rats, rabbits, guinea pigs and men (6-39). In mammals (3, 39) the brachial plexus is composed of nerves arising from the fourth to the ninth spinal roots, with species and individual variation within the species (39).

The morphological pattern of the "mammalian" brachial plexus when studied embryologically is regarded as being made

up of spinal roots which fuse together in various ways to form cranial and caudal trunks. These trunks are organized into cords from which the peripheral nerves of the forelimbs arise (38). This morphological pattern is not the same in all animals, and the complexity increases with the evolutionary scale. In amphibians there is no suggestion of trunks or cords. In reptiles there are defined cranial and caudal trunks which are combined into three cords, to form the ulnar and median peripheral nerve elements. In monotremes, marsupials and birds the brachial plexus is characteristic of the "mammalian" plexus. The form, distribution and complexity of the brachial plexus are determined by the general morphology and specialization of the pectoral limb musculature and the locomotion peculiar to the specific animal (38).

Gross dissection techniques have shown that the thoracic limbs are innervated primarily by the sixth cervical to the first thoracic spinal cord segment with small contributions from C5 and T2 (10). In general, the brachial plexus is derived from the last 3 or 4 cervical nerves and the first one or two thoracic nerves (16). There is general agreement on the course of the branches of the plexus and the structures innervated (2).

Studies of the brachial plexus of the dog have shown that the plexus is mainly confined to C6, 7, 8 and T1 with some contribution from C5 and T2 (2, 29, 38). Others state that the brachial plexus in the dog is composed of the sixth,

seventh and eighth cervical and the first and second thoracic nerves, with an inconstant contribution from the fifth cervical nerve. However, the contribution from the fifth cervical and second thoracic nerves are relatively very small (14, 17).

Researchers generally agree that the brachial plexus of the bovine, goat and sheep is formed by the junction of ventral branches of the last three or four cervical nerves and the first thoracic nerves, with a small inconstant contribution from the second thoracic nerve (11, 37). In ruminants, horses and pigs the brachial plexus derives its fibers from the ventral branches of the sixth, seventh and eighth cervical nerves and first thoracic nerve in the goat and sheep, from the sixth, seventh, and eighth cervical and the first and second thoracic in the ox and horse and from the fifth, sixth, seventh and eighth cervical and first thoracic nerve in the pig (17, 34, 35).

The Peripheral Nerves of the Brachial Plexus:

There are normally eleven peripheral nerves which branch from the brachial plexus. These branches are the suprascapular, subscapular, pectoral, musculocutaneous, ulnar, median, radial, axillary, long thoracic, thoracodorsal, and the lateral thoracic nerves (17). These nerves and their distribution have been studied by gross dissection techniques. Our studies will focus on the radial, musculocutaneous, ulnar and median nerves which are those that provide the sensory and motor supply of the bovine manus (20).

Gross techniques are of indispensable value, and they give a general view of the anatomical distribution of the larger more visible nerves. They also show the relationship of those nerves to the other structures but they do not show the smaller subgross elements. Other studies are needed to study the smaller nerves, their ramification, duplication, absence and branches (58, 61).

Depending upon the topographic location and distribution of the nerves in the forelimb, the placement of local anesthetic is divided into six regions. These include the pedal, interdigital, digital, subcarpal, supracarpal and cubital nerve blocks. Each of three proximal blocks except the cubital is subdivided into dorsal and palmar and into lateral and medial regions to facilitate the detection of forelimb lesions (28). Most operations upon the foot require blocking of several nerves when planning the injections. It is also necessary to know the depths of the nerves below the skin, as well as their individual course, connections and distribution (13). For successful anesthesia during surgery, it is important to block both sensory and motor innervation (20). Unfortunately such blocks become complicated because there are four, sometimes five, nerves which descend into the manus (13). In the foot region these nerves are further divided into axial, abaxial, common, and proper palmar digital nerves (42).

The terms axial and abaxial are used to refer to the side of each digit relative to the axis of the foot (23).

In English literature the terms "axial" and "abaxial" are often used to signify the dorsal and palmar digital nerves (19), but in reality, the medial and lateral dorsal nerves (or palmar) digital nerves are axial instead of abaxial nerves, because their relationship has changed due to the palmar migration of the second and fifth digits. Therefore, such terms are confusing and should be abandoned because they convey the wrong conception. Instead, they should be renamed as "proper" nerves in conformity with the Nomina Anatomica Veterinaria (41). To avoid further complication in renaming proper digital nerves, the Roman numeral of the digit along with the respective nerves should be added.

General Review of the Radial, Musculocutaneous, Ulnar and Median Nerves:

Radial Nerve: (N. radialis). The radial nerve derives its fibers from seventh and eighth cervical and first thoracic nerves in the goat, sheep, ox and pig and chiefly from the eighth cervical and first thoracic in the horse (17, 34, 35). In the dog (2) the radial nerve is formed by C8 together with a branch from C7 and T1 and sometimes with a slender filament from T2. The radial nerve in the dog is the largest and innervates all extensor muscles of the carpus and digits (15). Terminal branches of the radial nerves are often differently designated by different veterinary anatomists (19, 20).

At the ventral border of the teres major muscle the radial nerve gives off several muscular branches which

innervate the triceps brachii muscle (medial, lateral and long head). It also gives off small branches which enter the tensor fascia antebrachii and anconeous muscles (34). Then, the radial nerve divides into "dorsal cutaneous nerve of the forearm", and a muscular branch near the anterior border of the triceps muscle. The muscular branch distributes on the extensor muscles and the dorsal cutaneous nerve innervates the forearm and runs down to the digit (35). The dorsal cutaneous nerve of the forearm is also called the superficial branch (17, 18, 19, 20), and the muscular branch is called the deep branch (17, 19, 20). The superficial branch of the radial nerve gives off a long slender branch called nervus cutaneous antebrachii lateralis (19, 20) or lateral cutaneous antebrachii nerve (51), which in the forelimb of the horse ramifies on the lateral surface as far distally as the carpus. In the bovine the slender branch of the superficial branch of the radial nerve joins by means of several twigs to the medial cutaneous antibrachial nerve. This combined trunk furnishes twigs to the fascia and skin of the adjoining area, obliquely crosses the carpus and disappears in the fascia and skin on the medial aspect of the proximal half of the metacarpus (18, 19, 20).

The superficial branch of the radial nerve, which also supplies the fascia and skin of the carpus joint (19, 20), may receive a communicating branch from the musculocutaneous nerve (19, 22). It descends over the metacarpal bone and

supplies all the dorsal nerves to the dorsal aspect of the foot (13, 22), except the lateral dorsal nerve (22). Therefore, in radial paralysis there is a reduction or absence of skin sensation on the dorsal aspect of the manus, as all of this area, except the most lateral part, is supplied by the radial nerve (20).

The dorsal metacarpal nerve is the continuation of the cutaneous branch of the radial nerve (25). It descends under the deep fascia on the dorsal surface of the carpus and metacarpus (37) and supplies innervation to the fascia and skin of the proximal third of the metacarpal bone (18).

This superficial branch of the radial nerve lies medial to the tendon of the medial digital extensor tendon (37), and a little below the middle of the dorsal surface of the metacarpus; it can be palpated on the bone, and injection at this point blocks the axial dorsal nerves of both digits and the abaxial dorsal nerve of the third digit (23, 24).

The superficial branch of the radial nerve is also called dorsal metacarpal nerve. The branches given off by the division of this nerve receive different names according to different authors. One author (37) states that above the fetlock joint the superficial branch of the radial nerve divides into three dorsal digital nerves. Another (25) states that a little below the middle of the dorsal surface of the metacarpus, the superficial branch of the radial nerve gives off a medial branch, which is the abaxial dorsal nerve of the third digit, and the

major trunk continues on the common digital extensor tendon and divides into the axial dorsal digital nerves. The main continuation of the dorsal metacarpal nerve or superficial branch of the radial nerve is called N. metacarpus dorsalis communis III or N. digitalis dorsalis communis III (18, 19). The most commonly accepted division is into dorsal common digital nerve II and III (17).

The dorsal common digital nerve II furnishes the medial accessory second digit and continues on the abaxial side of the third digit as the dorsal proper (abaxial) digital nerve III (17) or medial dorsal digital nerve of the third digit (18). Sometimes there is a communicating branch between the medial branch of the superficial branch of the radial nerve and the medial branch of the median nerve (18).

The dorsal common digital nerve III divides into dorsal proper digital nerves III and IV (17), which supply the interdigital surfaces of the principal digits (18). Frequently, a communicating branch connects the dorsal and palmar proper digital nerves III and IV through the interdigital space (17, 18, 25). Across the middle of the proximal phalanx in the ox, a transverse connection exists between the dorsal proper digital nerve III and the palmar proper digital nerve IV (17, 35).

Musculocutaneous Nerve: (N. Musculocutaneous). This nerve derives its fibers from the sixth and seventh cervical nerves in the goat, chiefly from the sixth and seventh in the sheep and pig, from the seventh and eighth cervical nerves in

the horse, and chiefly from the sixth, seventh and eighth cervical nerves in the ox (17, 34). Sometimes in the bovine its fibers are derived either from the sixth and seventh or from the seventh and eighth cervical (17). In the dog the musculocutaneous nerve is formed entirely by two filaments from the cranial border of the seven cervical nerves (2). There is a controversial point about the origin of the musculocutaneous nerve. Some authors consider that this nerve is given off by the median nerve as the N. cutaneous antebrachii medialis (18, 20, 37). This N. cutaneous antebrachii medialis also is called dorsal cutaneous nerve of the forearm (37). Usually the musculocutaneous nerve is related to the craniomedial aspect of the median nerve and is enclosed in a common sheath with it in the axillary space (17). In the cat the musculocutaneous nerve is not associated with the median nerve in its distal course. Its cutaneous branch is all N. cutaneous antebrachii medialis which corresponds to the N. cutaneous antebrachii in the man (19). In the pig, goat and horse the musculocutaneous nerve is completely separable from the median nerve (34). In the ox, sometimes it is completely separated from the median nerve (35). Other authors consider that there are two musculocutaneous nerves, one of which is the main trunk which sends branches to join the musculocutaneous nerve of the median nerve (34); it is also called dorsal cutaneous nerve of the forearm (37). Both the musculocutaneous and the median nerves are so closely related that it is difficult to

discuss one without the other (35). In some cases, the musculocutaneous nerve contributes fibers to the median nerve (34, 35), and in others, it exchanges fibers with the latter nerve (34). The exchange of fibers between the musculocutaneous and the median nerves is a reciprocal one; the median nerve contributes fibers to the musculocutaneous nerve, and the musculocutaneous nerve contributes fibers to the median nerve (35).

For comparative reasons, the ramus musculocutaneous of the median nerve should be regarded as the ramus muscularis distalis of the musculocutaneous n. (19).

On the whole, there are two parts of the musculocutaneous nerve: the proximal part or independent part (13, 35) which supplies the biceps and the coracobrachialis muscle and the distal part, which appears as a branch of the median nerve (13); this last branch is the cutaneous nerve of the forearm and releases fibers to furnish the medial and dorsal aspect of the carpus (17, 18, 20). The main branch of the musculocutnaeous nerve joins to the radial nerve over the carpus (17, 18, 20). In general, it supplies the dorso-medial area of skin extending from the lower part of the forearm into the foot and overlaps the cutaneous distribution of the radial nerve (13). The musculocutaneous nerve may continue distally, but parallel to the radial nerve to form the abaxial dorsal nerve of the medial digit (13); or it continues distally, without exchanging fibers with the radial nerve, as the

dorsal common digital nerve II 917). In the dog the musculocutaneous nerve gives sensory innervation to the skin on the medial aspect of the forearm, and in this animal it ends at the carpus (14). In the horse the medial cutaneous antebrachial nerve supplies innervation to the medial aspect of the carpus and metacarpus as far distally as the fetlock joint (51).

Ulnar and Median Nerves: (Nn. Ulnaris et Medianus). The innervation of the palmar part of the forearm and manus is an important part of the brachial plexus in every species, and the ulnar and median nerve are responsible for that function (38). These nerves (ulnar and median) form the termination of the cranial divisions from all the spinal roots. In animals in which the manus is poorly developed the ulnar and median nerves are undifferentiated, and a single nerve trunk supplies the region. This condition is specially marked in the wing of the bird. Actual differentiation of the ulnar nerve is evident in the monotreme and marsupial in which the forelimbs are better developed and have greater range of actions. Conversely the nerves to the compressed forefoot of the dog are fused or anastomosed for a great part of their extent (38).

Ulnar Nerve: (N. Ulnaris). This nerve originates from the eighth cervical and first thoracic nerves in the goat, sheep and pig, from the second thoracic nerves in addition to the above in the ox, and chiefly from the first

and second thoracic nerves in the horse (17, 34, 35). In the middle of the arm region it divides into a small anterior and a larger porterior branch, which are distributed below the elbow (35).

About 2 cm. above the point of the elbow, the ulnar nerve detaches the caudal cutaneous nerve of the forearm or N. cutaneous antebrachii dorsalis superficialis (18, 19, 20). This nerve supplies the caudomedial aspect to the forearm (19, 20). It also supplies innervation to the fascia and skin of the craniomedial aspect of the carpus (20, 35). In the palmar region of the carpus a little above the accessory carpal bone the ulnar nerve terminates into three branches (38): the palmar cutaneous carpal nerve, the superficial lateral palmar nerve, and the deep lateral metacarpal nerve. The most accepted division is that in which the ulnar nerve divides into dorsal and palmar branches (17, 18, 20). Those branches can be called ramus dorsalis nervus ulnaris and ramus palmaris nervus ulnaris (19). The dorsal branch of the ulnar nerve detaches a small twig to the accessory carpal bone and furnishes the skin and fascia along the dorso-lateral aspect of the metacarpals (18, 20). This sensory innervation to the lateral aspect of the metacarpus is furnished as far as the fetlock joint (17).

In polydactyl animals, the ramus dorsalis nervus ulnaris (19) divides in different ways. This division, within the same species and among different species, receives different

names according to the author and the number of digits. Thus, the dorsal branch of the ulnar nerve above the fetlock joint divides into two twigs (20). The most important is the palmar twig which is called the dorsal common digital nerve IV (17, 20). This branch supplies the lateral accessory digit (17, 18, 20) and continues downward as the dorsal proper (abaxial) digital nerve IV (17, 20) or as the lateral dorsal digital nerve of the fourth digit (18). In general, this branch, which also is called the lateral dorsal nerve (22), contributes fibers to give sensory innervation to the fascia and skin of the fetlock joint (18, 20).

The palmal branch of the ulnar nerve runs in the groove between the interosseous tendon and the metacarpal bone (25). It can be blocked by injecting in the groove between the interosseous and the metacarpal bone (23).

The palmar branch is the distal continuation of the ulnar nerve (13, 17, 18). This branch gives off one deep twig to the interosseous muscle (19, 24). This deep branch is expended entirely inside the interosseous muscle except in the dog (19).

On the whole, the palmar branch of the ulnar nerves furnishes the fascia and skin of the proximal third of the medial surface of the metacarpus (17, 18). It receives the lateral palmar nerve of the median nerve (18) or a communicating branch of the median nerve (17, 23). The latter trunk supplies the lateral accessory digit (17, 18) and continues

downward as the lateral palmar digital nerve (18), or as the palmar proper (abaxial) digital nerve IV (17, 23). This nerve can be blocked in the groove between the interosseous and the deep flexor tendon on the lateral side (23).

Median Nerve: (N. Medianus). Its fibers are derived from the eighth cervical and first thoracic nerves in the goat and sheep, primarily from the preceding plus the second thoracic in the ox and horse, and from the seventh and eighth cervical and first thoracic nerves in the pig (17, 34, 35).

The median nerve continues through the carpal canal as the medial palmar nerve (13, 37). This nerve runs down to the medial side of the flexor tendons and is covered by the deep metacarpal fascia (25). At the middle of the metacarpus it divides in a variable manner and its branches receive different names according to different anatomists. In general, it supplies three palmar digital nerves and a part of the fourth palmar digital nerve (25). The median nerve is also divided into three branches: medial, middle and lateral (37). The most accepted division is that in which the median nerve divides into medial and lateral palmar nerves (17, 18, 19, 20).

The lateral and medial palmar branches divide into different branches, named in different ways by different authors. Thus, the medial branch is the abaxial palmar N. of the digit III, and the lateral branch forms a common trunk for the axial palmar nerve of both digits (13). One

author (20) states that the medial branch supplies the accessory digit (ramus medialis nervus digitalis palmaris communis II) and finally extends as the palmar proper digital nerve or nervus digitalis palmaris proprius. The same author divides the lateral palmar branch into a medial and a lateral branch in which the medial branch forms the palmar proper digital nerve of the fourth digit. The most commonly accepted division is that in which the medial branch soon divides into the palmar common digital nerve II and the palmar axial digital nerve III (17, 18). The lateral branch also divides into a medial and a lateral branch (18), or palmar axial digital nerve IV and a communicating branch (17).

The bovine palmar axial digital nerves III and IV often reunite for a short distance, forming the palmar common digital nerve III (17, 18). From this trunk arise the Nn. digitalis III et IV palmaris proprius (19), or palmar (axial) digital nerves III and IV (17). Those last nerves ramify in the axial structures (13, 20). In some cases a communicating branch exists among the dorsal proper digital nerves and the palmar proper digital nerves through the interdigital space (17, 20). In other cases, the area of innervation of both the palmar and dorsal proper digital nerves appears to overlap in the interdigital surface of the principal digits and consequently no anastomotic branch between them is distinctly visible (20). Sometimes the medial branch of the median nerve communicates with the medial branch of the superficial branch of the radial nerve (18, 20).

The communicating branch or lateral branch (17, 18, 25) joins to the palmar branch of the ulnar nerve, thereby constituting the palmar common digital nerve IV. The latter detaches a few twigs to the lateral accessory digits and continues as the palmar proper (abaxial) digital nerve IV.

In summary the median nerve supplies the axial palmar digital nerves, the abaxial palmar nerve of the third digit and a communicating branch to the fourth digit (23). All of these nerves can be blocked by injecting in the groove between the interosseous and the deep flexor tendon on the medial side above the middle of the metacarpus (23).

In the horse the median nerve usually is the largest nerve of the brachial plexus (17). The nerves that enter the foot are derived from a bifurcation of the medial and lateral (palmar) metacarpal nerves at the upper edge of the fetlock joint (56). At the carpus the lateral palmar nerves receive a contributing branch from the ulnar nerve (17). After the bifurcation the medial and lateral palmar branch ramify in the skin and corium of the hoof on the dorsal surface of the digit (56).

In the horse (17, 56) there is an inconstant intermediate branch which arises from the dorsal edge of the volar digital nerves. Failure to achieve desired results from a properly performed volar digital nerve block or neurectomy is due to the variations of this branch. In general, foot structures of the horse which are innervated by the dorsal digital nerves

(56) are the coronary corium, the dorsal part of the coffin joint, the capsule and dorsal part of the laminar and sole coria. The palmar digital nerve innervates the navicular bursa, the deep flexor tendon distal to the pastern joint, the palmar part of the coffin joint and the cartilage of P III, the palmar part of laminar, the sole coria, the corium of the frog and bars, the digital cushion and the skin on the volar surface of the pastern and digital cushion. Although the nerves to the foot are primarily sensory they also carry sympathetic vasomotor fibers of the autonomic nervous system (56).

Other Techniques Used in the Study of Nerve Distribution:

The gross dissection technique is of indispensable value in providing a general view of the larger nerves and their anatomical relationships to other structures, but it does not adequately reveal the smaller (subgross) nerves and more delicate tissues (61). Many times, the smaller nerves are very hard to distinguish from connective tissue. Therefore other techniques have been used to study the innervation of deep and fine structures. For instance, the blood supply and innervation of the choledochoduodenal junction in the cat was studied by gross dissection of fresh specimens (53). This technique has obvious disadvantages--namely the nerves had to be identified before cytolysis occurred. It was not always possible to distinguish fine nerves from delicate

vessels, but using the Wharton-Sihler's technique (53) it was possible to demonstrate the finer ramification of the nerve plexus in the choledochoduodenal region.

Cutaneous innervation (49) has also been demonstrated using the cholinesterase technique. With this standardized procedure the preparations show discrete localization. With silver impregnation upon the cholinesterase technique, the nerves appear dark or black. Even the finest nerve fibers are demonstrated as clear brown to black lines.

Electrophysiological studies have been done to demonstrate the cutaneous innervation on the thoracic limb of the dog. It was found that the cutaneous branch of the brachiocephalic, axillary, musculocutaneous, radial, median and ulnar nerves all had cutaneous areas which were overlapped by an adjacent cutaneous area. Thus, their anastomotic zones were much smaller than the cutaneous area usually depicted for these nerves in anatomy and neurology textbooks (31).

Nerve distribution of the equine digit has been studied with the light microscope using serial transverse sections of the fetal limb. It was found that nerve distribution is not mirror-image on the two sides of the foot. The dorsal branch of the ulnar nerve does not extend below the fetlock joint. In addition to that, the communication between the palmar metacarpal nerves is only a crossing of nerves without exchange of fibers. In this study the innervation of the deeper structures in the front digit of the horse was tabulated (52).

Some Diseases Related with the Brachial Plexus and Its Branches:

The formation and distribution of the brachial plexus has been studied by many investigators because of its importance in diagnosis and treatment of brachial plexus injuries. For example, the dog is subjected to traumatic injuries of the brachial plexus and its nerves with resultant paralysis of some of the muscles of the thoracic limb; therefore, it is of clinical importance to study the nature and extent of such injuries in order to arrive at intelligent prognosis (2).

High radial paralysis (27) is a term applied to extensor paralysis of the front limb resulting from a lesion of the radial nerve proximal to its innervation of the triceps brachii; by contrast low radial paralysis is the result of the paralysis of the radial nerve distal to the innervation of the tricep brachii. High radial paralysis is a more important clinical problem than low radial paralysis where sensory perception is usually absent on the dorsal and lateral aspect of the forepaw. However, this is not a constant finding, perhaps because of overlapping sensory innervation from other nerves in the limb (27).

One of the most common indications of the peripheral nerve surgery in the dog is in humeral fracture where the radial nerve has been damaged by bone segments. Diagnosis of the above mentioned conditions depends upon the knowledge of the formation and distribution of the brachial plexus (57).

The amputation of the bovine claw is a common practice for treatment of severe necrobacillosis (foot-rot) in cases where the infection has penetrated the pedal joint and/or infected the bone (2). Amputation of the claw removes the diseased area. The operation can be performed upon a cow in the standing position under local anesthesia. Knowledge of the location and distribution of nerves in the forelimb has been used to diagnose lameness in the ox by means of nerve blocks (28).

MATERIAL AND METHODS

Gross Dissection:

The forelimbs of ten bovine fetuses, 150-200 days of age, were collected from the Jack Polen Beef Co., Kansas City, Kansas. The ages were estimated from a developmental growth chart for the bovine (47, 63). After the forelimbs were fixed in 10% formalin, the radial, musculocutaneous, ulnar and median nerves were dissected and followed from the carpus to and including the digits. The smaller nerves and communicating branches were studied with the aid of an optic visor.[a/]

The routes and distribution of the nerves were traced on plastic sheets placed over radiographs taken of fetal limbs. From the tracings, drawings were made of medial, lateral, dorsal and palmar views of the carpus, metacarpus and front digits. The tracings were made directly from the dissected limbs as they were being dissected. All tracings were compared to adult specimens previously dissected in the gross anatomy laboratory.

[a/] Optic Visor Model No. DA-7 manufactured by Donegan Optical Company, Inc., Kansas City, Missouri.

Histological Studies:

Seven bovine fetuses (two of 60 days old and five of 80 days) were collected from the Jack Polen Beef Co., Kansas City, Kansas. The ages were estimated from a developmental growth chart for the bovine (47, 63). The fetuses were fixed in 2.5% glutaraldehyde or 10% buffered neutral formalin. Following fixation the forelimbs were removed, decalcified in RDO[b/] for a period of 3 hours and washed under running tap water for one hour. Each forelimb was cut off above the carpus and placed in the Autotechnicon[c/] for routine dehydration, clearing and infiltration. Then the tissues were embedded in paraffin and sectioned at 9 or 15 µm. One manus of 60 days and one of 80 days were sectioned at 9 µm; one manus of 60 days and four of 80 days were sectioned at 15 µm. Each fifth section was stained with Bodian's method (33) and the others were stained with Harris Hematoxilin and Eosin (54).

The serial transverse sections were studied with the aid of a Nikon compound miscroscope at 40, 100 and 400x. The nerves were traced to determine their distribution to superficial and deeper structures of the manus. The route of each major nerve and its branches were plotted on life

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[b/] Commercial Decalcifier, Dupage Kinetic Laboratories, Inc.; P.O. Box 416, Downers Grove, Illinois 60515.

[c/] Autotechnicon: Automatic Tissue Processor Model #2500; made in U.S.A. by Lipshaw Manufacturing Corporation, Detroit, Michigan 48210.

size silhouettes of adult bovine forelimbs. These silhouettes were complemented by tables which contain the major nerves and structures innervated. Photomicrographs from transverse sections were taken at 5, 20, 50 and 100 x on an Olympus microscope, using a 5x ocular lens and obective lenses of 1, 4, 10 and 20 of magnification.

RESULTS

General:

The fetal bovine manus is innervated by four major nerves. Those are the Radial, Musculocutaneous, Median and Ulnar nerves.

Radial nerve:

Pathways and Branches: This nerve originated from the branchial plexus and divided into a muscular branch and cutaneous or superficial branch. The superficial branch (Figure 1:RN-SB) was the most important one because it supplied innervation to the bovine fetal manus. At first it associated with the extensor carpi radialis and the accessory cephalic vein on the dorsal region of the forearm. At this region the superficial branch of the radial nerve gave off about 5 to 8 cutaneous branches which distributed in the fascia and skin of the dorsolateral aspect of the forearm. Three of those branches extended to the dorsolateral region of the carpal joint (Figure 1:RN-CB). One of these continued downward and innervated the dorsolateral zone of the carpal joint. The main branch of the superficial branch of the radial nerve continued downward and near the distal one-third of the forearm exchanged fibers with the musculocutaneous nerve (medial cutaneous antebrachial nerve). At the level

of the carpal joint those two nerves communicated at about two or three different points (Figure 1:MCRN-J). Below the articulation and in front of the metacarpal bone (Figure 1: MCMN-P) a plexus was found between the radial and the musculocutaneous nerves. Thus the main nerve was a mixed trunk which crossed obliquely the medial aspect of the carpus. In front of the metacarpal bone the main nerve associated laterally with the medial digital extensor tendon and ran downward together with the dorsal common digital vein III. About 4 cm above the metacarpophalangeal joint the main trunk divided into dorsal common digital nerves II and III (Figure 1:DC-DN II; DC-DN III). Sometimes this division occurred 2-3 cm below the carpal joint. Before dividing the nerve gave off 3 to 4 cutaneous branches which ramified on the dorsolateral aspect of the metacarpal bone. One of those branches ran down and innervated the fascia and skin of the dorsal surface of the metacarpophalangeal joint. Sometimes this branch joined to another which came from the dorsal branch of the Ulnar nerve.

The common digital nerve II continued distal medially and furnished small twigs to the dorsomedial surface of the metacarpophalangeal joint and one small twig to the second digit (Figure 1:B II F-DC-DN II). Then, it continued as the dorsal proper (abaxial) digital nerve III (Figure 1:DPAb-DN III) and exchanged fibers with the palmar proper (abaxial) digital nerve III, which originated from the median nerve. The dorsal proper (abaxial) digital nerve III supplied 4 to 6 branches

which distributed on the dorsomedial aspect of the proximal phalanx, proximal interphalangeal joint and middle phalanx. Two of those branches ran distally and disappeared mediodorsally on the perioplic and coronary corium (Figure 1:BPCCF-DAb-DN III). In one of ten forelimbs the dorsal proper (abaxial) digital nerve III originated from the musculocutaneous nerve (medial cutaneous antebrachial nerve) which ran all the way down to the digits without exchanging fibers with the radial nerve. In this case the radial nerve gave only the dorsal common digital nerve III.

The dorsal common digital nerve III (lateral branch of the superficial branch of the radial nerve) extended distally and obliquely crossed over the medial digital extensor tendon. Then it located over the common digital extensor tendon. Below the metacarpophalangeal joint this nerve coursed dorsodistally and between the division of the common digital extensor tendon; at the middle of the first phalanx it divided into dorsal proper (axial) digital nerves III and IV (Figure 1:DPAx-DN III and DPAb-DN IV). Both nerves extended distally along with each proper digital extensor tendon and supplied innervation over the dorsal region of the proximal phalangeal joint, the first phalanx, the second phalanx, and the perioplic and coronary corium. The dorsal proper (axial) digital nerves III and IV received communicating branches which come from the palmar proper (axial) digital nerve III and IV respectively (Figure 1:CBF-PPAx-DN IV

and CBF-PPAb-DN IV). Those last two branches originated from the median nerve. This junction was found at the level of the first interphalangeal joint. Therefore below this articulation, the dorsal region was also innervated by the median nerve.

Innervation: In general, the superficial innervation of the radial nerve (Figure 5b) included the dorsolateral surface of the carpal joint and dorsal surface of the metacarpus. Once the nerve divided into dorsal common digital nerve II and III, it supplied innervation to the dorsal region from lateral to medial sides and including the digits. In this case there was a small laterodorsal area, from the metacarpophalangeal joint to the digit, which was innervated by the Ulnar nerve (Figure 5a).

The deep structures innervated by the radial nerve (Tables No. 1, No. 2) were the carpus joint capsule, the end of the extensor carpi radialis tendon, and the extensor carpi obliquus tendon. Below the carpal joint this nerve supplied innervation to the medial, lateral and common digit extensor tendons, dorsal and medial region of metacarpophalangeal and first interphalangeal joint capsules. Finally, this nerve distributed dorsomedially into the perioplic and coronary corium.

Musculocutaneous nerve (medial cutaneous antebrachial nerve, Figure 1:MCN):

Pathways and branches: This nerve branched from the brachial plexus, found between the biceps brachii and brachiocephalicus muscles. At the forearm region the medial cutaneous antebrachial nerve located on the medial side and related with

the accessory cephalic vein and extensor carpi radialis. Over the distal one third of the forearm it gave off several twigs which supplied the adjoining area and extended downward to innervate the fascia and skin of the dorsomedial aspect of the carpus. The medial cutaneous antebrachial nerve joined to the superficial branch of the radial nerve. This junction is normally found above the carpal joint and over the same articulation (Figure 1:MCN-CB, MCRN-J). Below the carpus and in front of the metacarpal bone both nerves exchanged fibers and formed a plexus. At the middle of the forearm and on the medial side the musculocutaneous nerve gave off two superficial branches which ran toward the mediopalmar side. The more superficial of these (Figures 1 and 3:MCN-SB) extended medially near the metacarpophalangeal joint and supplied innervation to the mediopalmar aspect of the carpus and metacarpal bone; the deeper branch (Figures 1, 2 and 3:MCN-DB) exchanged fibers with cutaneous branches from the median nerve. Thus the mediopalmar surface of the carpus and of the metacarpal bone was also innervated by the median nerve. As mentioned before, in one case the musculocutaneous nerve ran all the way down to the digit and formed the dorsal proper (abaxial) digital nerve III.

Innervation: The musculocutaneous nerve (Figures 5a, 6c and 7a) gave sensory innervation to the dorsomedial aspect of the carpal joint, metacarpal bone, metacarpophalangeal joint,

first and second phalanges. Also it gave innervation to the palmaromedial region of the carpus and metacarpal bone.

Deep structures supplied by the musculocutaneous nerve (Tables 1 and 2) included the carpal joint capsule on the medial side and the medial collateral ligament of this articulation. It is assumed that the radial nerve and the musculocutaneous nerve contributed to form the palmar proper abaxial digital nerve III and the dorsal proper axial digital nerve III and IV. Therefore, the musculocutaneous nerve may innervate the metacarpophalangeal and proximal interphalangeal joint capsules, and the perioplic and coronary corium.

Median nerve:

Pathways and branches: This nerve is the most important for supplying innervation to the fetal bovine manus. In gross dissection it was found on the palmar surface of the forearm between the flexor carpi radialis and the superficial digital flexor muscle (Figure 2:MN). At this level the median nerve was associated with the median artery and vein. About 2 cm above the carpal joint the median nerve gave off two subcutaneous branches (Figure 2:MN-SB) which supplied innervation to the skin and fascia of the mediopalmar aspect of the carpal joint and metacarpus; they ran medio-distally associated with the radial artery. At the palmar zone of the carpus they exchanged fibers with twigs which come from the musculocutaneous nerve (Figure 2:MCMN-J). Before the carpal canal the median nerve was associated with the medio-palmar surface of

the forearm and lay between the superficial and deep digital flexor muscles. In the carpal canal the median nerve was related with the deep digital flexor muscle, the deep belly of the superficial digital flexor muscle, and the median artery and vein. At the metacarpal bone the median nerve was associated with the medial aspect of the superficial digital flexor tendon; while at the middle of the metacarpal bone it divided into medial and lateral palmar nerves (Figure 2: MPN and LPN). Sometimes this division occurred about 2 cm below the carpal joint or a little above the middle of the metacarpal bone.

The medial and lateral palmar nerves: The medial palmar nerve soon divided into palmar common digital nerve II and palmar proper (axial) digital nerve III (Figure 2:PC-DN II and PPAx-DN III). The lateral palmar nerve gave off the palmar proper (axial) digital nerve IV and then continued laterally as communicating branch which communicated with the palmar branch of the Ulnar nerve about 2 cm above the metacarpo-phalangeal joint to form the palmar common digital nerve IV (Figure 2:PPAx-DN IV, CMBF-LPN and PC-DN IV). The description given above is the most common found in the gross dissection; however the dividion of the median nerve sometimes formed in different ways. For instance, the medial palmar nerve soon divided and gave one branch which communicated with the lateral palmar nerve. In this case the lateral palmar nerve gave off a single branch called common digital nerve III. This last

one divided into palmar proper (axial) digital nerve III and IV. Sometimes also these last two branches separately come from the lateral palmar nerve. The division of the palmar common digital nerve III may occur above the metacarpophalangeal joint or between the digit and a little below the same articulation.

The palmar common digital nerve II continued distally and near the metacarpophalangeal joint gave one small twig to the accessory second digit and ran down on the mediopalmar aspect of the articulation as the palmar proper (abaxial) digital nerve III (Figure 2:B II F-PC-DN II and PPAb-DN III). This nerve supplied innervation to the proximal phalanx, to the proximal interphalangeal joint, and to the middle phalanx. At the level of the first phalanx the palmar proper (abaxial) digital nerve III exchanged fibers with the dorsal proper (abaxial) digital nerve III. The main trunk divided into two branches at the level of the middle phalanx. The smaller of them distributed on the bulb of the hoof and the larger one went to the dorsal region of the distal phalanx and gave off 3 to 4 twigs which ramified on the laminar corium of this region (Figure 2:BLCF-PPAb-DN III). Sometimes the palmar common digital nerve II communicated with the dorsal common digital nerve II through a small branch.

The palmar proper (axial) digital nerve III (Figure 2: PPAx-DN III) continued downward between the digits, supplied innervation to the interdigital space, metacarpophalangeal

joint, and first and second interphalangeal joints of the third digit. This nerve also supplied a small twig to the accessory second digit (Figure 2:B II F-PPAx-DN III) and gave three branches. One of them distributed in the digital cushion (Figure 2:DCBF-PPAX-DN III); the second one ramified on the bulb of the hoof (Figure 2:BBF-PPAx-DN III) and the biggest one continued distally on the medial surface of the distal phalanx, divided into 3 to 4 branches and supplied innervation to the laminar corium (Figure 2:BLCF-PPAx-DN III). This nerve also gave one small branch which passed between the digits to the dorsal region and communicated with the dorsal proper (axial) digital nerve III (Figure 2:CBF-PPAx-DN III).

The palmar proper (axial) digital nerve IV (Figure 2: PPAx-DN IV) also went down within the interdigital space and supplied innervation to the same structures mentioned above but related with the fourth digit. Thus, this nerve gave branches to the fifth digit (Figure 2:BVF-PPAx-DN IV), the metacarpophalangeal joint, and the proximal and distal interphalangeal joints. Also it gave a branch to the digital cushion (Figure 2:DCBF-PPAx-DN IV) and a branch to the bulb (Figure 2:BBF-PPAx-DN IV). The main trunk continued distally and passed toward the medial surface of the third phalanx and supplied innervation to the laminar corium by means of 3 or 4 twigs (Figure 2:BLCF-PPAx-DN-IV). Within the interdigital space the palmar (axial) digital nerve IV gave one small branch which ran between the digits toward the dorsal region

and joined to the dorsal proper (axial) digital nerve IV (Figure 2:CBF-PPAx-DN IV).

The palmar common digital nerve IV (Figure 2:PC-DN IV), supplied a small twig to the fifth digit (Figure 2:BVF-PC-DN IV) and continued distally as the palmar proper (abaxial) digital nerve IV (Figure 2:PPAb-DN IV). This nerve supplied some branches to the metacarpophalangeal joint, to the proximal and distal interphalangeal joints as well as to the first and second phalanges. The main trunk at the level of the distal phalanx divided into two twigs. The smaller one innervated the bulb of the hoof and the larger one ran to the dorsal surface of the third phalanx and ramified into 3 or 4 branches which distributed on the laminar corium (Figure 2:BBF-PPAb-DN IV) and BLCF-PPAb-DN IV). At the level of the proximal phalanx the palmar proper (abaxial) digital nerve IV exchanged fibers with the dorsal proper (abaxial) digital nerve IV.

Innervation: The median nerve (Figures 6a, 7c and 8a) gave innervation to the palmaromedial aspect of the carpal joint, the mediopalmar surface of the metacarpal bone and the palmar region from medial to lateral and below the metacarpophalangeal articulation. There was a small area below the fetlock joint which was also innervated by the palmar branch of the Ulnar nerve. The palmar proper (axial) digital nerve III and IV gave communicating branches which ran between the digits toward the dorsal region and joined to the dorsal proper (axial) digital nerve III and IV at the level of the

first interphalangeal joint. Therefore below the proximal interphalangeal joint the dorsal region was also innervated by the median nerve.

The deep innervation of the median nerve included structures innervated by the nerve as a main trunk and structures innervated by its branches (Tables 1 and 2). Thus at the level of the distal one-third of the forearm this nerve gave two branches which distributed in the flexor retinaculum especially on the mediopalmar side. One of those branches also supplied innervation to the radial artery. A small twig from the median nerve innervated the distal end of the flexor carpi radialis. At the carpal canal two or three branches innervated the deep belly of the superficial digital flexor tendon, deep digital flexor tendon, the median artery and carpal sheath. During its distal course from the carpal canal to the metacarpophalangeal joint, the nerve innervated the deep digital flexor tendon, gave off branches which distributed in the deep fascia of the metacarpal bone, and, at the level of the metacarpophalangeal joint, innervated the palmar pouch of this articulation. The deep innervation at this level came mainly from the palmar proper (axial) nerve III and IV. Sometimes this innervation came from a common trunk formed by both branches. In either case the median nerve was the main source for supplying innervation to the palmar region. Small twigs innervated the medio and lateropalmar side of the metacarpophalangeal articulation. In general, the axial palmar

branches innervated the interdigital space structures, especially the proximal and distal interdigital ligaments, and the digital cushion. The synovial sheath of the superficial and deep digital flexor tendons received innervation from the palmar proper (axial) digital nerve III and IV as well as the palmar proper abaxial digital nerve III and IV. Deep innervation to the first and second interphalangeal joints as well as the navicular bursa came mainly from the palmar proper (axial) digital nerve III and IV. The median nerve had the greatest influence over the corium of the hoof (Table 2); it innervated the perioplic and coronary corium, particularly around the bulb and the toe of the third and fourth digits. The laminar corium of the wall, the corium of the sole and the corium of the bulb were innervated mainly by the median nerve.

Ulnar nerve (Figure 2:UN):

Pathways and branches: This nerve descended between the carpi ulnaris and ulnaris lateralis muscles. About 2 cm above the accessory carpal bone, it divided into palmar and dorsal branches (Figure 2:UN-PB, UN-DB).

The palmar or deep branch of the ulnar nerve took the distal continuation of the main trunk, descended medial to the accessary carpal bone, along the superficial digital flexor tendon and on the palmaromedial aspect of the interosseous muscle. Slightly above the accessory carpal bone, in five cases, the palmar branch of the ulnar nerve gave two

subcutaneous branches which distributed on the fascia and skin of the palmar surface of the carpal joint. These subcutaneous branches exchanged fibers with twigs from the median nerve. Above the accessary carpal bone the palmar branch gave one twig which supplied the interosseous muscle. About 2 cm above the metacarpophalangeal joint the deep branch of the ulnar nerve received the communicating branch from the median nerve and formed the palmar common digital nerve IV which supplied a small twig to the fifth digit and continued distally as the palmar proper (abaxial) digital nerve IV (Figures 2 and 4:CMBF-LPN, PC-DN IV, BVF-PC-DN IV and PPAb-DN IV). This nerve has already been described.

The dorsal branch of the Ulnar nerve (Figures 2 and 4: UN-DB): At the distal one-third of the forearm region this nerve was located between the flexor carpi ulnaris and ulnaris lateralis muscles. It further descended along the palmarolateral region of the carpus, where small twigs branched off to supply the adjoining area. Farther on the nerve continued distally along the dorsolateral aspect of the metacarpal bone. During its course it gave small branches to innervate the fascia and skin of that region. One of those branches communicated with one twig which came from the superficial branch of the radial nerve, and the combined trunk thus formed distributed over the dorsal surface of the metacarpophalangeal articulation. The dorsal branch of the Ulnar nerve called dorsal common digital nerve IV, (Figures 1 and 4:DC-DN IV) detached a small

twig to the fifth digit and descended as the dorsal proper (abaxial) digital nerve IV (Figures 1 and 4:BVF-DC-DC-DN IV, DPAb-DN IV). This nerve exchanged fibers with the palmar proper (abaxial) digital nerve IV and gave off branches to the metacarpophalangeal articulation, proximal and distal interphalangeal joints as well as first and second phalanges. At the level of the second phalanx the main trunk divided into two major branches which distributed on the perioplic and coronary corium (Figures 1 and 4:BPCCF-DPAb-DN IV).

Innervation: The dorsal branch of the Ulnar nerve (Figures 5a and 6b) gave innervation to the dorsolateral region of the fetal bovine manus, including the proximal end of the metacarpal bone to and including the digit. The palmar branch supplied innervation to the palmolateral aspect of the fetal bovine manus from the palmar region of the carpus to and including the digit.

The deep innervation of this nerve included structures innervated by the palmar branch and structures innervated by the dorsal branch.

At the level of the carpal joint the palmar branch gave innervation to the interosseous muscle; also it gave one branch which distributed in the palmar carpal ligament. Through this ligament some small twigs supplied innervation to the intraarticular ligament of the carpal articulation. The palmar branch of the Ulnar nerve also gave one branch to the distal ligament of the accessory carpal bone, and small

twigs which distributed in the flexor retinaculum specifically on the lateral side. Below the carpal joint this nerve supplied two branches which distributed in the superficial belly of the superficial digital flexor tendon. During its distal course it supplied innervation to the deep fascia of the metacarpal bone. Together with the median nerve the palmar branch of the ulnar nerve supplied innervation to the metacarpophalangeal joint and first and second interphalangeal joints. This nerve also gave small branches to the tendon sheath of the superficial and deep digital flexor tendons, the navicular bursa, the perioplic and coronary corium of the bulb, the corium of the bulb, the corium of the sole and the laminar corium (Tables 1 and 2).

At the level of the carpal joint the dorsal branch gave deep innervation to the extensor retinaculum, lateral collateral ligament of the carpal joint and the lateral digital extensor tendon. It also gave small twigs to the distal ligament of the accessory carpal bone and the flexor retinaculum on the palmarolateral side. During its distal course it innervated the lateral side of the metacarpophalangeal joint, pastern joint and perioplic and coronary corium on the lateral side of the fourth digit.

DISCUSSION

The distribution of the radial, musculocutaneous, median and ulnar nerves was studied in the fetal bovine manus. These nerves were followed from gross dissection and from serial transverse sections. The gross dissections were performed on ten fetal forelimbs ranging from 150-200 days of age. It was found that the 200 day fetuses was the best age to follow and study the distribution of both the larger and smaller branches. The serial transverse sections were made from seven fetal manus ranging from 60-80 days of age. The best age for following the nerves to the deeper structures innervated was at 80 days, cut at 15 μm and stained with H and E. The gross dissections were mainly used to determine the cutaneous zones of innervation. The serial transverse sections were mainly used to study the innervation of the deeper structures by these major nerves.

There were many communications occurring among the radial, musculocutaneous, median and ulnar nerves. These communications were noted grossly and it was thought to cause much overlapping of the cutaneous innervation. These overlapping areas were studied and verified from the serial transverse sections (Figs. 5, 6, 7 and 8).

The radial nerve communicated with the musculocutaneous nerve at the level of the carpal joint (Fig. 1), and with the medial nerve at the level of the proximal interphalangeal joint (Figs. 1 and 2). Thus as a mixed trunk the radial nerve supplied cutaneous innervation to the dorsolateral surface of the metacarpus, the dorsal aspect of the metacarpus, the dorsomedial aspect of third digit and the dorsal region of the fourth digit (Figs. 5 and 7).

The muscutaneous nerve furnished cutaneous innervation to the dorsomedial and palmaromedial aspects of the carpus, the dorsomedial surface of the metacarpus, the medial aspect of the metacarpophalangeal area, and the medial surface of the third digit (Figs. 5, 6 and 7). It is assumed that both the radial and the musculocutaneous nerves have influence over the entire dorsal region of the fetal bovine manus because of the communication which occurs between these two nerves (Fig. 1). The musculocutaneous nerve also communicated with the median nerve at the level of the palmaromedial side of the carpus (Fig. 2). Thus both the musculocutaneous and the median nerves supplied cutaneous innervation to the mediopalmar side of the carpus and metacarpus (Figs. 6 and 7).

The median nerve gave cutaneous innervation to the palmaromedial aspect of the carpus, the mediopalmar surface of the metacarpus, the entire palmar surface of the digits and the dorsal surface over the second phalanx of the third and fourth digits (Figs. 5, 6, 7 and 8). The median nerve

communicated with the musculocutaneous nerve at the mediopalmar side of the carpus (Fig. 2). Thus the median and the musculocutaneous nerves share cutaneous innervation over the mediopalmar side of the carpus and metacarpus (Fig. 6). This overlapping of cutaneous innervation has been omitted by other investigators (17, 18, 20). The cutaneous innervation over the dorsal surface of the second phalanx is due to the communicating branches between the palmar and dorsal proper (axial) digital nerves III and IV (Figs. 1 and 2). These communications occur in the interdigital space. The palmar proper (axial) digital nerves III and IV are branches of the median nerve. The dorsal proper (axial) digital nerves III and IV are, because of the communication, branches of the median and radial nerves. Contrary to other investigators (17, 18, 25), this radial and median nerve communication was always present. Perhaps in adult forelimbs, when grossly dissected, these communicating branches are too small and too difficult to identify from the surrounding connective tissue.

The ulnar nerve gave cutaneous innervation to the palmarolateral and dorsolateral aspects of the manus (Figs. 6 and 8).

In serial sections the smaller and deeper branches of the radial, musculocutaneous, median and ulnar nerves were identified and traced to structures innervated (Tables 1 and 2).

From the microscopic studies it was determined that the radial nerve innervated the extensor retinaculum, the extensor carpi radialis tendon, the extensor carpi oblique tendon, the

lateral digital extensor tendon, the medial digital extensor tendon, the common digital extensor tendon, the metacarpophalangeal joint capsules, the proximal interphalangeal joint capsules and the perioplic and coronary corium (Tables 1 and 2). In serial sections it was found that the radial nerve did not innervate structures below to the perioplic and coronary corium of the third and fourth digits.

The musculocutaneous nerve supplied deep innervation to the extensor retinaculum, the medial collateral ligament of the carpal joint, the flexor retinaculum, the metacarpophalangeal joint capsules and the perioplic and coronary corium. Previously, the musculocutaneous nerve was associated with the third digit. In this research it was found that this nerve also has influence over the dorsal surface of the fourth digit (Tables 1 and 2).

The median nerve was found as having deep innervation to the carpal sheath, the flexor retinaculum, the median artery, the deep digital flexor tendon, the deep fascia of the metacarpal bone (Figs. 10 and 10a), the metacarpophalangeal joint capsules, the proximal and distal interphalangeal joint capsules, the synovial sheath of the superficial and deep digital flexor tendons, the proximal interdigital ligament, the distal interdigital ligament, the navicular bursa, the digital cushion, the perioplic corium, the coronary corium of both digits, the corium of the sole, the corium of the bulb and the laminar corium. This nerve was considered

as the major nerve supply of the corium of the sole, the wall and the bulb of both digits (Tables 1 and 2).

One investigator (20) states that the area of innervation by the dorsal proper axial digital nerves III and IV, and by the palmar proper axial digital nerves III and IV appear to overlap in the interdigital space and consequently no communicating branches between them are distinctly possible. Studying serial sections, it was found that the median nerve innervated the interdigital space and communicated with the dorsal proper axial digital nerves III and IV. Therefore, the median nerve also innervated deep structures at and below the pastern joint (Tables 1 and 2).

Communication has been described between the palmar proper abaxial digital nerve III and dorsal abaxial digital nerve III (17, 18). Using serial sections it was found that these communicating branches run from the palmar abaxial digital nerve III to the dorsal abaxial digital nerve III. The same characteristic was found for the palmar and dorsal abaxial digital nerves IV.

Microscopic study showed that the ulnar nerve gave deep innervation to the distal ligament of the accessory carpal bone (Figs. 9 and 9a), the interosseous muscle (Fig. 12), the palmar ligament of the carpal joint, the flexor retinaculum, the lateral collateral ligament of the carpal joint, the lateral digital extensor tendon, the extensor retinaculum, the superficial digital flexor tendon (Fig. 12), the deep fascia of

the metacarpal bone, the metacarpophalangeal joint capsule, the proximal and distal interphalangeal joint capsules, the synovial sheath of the superficial and deep digital flexor tendons, the navicular bursa, the perioplic corium, the coronary corium, the corium of the sole, the corium of the bulb and the laminar borium. Those structures innervated by the ulnar nerve below the fetlock joint are associated with the fourth digit (Tables 1 and 2).

Normally the ulnar nerve has been described as receiving a communicating branch from the median nerve. From serial sections this communication was found to occur about 2 cm proximal to the metacarpophalangeal joint (Fig. 11).

This study has confirmed that the nerve distribution to the bovine manus can be accomplished by studying fetal specimens. The results gained from serial section were more reliable and accurate than those gained from gross dissection.

From this study it can be seen that a whole new concept should be developed to block specific nerve to desensitize the bovine manus. The specific structures innervated should be taken into consideration.

It is hoped that this study will serve as a model for future nerve studies. It is felt that these results are accurate but they need to be confirmed and verified by other techniques such as electrophysiological and clinical nerve block studies.

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FIGURES WITH EXPLANATIONS

Nerve supply on the dorsal surface of right manus of the bovine fetus (schematic drawing).

Abbreviations for Figure 1:

L . . . . . Lateral

RN . . . . . Radial nerve

RN-CB . . . . . Radial nerve cutaneous branch

UN-DB . . . . . Ulnar nerve dorsal branch

DC-DNIII . . . . . Dorsal common digital nerve IV

BVF-DC-DNIV . . . Branch to the 5th digit from [dorsal common digital nerve IV]

DPAb-DNIV . . . . Dorsal proper (abaxial) digital nerve IV

DPAx-DNIV . . . . Dorsal proper (axial) digital nerve IV

CBF-PPAx-DNIV . . Communicating branch from [palmar proper (axial) digital nerve IV]

BPCCF-DAb-DNIV . . Branches to perioplic and coronary corium from [dorsal (abaxial) digital nerve IV]

M . . . . . Medial

MCN . . . . . Musculocutaneous nerve

MCN-DB . . . . . Musculocutaneous nerve superficial branch

MCN-CB . . . . . Musculocutaneous nerve (communicating branch)

MCRN-J . . . . . Musculocutaneous-Radial nerve (junction)

MCN-CB . . . . . Musculocutaneous nerve (cutaneous branch)

MCRN-P . . . . . Musculocutaneous-Radial nerve (plexus)

DC-DNII . . . . . Dorsal common digital nerve II

BIIF-DC-DNII . . . Branch to the 2nd digit from [dorsal common digital nerve II]

DPAx-DNIII . . . . Dorsal proper (axial) digital nerve III

DPAb-DNIII . . . . Dorsal proper (abaxial) digital nerve III

Abbreviations for Figure 1 (cont'd)

CBF-PPAx-DNIII . . Communicating branch from [palmar proper (axial) digital nerve III]

BPCCF-DAb-DNIII . Branches to perioplic and coronary corium from [dorsal (abaxial) digital nerve III]

Nerve supply on the dorsal surface of right manus of the bovine fetus (schematic drawing).

Figure 1

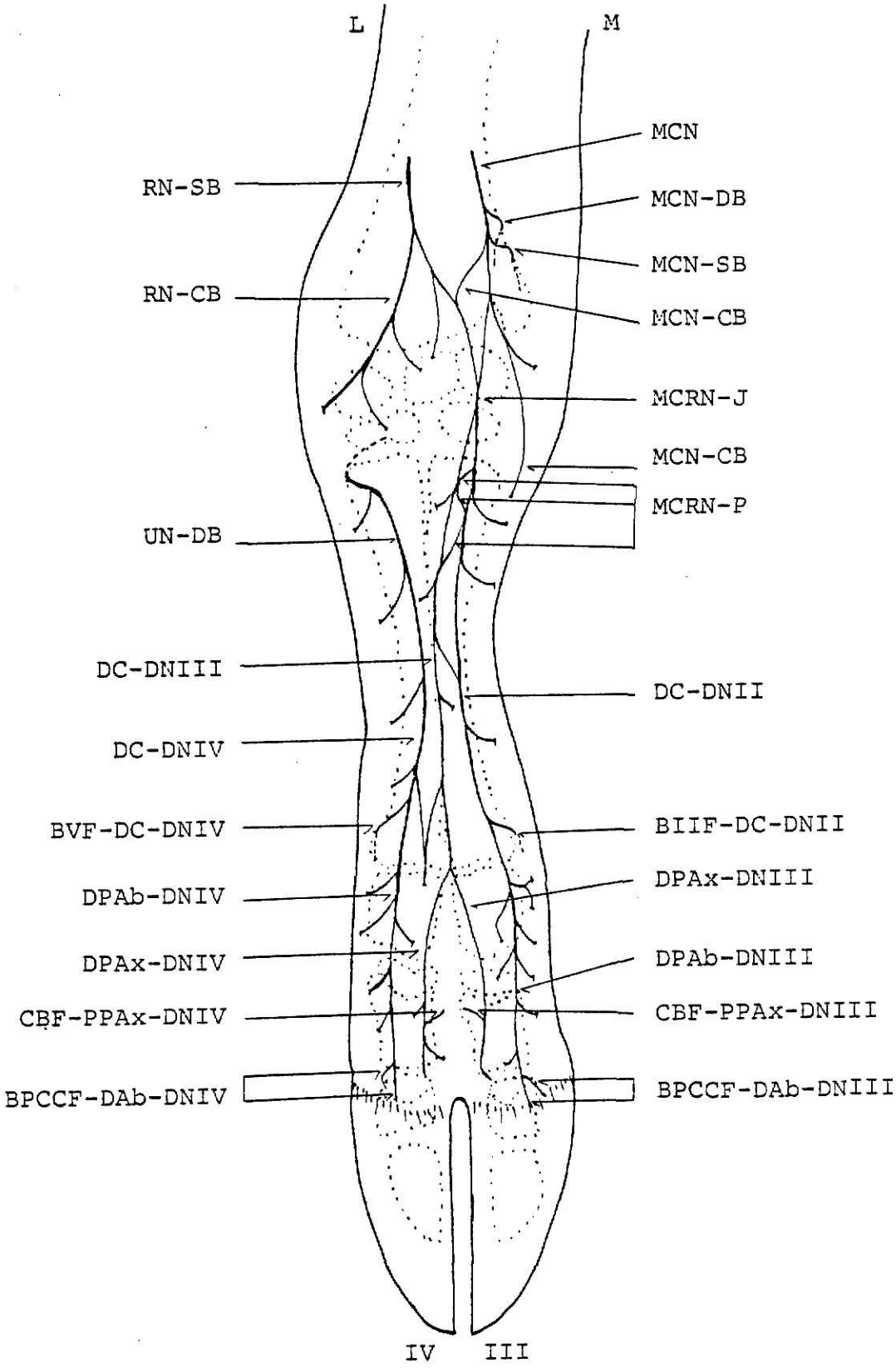


Figure 2. Nerve supply on the palmar surface of right manus of the bovine fetus (schematic drawing).

Abbreviations for Figure 2:

L . . . . . Lateral

UN . . . . . Ulnar nerve

UN-DB . . . . . Ulnar nerve dorsal branch

UN-PB . . . . . Ulnar nerve palmar branch

LPN . . . . . Lateral palmar nerve

CMBF-LPN . . . . . Communicating branch from [lateral palmar nerve]

PC-DNIV . . . . . Palmar common digital nerve IV

PPAx-DNIV . . . . Palmar proper (axial) digital nerve IV

BVF-PPAx-DNIV . . Branch to the 5th digit from [palmar proper (axial) digital nerve IV]

BVF-PC-DNIV . . . Branch to the 5th digit from [palmar common digital nerve IV]

CBF-PPAx-DNIV . . Communicating branch from [palmar proper (axial) digital nerve IV]

PPAb-DNIV . . . . Palmar proper (abaxial) digital nerve IV

DCBF-PPAx-DNIV . . Digital cushion branch from [palmar proper (axial) digital nerve IV]

BBF-PPAx-DNIV . . Branch to the bulb from [palmar proper (axial) digital nerve IV

BBF-PPAb-DNIV . . Branch to the bulb from [palmar proper (abaxial) digital nerve IV]

BLCF-PPAx-DNIV . . Branch to the laminar corium from [palmar proper (axial) digital nerve IV

BLCF-PPAb-DNIV . . Branch to the laminar corium from [palmar proper (abaxial) digital nerve IV]

M . . . . . Medial

MN . . . . . Median nerve

Abbreviations for Figure 2 (cont'd)

MCN-DB . . . . . Musculocutaneous nerve deep branch

MCMN-J . . . . . Musculocutaneous-Median nerve (junction)

MN-SB . . . . . Median nerve superficial branches

MPN . . . . . Medial palmar nerve

PC-DNII . . . . . Palmar common digital nerve II

PPAx-DN III . . . Palmar proper (axial) digital nerve III

BIIF-PPAx-DNIII . Branch to the 2nd digit from [palmar proper (axial) digital nerve III]

BIIF-PC-DNII . . . Branch to the 2nd digit from [palmar common digital nerve II]

CBF-PPAx-DNIII . . Communicating branch from [palmar proper (axial) digital nerve III]

PPAb-DNIII . . . . Palmar proper (abaxial) digital nerve III

DCBF-PPAx-DN III . Digital cushion branch from [palmar proper (axial) digital nerve III]

BBF-PPAx-DNIII . . Branch to the bulb from [palmar proper (axial) digital nerve III]

BLCF-PPAx-DNIII . Branch to the laminar corium from [palmar proper (axial) digital nerve III]

BLCF-PPAb-DNIII . Branch to the laminar corium from [palmar proper (abaxial) digital nerve III]

Nerve Supply on the palmar surface of right manus of the bovine fetus (schematic drawing).

Figure 2

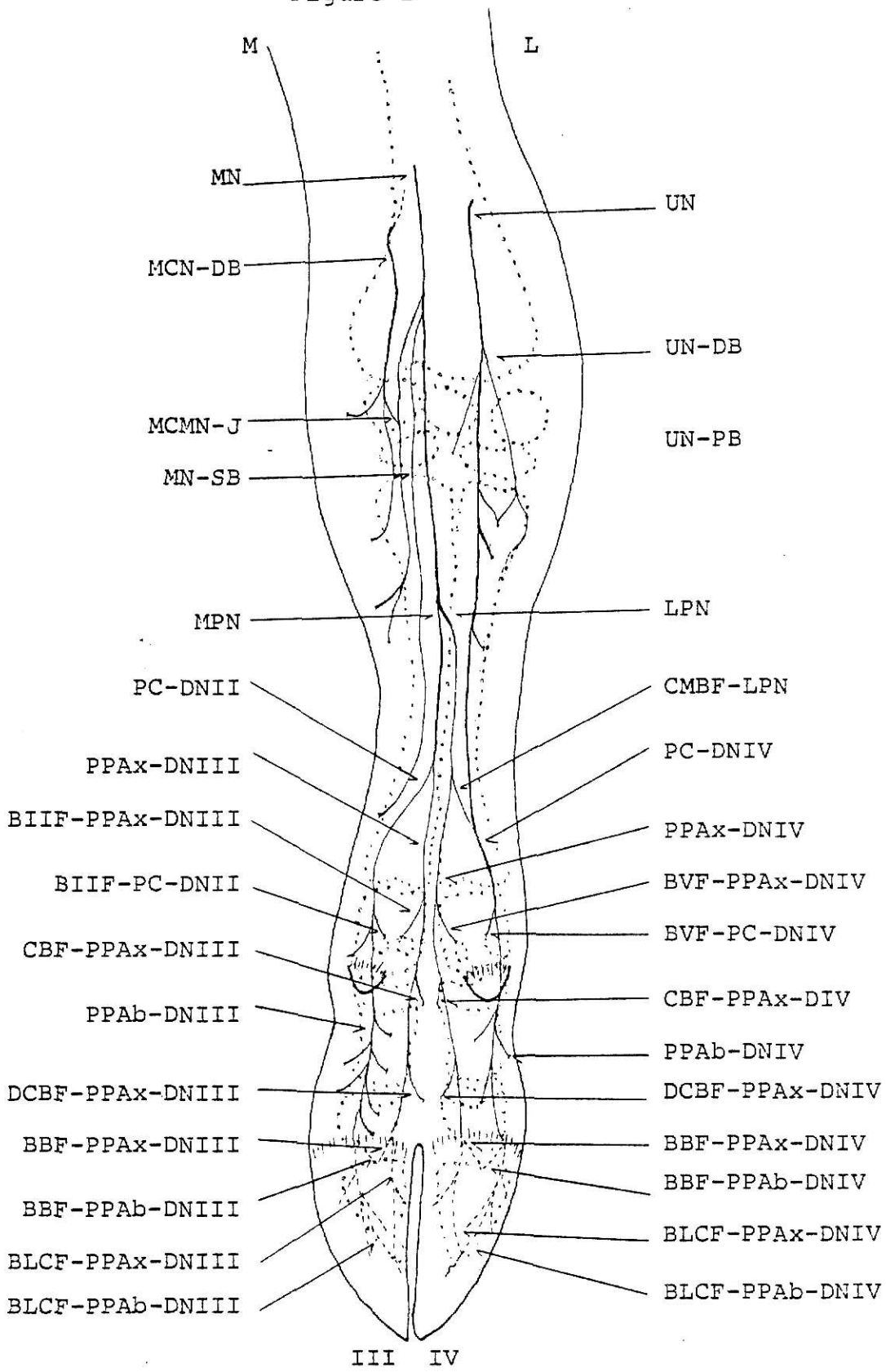


Figure 3. Nerve supply on the medial surface of left manus of the bovine fetus (schematic drawing).

Abbreviations for Figure 3:

To the Right:

MCN . . . . . Musculocutaneous nerve

MCN-SB . . . . . Musculocutaneous nerve superficial branch

MCN-CB . . . . . Musculocutaneous nerve cutaneous branch

DC-DNII . . . . . Dorsal common digital nerve II

BIIF-DC-DNII . . . Branch to the 2nd digit from [dorsal common digital nerve II]

DPAb-DNIII . . . . Dorsal proper (abaxial) digital nerve III

BPCCF-DPAb-DNIII . Branches to perioplic and coronary from [dorsal proper (abaxial) digital nerve III]

To the Left:

MCN-DB . . . . . Musculocutaneous nerve deep branch

MN . . . . . Median nerve

MPN . . . . . Medial palmar nerve

PPAx-DNIII . . . . Palmar proper (axial) digital nerve III

PC-DNII . . . . . Palmar common digital nerve II

BIIF-PC-DNII . . . Branch to the 2nd from [palmar common digital nerve II]

PPAb-DNIII . . . . Palmar proper (abaxial) digital nerve III

BBF-PPAb-DNIII . . Branch to the bulb from [palmar proper (abaxial) digital nerve III]

BLCF-PPAb-DNIII . Branch to the bulb from [palmar proper (abaxial) digital nerve III]

Nerve supply on the medial surface of left manus of the bovine fetus (schematic drawing).

Figure 3

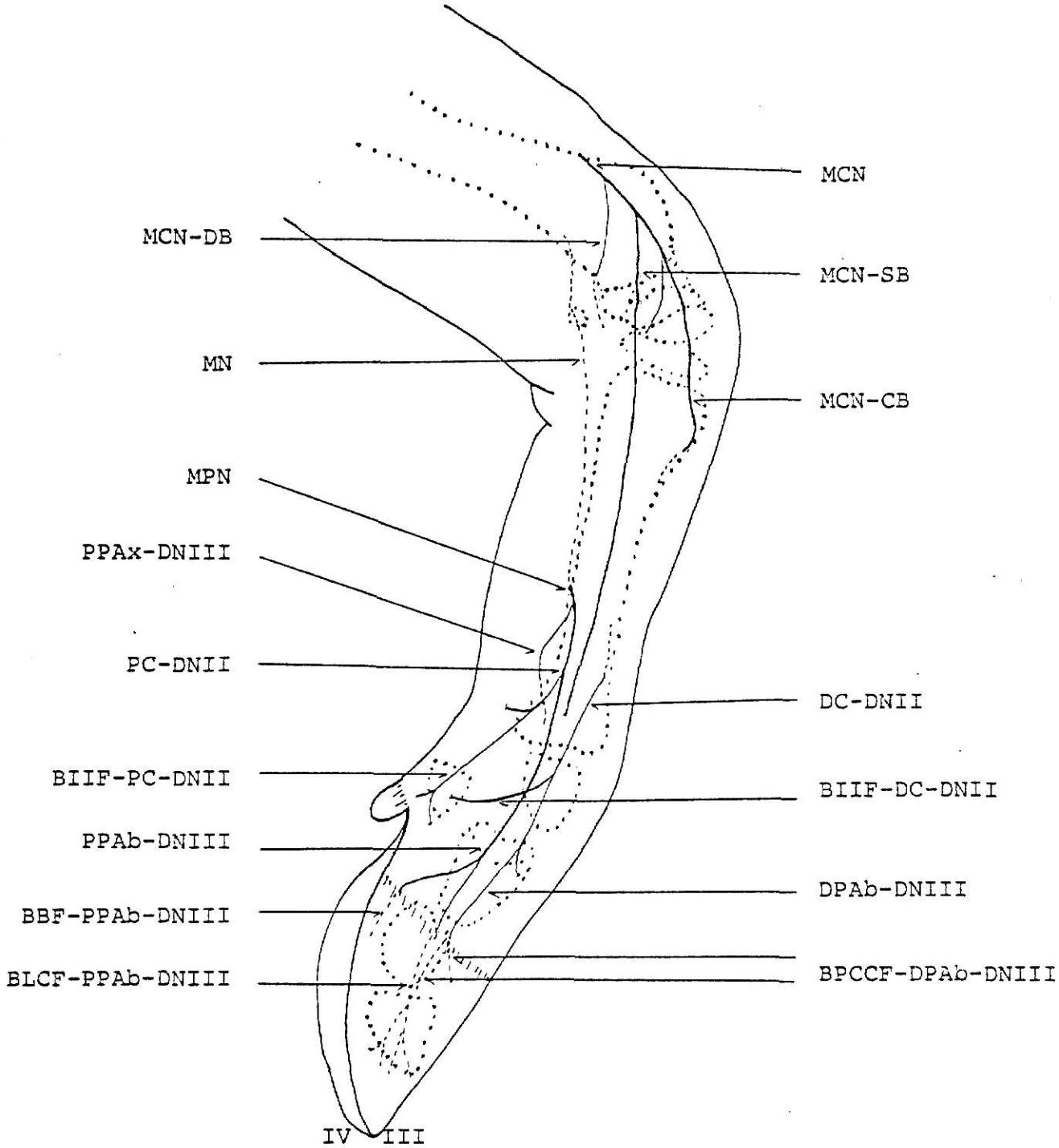


Figure 4. Nerve supply on the lateral surface of left manus of the bovine fetus (schematic drawing).

Abbreviations for Figure 4:

To the Right:

UN-DB . . . . . Ulnar nerve dorsal branch

UN-PB . . . . . Ulnar nerve palmar branch

CMBF-LPN . . . . . Communicating branch from [lateral palmar nerve]

PC-DNIV . . . . . Palmar common digital nerve IV

BVF-PC-DNIV . . . Branch to the 5th digit from [palmar common digital nerve IV]

PPAb-DNIV . . . . Palmar proper (abaxial) digital nerve IV

BBF-PPAb-DNIV . . Branch to the bulb from [palmar proper (abaxial) digital nerve IV]

BLCF-PPAb-DNIV . . Branch to the laminar corium from [palmar proper (abaxial) digital nerve IV]

To the Left:

DC-DNIV . . . . . Dorsal common digital nerve IV

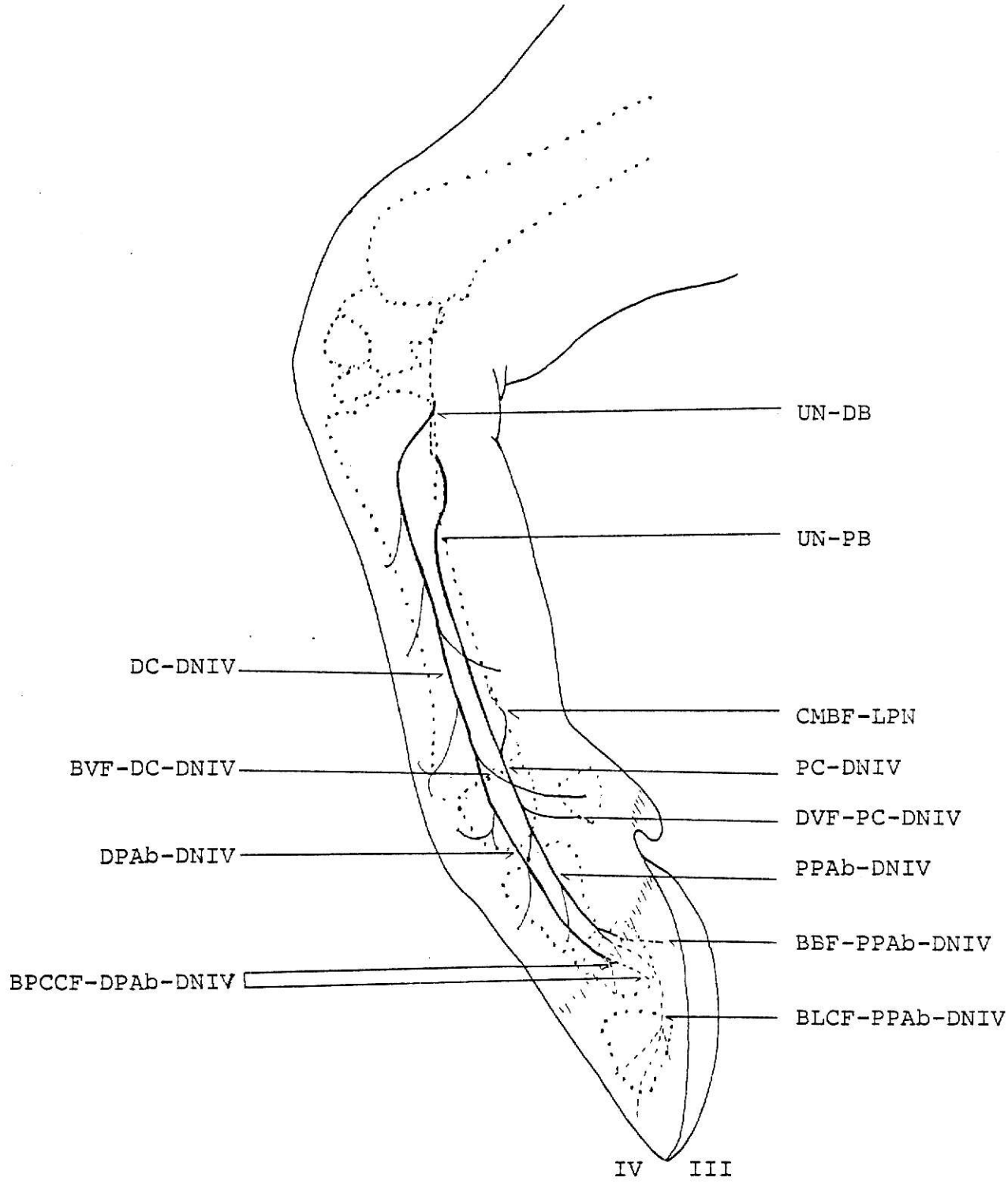
BVF-DC-DNIV . . . Branch to the 5th digit from [dorsal common digital nerve IV]

DPAb-DNIV . . . . Dorsal proper (abaxial) digital nerve IV

BPCCF-DPAb-DNIV . Branches to the perioplic coronary corium from [dorsal proper (abaxial) digital nerve IV]

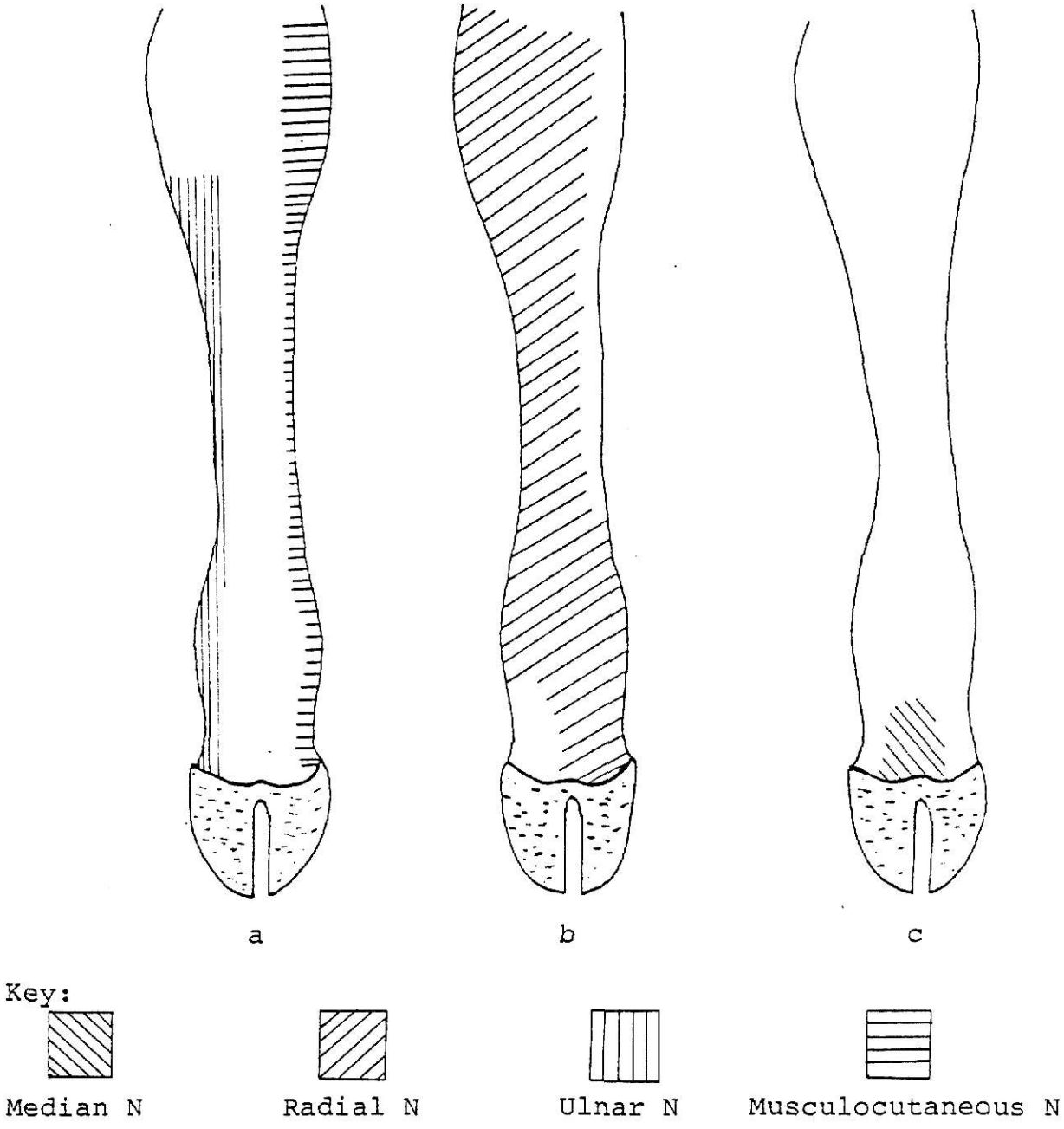
Nerve supply on the lateral surface of left manus of the bovine fetus (schematic drawing).

Figure 4



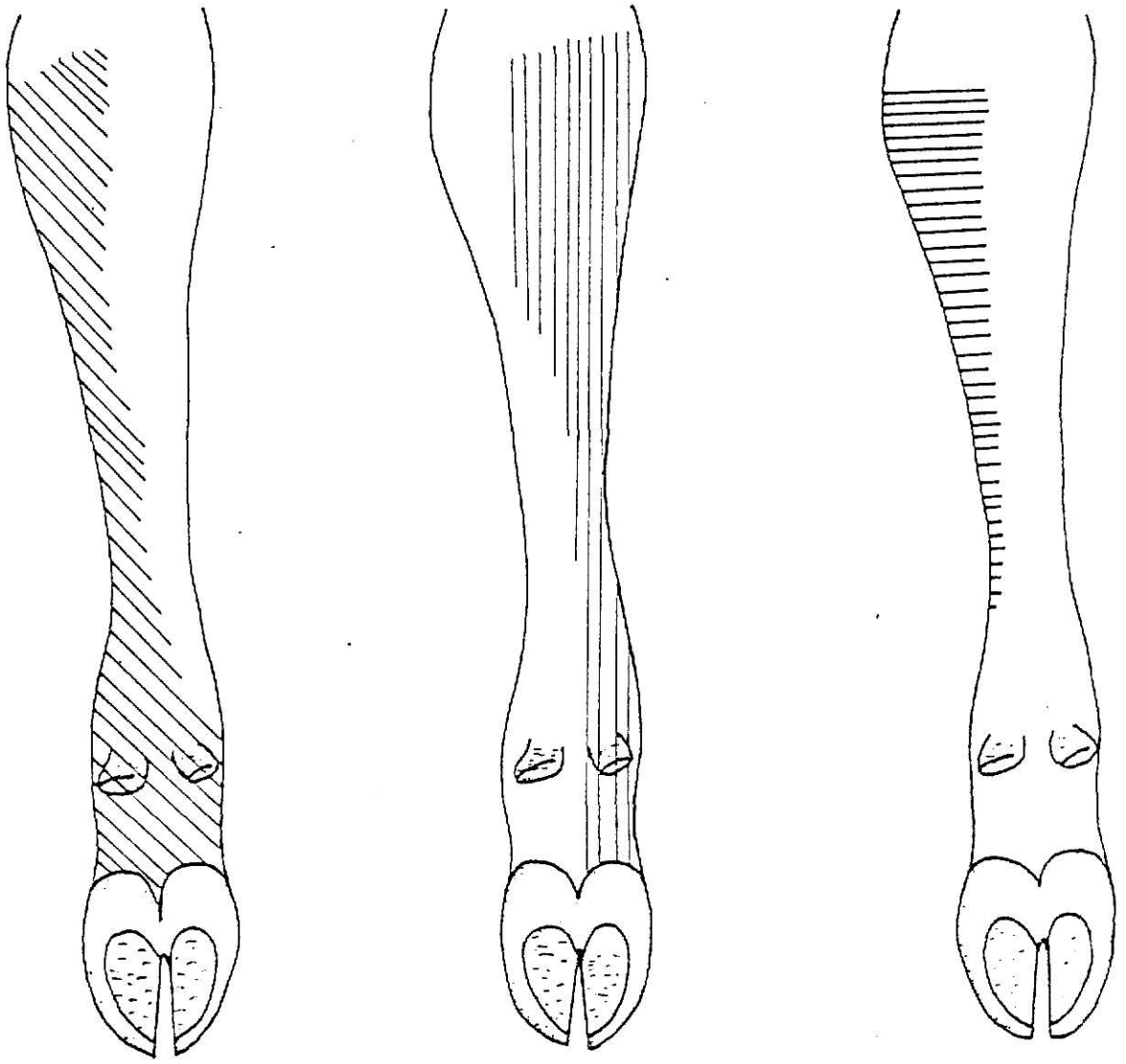
Sensory innervation on the dorsal surface of right manus of the bovine fetus.

Figure 5



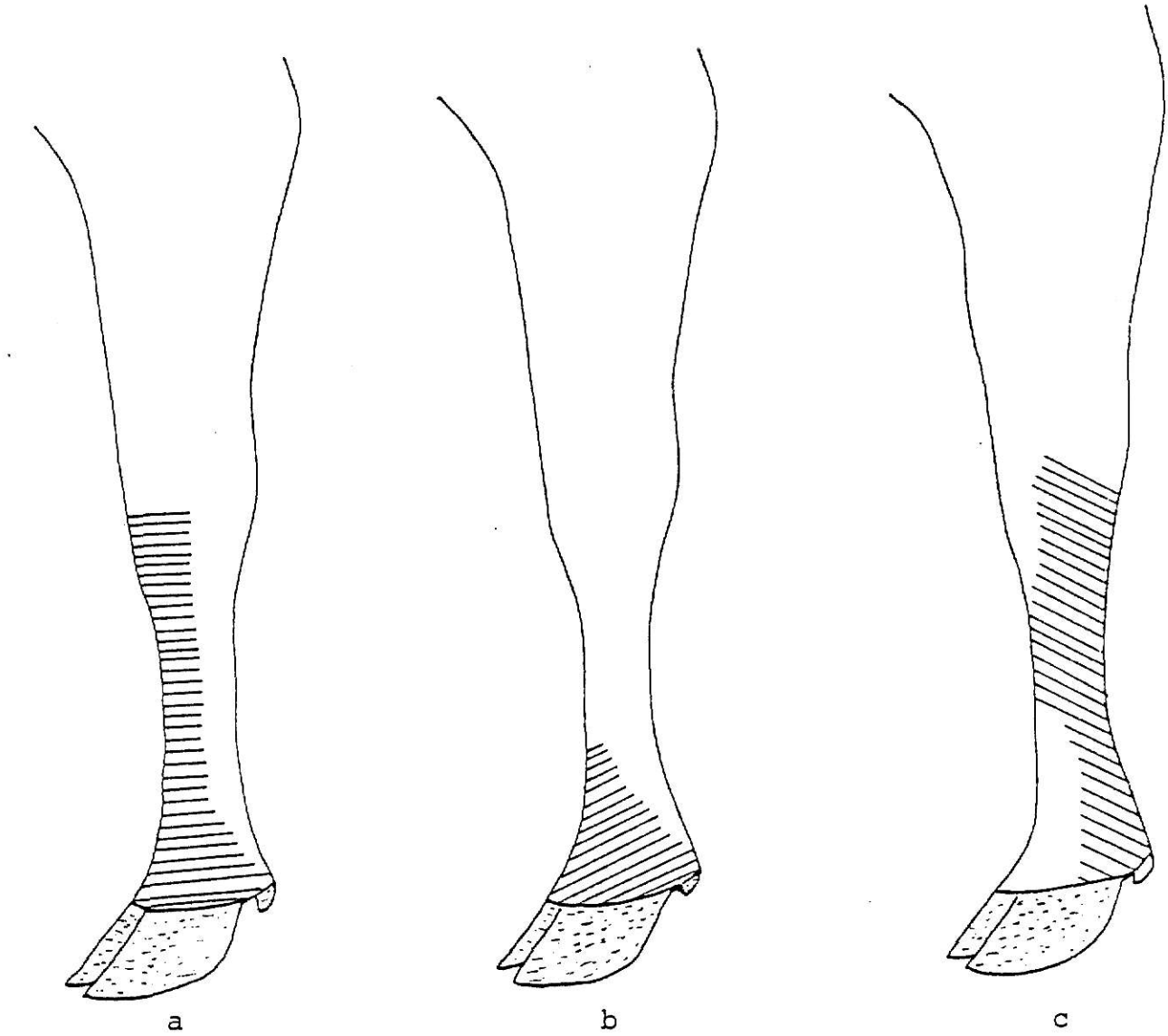
Sensory innervation on the palmar surface of right manus of the bovine fetus.

Figure 6



Sensory innervation on the medial surface of right manus of the bovine fetus.

Figure 7



Sensory innervation on the lateral surface of right manus of the bovine fetus.

Figure 8

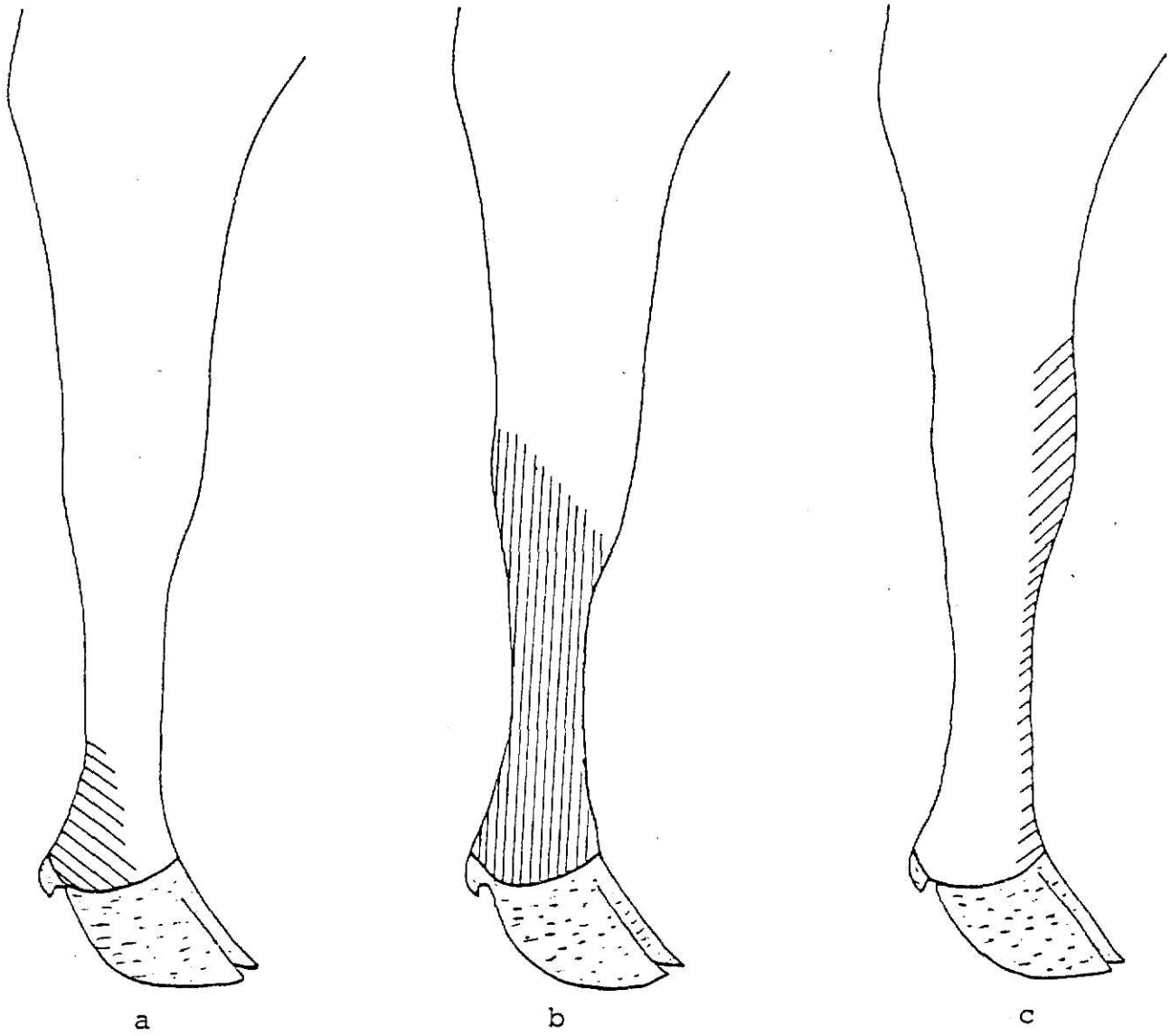


Figure 9: Transverse section through the carpal joint. x 5

A = Median nerve

B = Ulnar nerve (palmar branch)

C = Ulnar nerve (dorsal branch)

D = Radial nerve

E = Musculocutaneous nerve

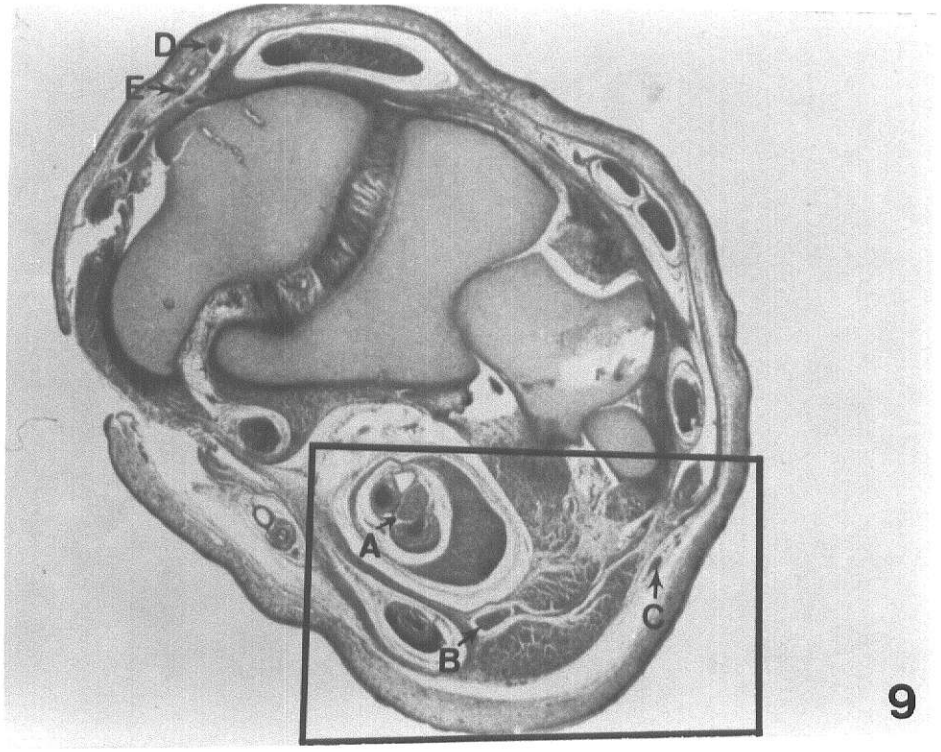
Figure 9a: Enlargement (x 20) of Figure 9. Look at the area enclosed in the rectangle.

A = Median nerve

B = Ulnar nerve (palmar branch)

C = Ulnar nerve (dorsal branch)

Note: The arrows without letters indicate the direction of one branch from (B) which innervates the distal ligament of the accessory carpal bone.



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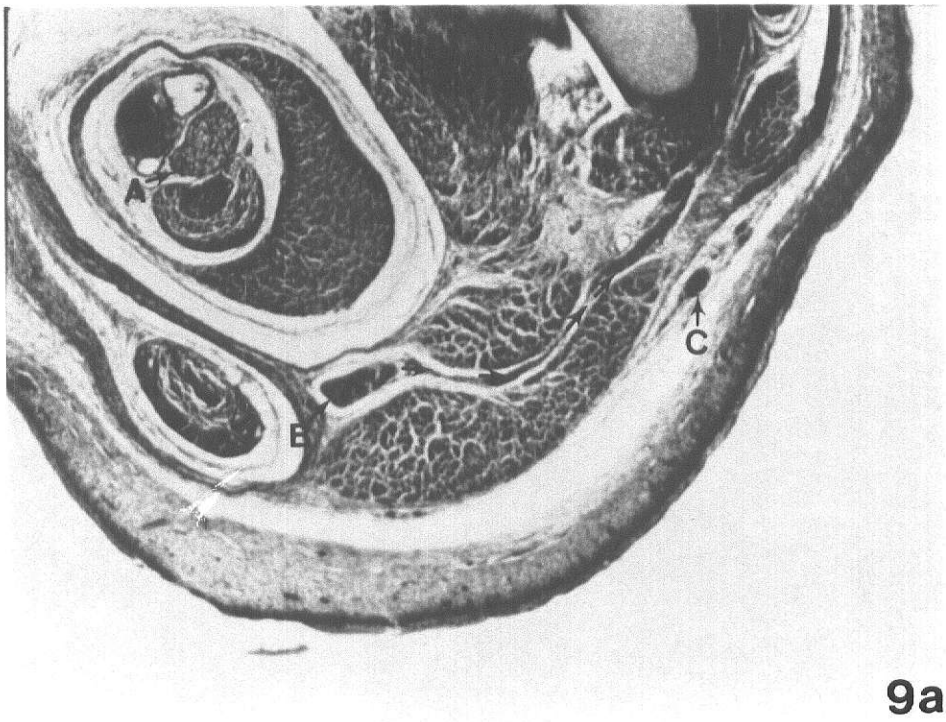


9a

Figure 10: Transverse section through the middle of the metacarpal bone. x 5

A = Palmar proper (axial) digital nerve III

B = Palmar common digital nerve II

C = Palmar proper (axial) digital nerve IV

D = Communicating branch

E = Ulnar nerve (palmar branch)

F = Ulnar nerve (dorsal branch)

G = Radial nerve

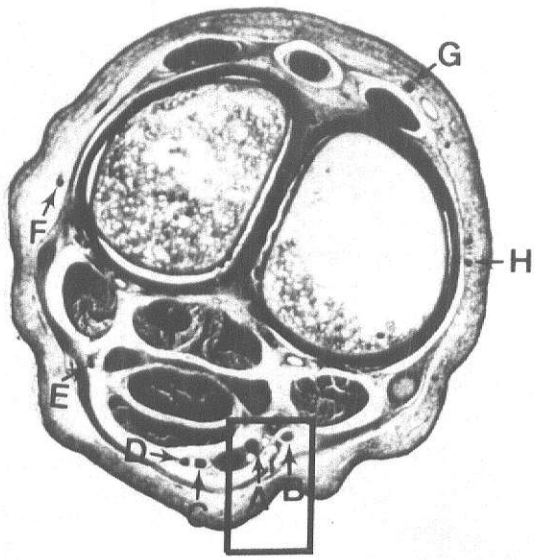
H = Musculocutaneous nerve

Figure 10a: Enlargement of the area enclosed in the rectangle in Figure 10. x 50

A = Palmar proper (axial) digital nerve III

B = Palmar common digital nerve II

D = Branch to the deep fascia and skin at the metacarpal bone from (B)



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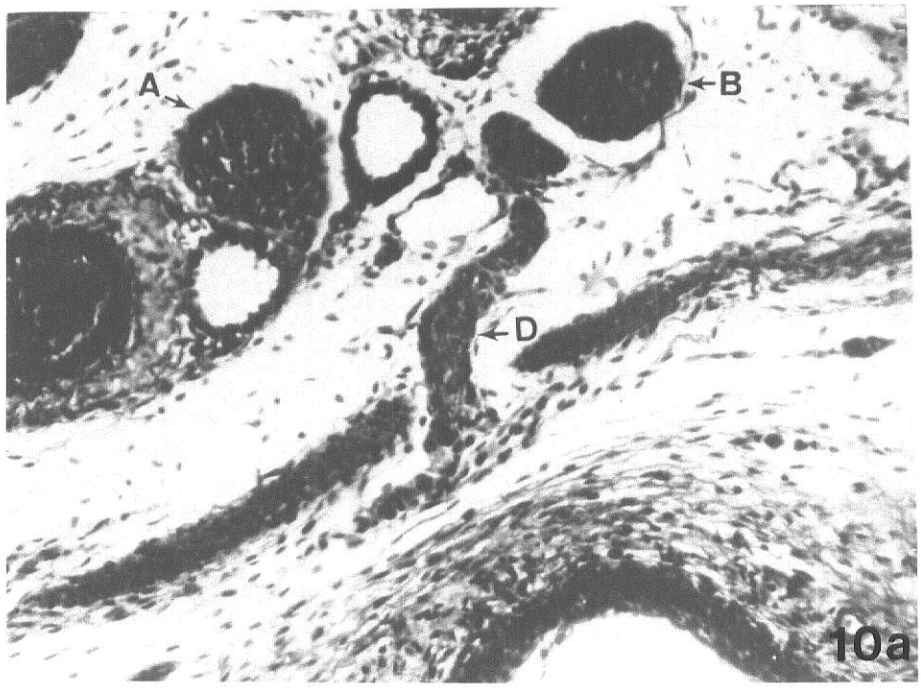


10a

Figure 11: Transverse section through the distal one-third of metacarpal bone. x 5

A = Palmar common digital nerve II

B = Palmar proper (axial) digital nerve III

C = Palmar proper (axial) digital nerve IV

D = Communicating branch which communicates with (E)

E = Ulnar nerve (palmar branch)

F = Ulnar nerve (dorsal branch)

G = Radial nerve

H = Musculocutaneous nerve.

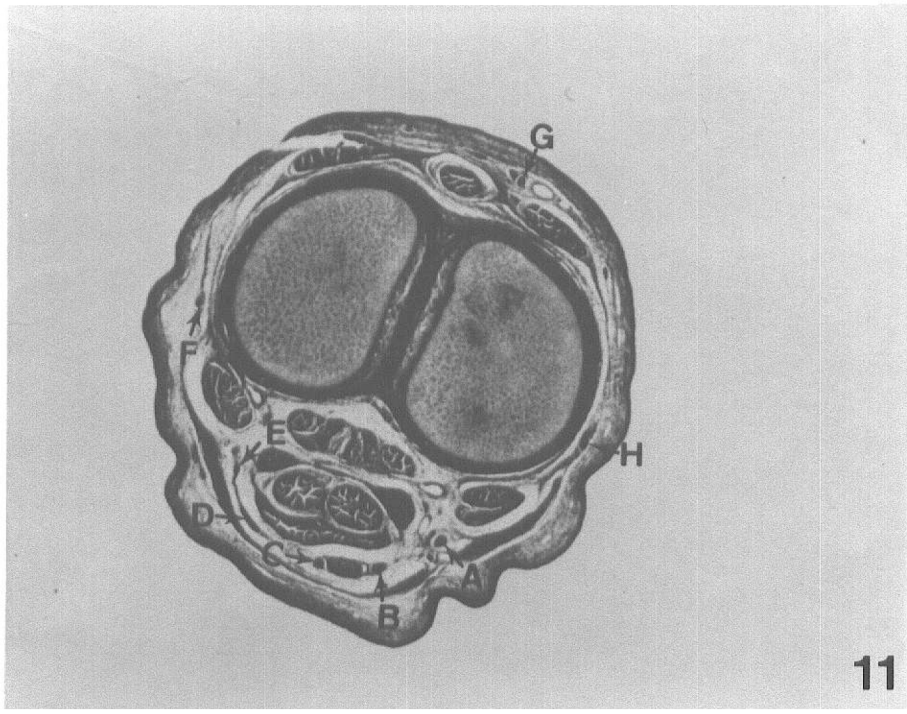
Figure 12: Transverse section through the proximal one-third of the metacarpal bone. x 5

A = Median nerve

B = Ulnar nerve (palmar branch)

C = Branch from (B) to the superficial digital flexor tendon

D = Branch from (B) to the interosseous muscle



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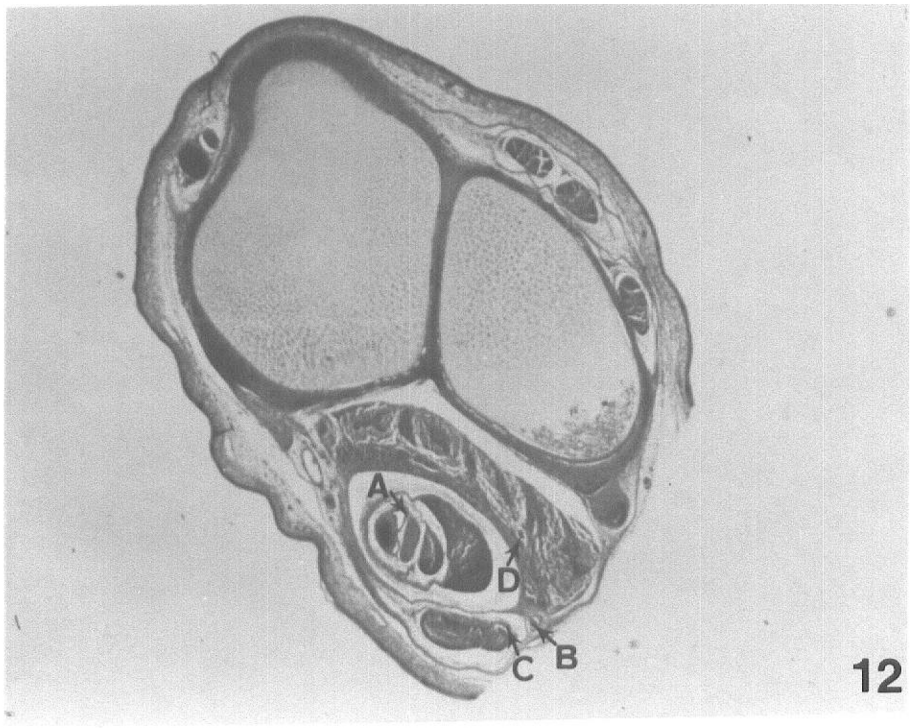

12

TABLES

Table No. 1 Innervation of deep structures of fetal bovine manus

	M N	PP Ab DN III	PP Ax DN III	PP Ax DN IV	PP Ab DN IV	UN PB	UN DB	R N	DP Ab DN III	DP Ax DN III	DP Ax DN IV	DP Ab DN IV	M C N
Carpal Sheath	+	-	-	-	-	-	-	-	-	-	-	-	-
Flexor Retinaculum	+	-	-	-	-	+	+	-	-	-	-	-	+
Extensor Retinaculum	-	-	-	-	-	-	+	+	-	-	-	-	+
Intra-articular Ligament (carpal joint)	-	-	-	-	-	+	-	-	-	-	-	-	-
Deep digital flexor tendon (proximal) of the metacarpal phalangeal joint	+	-	-	-	-	-	-	-	-	-	-	-	-
Superficial digital flexor tendon (proximal) to the metacarpalphalangeal joint	+	-	-	-	-	+	-	-	-	-	-	-	-
Interosseous muscle	-	-	-	-	-	+	-	-	-	-	-	-	-
Median Artery	+	-	-	-	-	-	-	-	-	-	-	-	-
Palmar carpal ligament	-	-	-	-	-	+	-	-	-	-	-	-	-
Distal ligament of the accessory carpal bone	-	-	-	-	-	+	-	-	-	-	-	-	-
Deep fascia of metacarpal bone	+	-	-	-	-	+	-	-	-	-	-	-	-
Common digital extensor tendon	-	-	-	-	-	-	-	+	-	+	+	-	-
Medial digital extensor tendon	-	-	-	-	-	-	-	+	+	-	-	-	-
Lateral digital extensor tendon	-	-	-	-	-	-	+	+	-	-	-	-	-
Fetlock joint (III digit)	+	+	+	-	-	-	-	+	+	-	-	-	+
Fetlock joint (IV digit)	+	-	-	+	+	+	+	+	-	-	-	+	+[1]
Proximal interdigital ligament	+	+	+	+	-	-	-	-	-	-	-	-	-
Distal interdigital ligament	+	+	+	+	-	-	-	-	-	-	-	-	-
Synovial sheath of deep digital flexor tendon	+	+	+	+	+	+	-	-	-	-	-	-	-
Synovial sheath of superficial digital flexor tendon	+	+	+	+	+	+	-	-	-	-	-	-	-
Pastern joint III	+	+	+	-	-	-	-	+	+	+	-	-	+
Pastern joint IV	+	-	-	+	+	+	+	+	-	-	+	+	+
Coffin joint III	+	+	+	-	-	-	-	-	-	-	-	-	-
Coffin joint IV	+	-	-	+	+	+	-	-	-	-	-	-	-
Navicular bursa	+	+	+	+	+	+	-	-	-	-	-	-	-
Deep digital flexor tendon distal to the metacarpalphalangeal joint	+	+	+	+	+	+	-	-	-	-	-	-	-
Superficial distal flexor tendon distal to the fetlock joint	+	+	+	+	+	+	-	-	-	-	-	-	-
Digital cushion	+	-	+	+	-	-	-	-	-	-	-	-	-
Perioplic and coronary corium	+	+	+	+	+	+	+	+	+	+	+	+	+
Laminar corium *	+	+	+	+	+	+	-	-	-	-	-	-	-
Corium of sole *	+	+	+	+	+	+	-	-	-	-	-	-	-
Corium of bulb *	+	+	+	+	+	+	-	-	-	-	-	-	-

1: the musculocutaneous nerve may have some influence through the radial nerve

*See table No. 2

Table No.2 Coriums of hoof

			MN	PP Ab DN III	PP Ax DN III	PP Ax DN IV	PP Ab DN IV	UN PB	UN DB	RN	DP Ab DN III	DP Ax DN III	DP Ax DN IV	DP Ab DN IV	MCN
D III	Prioplic corium of	toe	+	-	+	-	-	-	-	+	-	+	-	-	+[1]
		wall	+	+	+	-	-	-	-	+	+	-	-	-	+[1]
		bulb	+	+	+	-	-	-	-	-	-	-	-	-	-
	Laminar corium of	toe	+	+	+	-	-	-	-	-	-	-	-	-	-
		Lateral wall	+	+	+[2]	-	-	-	-	-	-	-	-	-	-
		Medial wall	+	+[3]	+	-	-	-	-	-	-	-	-	-	-
	Corium of	bulb	+	+	+	-	-	-	-	-	-	-	-	-	-
		sole	+	+	+	-	-	-	-	-	-	-	-	-	-
D IV	Perioplic Corium	toe	+	-	-	+	-	-	-	+	-	-	+	-	+[1]
		wall	+	-	-	+	+	+	+	-	-	-	+	+	-
		bulb	+	-	-	+	+	+	-	-	-	-	-	-	-
	Laminar Corium of	toe	+	-	-	+	+	+	-	-	-	-	-	-	-
		Lateral wall	+	-	-	+[4]	+	+	-	-	-	-	-	-	-
		Medial wall	+	-	-	+	+[5]	+[5]	-	-	-	-	-	-	-
	Corium of	bulb	+	-	-	+	+	+	-	-	-	-	-	-	-
		sole	+	-	-	+	+	+	-	-	-	-	-	-	-

1) Assumed that the radial and the musculocutaneous nerves exchange fibers this last one must have some influence on the perioplic and coronary corium.

2) May innervate the lateral wall.

3) May innervate the medial wall.

4) May innervate the lateral wall.

5) May innervate the medial wall.

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NERVE DISTRIBUTION OF THE FETAL BOVINE MANUS

by

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ABSTRACT

The nerve distribution of the fetal bovine manus was studied by gross dissection and from serial transverse sections.

Gross dissection was performed on ten fetal forelimbs which ranged from 150-200 days of age. The radial, musculocutaneous, median and ulnar nerves were identified and their cutaneous distribution was followed from above the carpus to and including the digits. Major emphasis was placed on the communicating branches occurring between these nerves to determine the overlapping zones of cutaneous innervation of the manus.

From gross dissection it was determined that the radial nerve supplied cutaneous innervation to the dorsolateral surface of the carpus, the dorsal aspect of the metacarpus, the dorsal region of the fourth digit and the dorsomedial region of the third digit. The musculocutaneous nerve furnished cutaneous innervation to the dorsomedial and palmaromedial aspects of the carpus, the dorsomedial surface of the metacarpus, the medial aspect of the metacarpophalangeal area, and the medial surface of the third digit. The median nerve supplied cutaneous innervation to the palmaromedial aspect of the carpus, the mediopalmar surface of the metacarpus, the entire palmar surface of the digits and the dorsal surface over the second phalanx of the third and fourth digits. The ulnar nerve, via its palmar branch, gave cutaneous innervation to the palmarolateral aspect of the manus and its dorsal branch supplied the dorsolateral region of the manus.

Serial transverse sections were made from seven fetal bovine manus ranging from 60 to 80 days old. The manus was sectioned at 9 or 15 μm, from the carpus to and including the digits. The smaller and deeper branches of the radial, musculocutaneous, median and ulnar nerves were identified and traced to the structures innervated. Communication among these nerves was also verified. It was learned that the smaller nerves and deeper structures could best be identified from the sections of the 80 days fetuses, cut at 15 μm. and stained with Hematoxylin and Eosin.

From the microscopic studies it was determined that the radial nerve innervated the extensor retinaculum, the distal end of the extensor carpiradialis tendon, the distal end of the extensor carpi obliquus tendon, the lateral digital extensor tendon, the medial digital extensor tendon, the common digital extensor tendon, the metacarpalphalangeal joint capsule, the proximal interphalangeal joint capsules and the perioplic and coronary corium of the third and fourth digits.

The serial sections showed that the musculocutaneous nerve gave deep innervation to the extensor retinaculum, the medial collateral ligament of the carpal joint, the flexor retinaculum, the metacarpophalangeal joint capsule, the proximal interphalangeal joint capsules, the perioplic corium, and the coronary corium. The musculocutaneous nerve was mainly associated with the third digit.

The histologic studies showed that the median nerve supplied deep innervation to the carpal sheath, the flexor

retinaculum, the median artery, the deep digital flexor tendon, the deep fascia of the metacarpal bone, the metacarpophalangeal joint capsule, the proximal and distal interphalangeal joint capsules, the synovial sheath of the superficial and deep digital flexor tendons, the proximal interdigital ligament, the distal interdigital ligament, the navicular bursa, the digital cushion, the perioplic corium, the coronary corium of both digits, the corium of the sole, the corium of the bulb and the laminar corium. This nerve was considered as the major nerve supply of the corium of the sole, wall and bulb of both digits.

Microscopic studies showed that the ulnar nerve gave deep innervation to the interosseous muscle, the palmar ligament of the carpal joint, the flexor retinaculum, the lateral collateral ligament of the carpal joint, the lateral digital extensor tendon, the extensor retinaculum, the superficial digital flexor tendon, the deep fascia of the metacarpal bone, the metacarpophalangeal joint capsule, the proximal and distal interphalangeal joint capsules, the synovial sheath of the superficial and deep digital flexor tendons, the navicular bursa, the perioplic corium, the coronary corium, the corium of the sole, the corium of the bulb and the laminar corium. Those structures innervated by the ulnar nerve below the fetlock joint are associated with the fourth digit.