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BACTERIAL STRANDS: A POSSIBLE ROLE IN FIRE BLIGHT¹

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ABSTRACT. Strands containing Erwinia amylovora, the causal organism of fire blight, plus unidentified material have been observed exuding from infected pear shoots. These bacterial strands appear on the surface of infected petioles and midveins within 24 hrs of infection. They may be blown readily by wind; they dissolve instantly in water; and they may provide a method of disease dissemination before the usual fire blight symptoms are evident.

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The presence of bacterial strands or pedicels, fruits, and shoots of pear infected by Erwinia amylovora Winslow et al. was reported in 1937 by Ivanoff and Keitt (4). They described these strands as composed of cells of the fire blight pathogen bound together by a cementing substance, more or less curved in shape, glistening, and usually colorless. Solubility in water was the major feature distinguishing such strands from down of cottonwood seeds, spider webs, and trichomes. They observed these strands both indoors and outdoors on inoculated blossom clusters.

Similar strands were observed on infected petioles, midveins, and stems of pears in Iowa. This paper presents evidence of their role in fire blight epiphytology in the Midwest.

MATERIALS AND METHODS

Isolates of E. amylovora were obtained from infected pear and apple shoots in the field or from infected pear fruits kept in an ordinary home freezer. Bacteria were cultured on nutrient agar slants. Bacterial strands of the pathogen were gathered from infected pear trees.

Inoculum was produced by transferring a wire loop full of an agar slant culture into 5 ml of nutrient broth and incubating at room temperature for 48 hrs.

One- or 2-year-old Bartlett pear trees were used for all experiments. In the greenhouse they were pruned and potted with field soil in 6-inch clay pots.

An oscillating fan, which produced a 14 mph air stream 2 ft from its center, was used to simulate wind.

Glycerol was the most satisfactory liquid in which to place bacterial strands for microscopic examination.

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PROCEDURES AND RESULTS

Pathogenicity of bacteria in these strands was determined by placing portions of strands in young leaf axils, in unfolding leaf buds, or by embedding them in petioles and observing subsequent fire blight symptoms. Pathogenicity was also demonstrated by placing strands in sterile nutrient broth and 48 hrs later injecting the turbid broth into pear petioles or shoot tips with hypodermic needles. Eight of 10 such inoculations produced infections.

The physical description of the strands presented by Ivanoff and Keitt matches that of the strands I observed. Measurements were made of 25 strands selected at random. Although considerable coiling and brittleness made accurate measurements difficult, strands ranged from 2.55 mm to 10.86 mm long. Strand diameters varied from 0.017 mm to 0.034 mm. By comparison pear trichomes measured from 0.728 mm to 3.75 mm in length and from 0.012 mm to 0.015 mm in diameter (Figs. 1-4).

When placed in water, these strands dissolved immediately into a suspension of bacteria, but if placed in glycerol, they retained their form for several hours. They could also be preserved for a comparable time in 100% alcohol.

Several strands were kept in a glass vial at 5°C for one year, then they were placed in nutrient broth and the bacteria incubated for 48 hrs at room temperature. The resulting culture was injected into 28 pear petioles of which 25 became infected. Infection was as rapid and progressive as any observed that resulted from fresh bacterial inoculum.

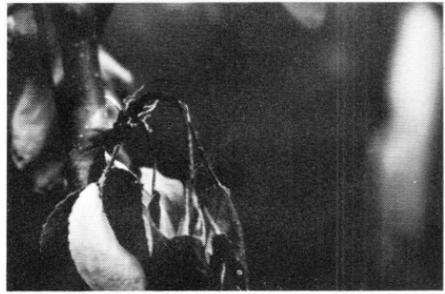
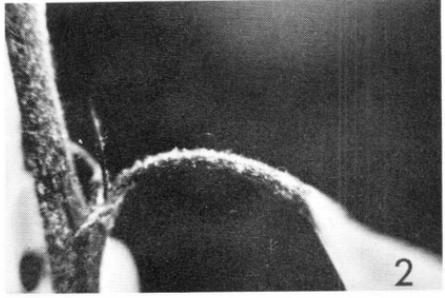
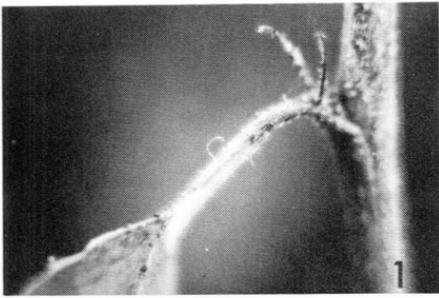
Several other strands, however, which were kept in a glass vial at room temperature for 2 years, were no longer virulent when similarly tested.

Sections of infected petioles with strands attached were placed in glycerol and scrutinized to determine the openings through which these bacterial strands might exude. Although strands always developed above a region high in bacterial population, their emergence through natural openings could not be confirmed. Strands were lost when serial sections of such material were processed in the conventional manner.

Portions of strands are readily airborne. A 14 mph wind of 5 min duration dislodged some of them from infected petioles and midveins in the greenhouse.

Following the observations of bacterial strands in the greenhouse, strands were searched for outdoors. Thousands of pear trees were examined including several hundred having obvious fire blight symptoms during two growing seasons. Strands were found only on 1 day following an extremely dry 2-day period; these were on two inoculated Bartlett pear trees. However, young pear shoots from uninoculated trees just beginning to show fire blight symptoms in the nursery blocks (and of many different varieties) were cut, and the cut ends were immersed in water in the laboratory. Four days later strands had formed on many of the petioles. Twenty of 37 shoots examined produced strands.

Because of their similarity to trichomes, strands are difficult to identify in early stages of development. Many of the strands were observed before the exudate commonly associated with necrotic tissues



Figures 1-4.

1. Bacterial strand in early stages of development.
2. Two strands in early stages of coiling having formed first loop.
- 3, 4. Advanced stage of strand development.

and often before any other fire blight symptoms. How soon after infection might bacteria from these strands appear on the plant surface? A partial answer was obtained by inoculating many petioles at their axils with a single drop of inoculum. At 24 hr intervals beginning 48 hrs after inoculation, one petiole from each of three shoots was cut 1/4-inch above the point of inoculation and dipped in nutrient broth under aseptic conditions. The exposed cut end, as well as the area to which the inoculum was applied, was not contacted by the broth. Following incubation this broth was inoculated into three other pear petioles. Uninoculated petioles from other shoots were used as checks. This procedure was repeated three times with slight modifications. In most cases virulent bacteria were recovered from the surface of infected petioles and midveins within 48 hrs of inoculation, 24-72 hrs before the usual symptoms were visible (Table 1). It is possible that bacteria may be on the surface in less than 48 hrs.

Table 1. Number of recoveries of E. amylovora from the surface of inoculated but symptomless pear leaves and petioles

Hrs. after inoculation	Number of inoculated petioles yielding <u>E. amylovora</u>		
	Tree A	Tree B	Tree C
48	2 ^{a)}	3	2
72	2	2	3
96	2	2	2
120	3	3	2

a) Three petioles inoculated in each case

DISCUSSION

Bacterial strands within tissues infected by E. amylovora have been reported by Nixon (6), Rosen (7), and others. They also reported the rapid development of these strands in all directions within the tissue including the direction of the epidermis. There is disagreement on whether these are organized pseudopod-like strands or merely the compression of bacteria in the intercellular spaces. Hildebrand (3) reported that the strands were a slime or ooze composed of encapsulated bacteria and that the capsules are not produced by the bacteria but are a plant material. Strands have not been observed in pure cultures.

Similar bacterial strands are pictured by Smith (8, p. 343) exuding from lenticels on mulberry stems, where they are sometimes found when mulberry is infected by Pseudomonas mori Stevens. He called these strands cirri. They seem analogous to the thicker bacterial strands found on pear stems. Smith tried unsuccessfully to infect mulberry with E. amylovora.

The occurrence of bacterial strands on fire blighted pear trees suggests some intriguing possibilities. Such strands could be wafted for miles by strong winds. A seasonal wave of infection, as suggested by Gossard and Walton (2), moving northward each spring similar to that observed in wheat rust epiphytotics might be possible. Many of the questions about initial infection could be explained by the presence of bacterial strands. But, though Ivanoff and Keitt (4) reported these over 30 years ago, little mention of such strands can be found in the literature with the exception of undocumented popular articles about fire blight.

I have observed strands only on young, rapidly growing, succulent shoots in which bacterial growth is reportedly very rapid. Indoors, where dry leaf surfaces can be maintained, the strands grow in length and coil freely much like a spring. These can be seen easily without a lens. In the nursery area of southwestern Iowa, dew, which occurs almost daily during the growing season, evidently dissolves these strands before they can attain enough length to be visible.

Bacterial strands dissolved in dew or rain could provide a ready source of inoculum for further spread of this disease. That this inoculum may be present on surface tissues soon after initial infection has been shown in experiments described earlier. Occasionally E. amylovora was recovered from the surface of leaves not directly inoculated but on shoots where other leaves had been inoculated 48 hrs previously. Explanation for this phenomenon was suggested by observations of Lewis and Goodman (5) who found that this bacterium moves much faster in host tissues than was formerly supposed. They recorded movement of bacteria in actively growing shoots of 15.25 cm in 6 hrs 42 min. They also found the pathogen in tissues which did not exhibit symptoms.

On the basis of these reports and observations one can conjecture that following invasion of succulent tissues there is rapid increase in bacterial numbers. The resulting increase in bacterial mass forces its extrusion through intercellular spaces radiating in many directions. By chance some of these bacteria may reach a substomatal cavity. The easiest exit under pressure of increasing bacterial numbers is through the stomatal opening. In the absence of exterior moisture, these bacteria would then be extruded outward through the stomate in the form of a strand like paste from a tube. Should water be on the exterior, the strand would dissolve as it was extruded.

The exudate more commonly observed on necrotic tissues would emerge later through rifts in the epidermis as the internal cells broke down, and their contents were released.

Whether in the form of strands or not, the presence of bacteria on the surface of recently infected plants provides a possibility for rapid dissemination of the fire blight pathogen by wind (1) or other agents before the typical disease symptoms are present.

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THE ARTERIAL BLOOD SUPPLY TO THE APPENDAGES OF THE
DOMESTIC PIG (SUS SCROFA DOMESTICUS)N.G. Ghoshal¹ and Robert Getty²

ABSTRACT. Seven thoracic and seven pelvic limbs of the domestic pig (Sus scrofa domesticus) have been dissected to describe the systematic topographical blood supply to the appendages. Breed, age, sex and body weight of the animals were not considered in this study. Already published work both in the English and foreign literature is being evaluated in view of our limited observations and the discrepancies existing therein are pointed out. An attempt has been made to evolve a uniform nomenclature for both blood vessels and nerves supplying these areas according to their topography. The findings are represented by composite illustrations.

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INTRODUCTION

The blood supply to the appendages of the domestic pig has been very inadequately described in the English veterinary anatomical textbooks. Frequently it has simply been compared with that of the horse without specific detailed description. Some detailed work, however, has been published in the foreign literature, often with conflicting statements.

Because the pig is frequently used as an experimental animal in various comparative medical research facilities in this country and abroad and in order to have a better understanding of the domestic species differences, if any, this investigation has been undertaken.

REVIEW OF LITERATURE

The blood supply of the thoracic and pelvic limbs of the domestic pig has been inadequately described in the standard anatomical textbooks and in articles, especially in the English literature (see bibliography). A detailed literature review will be incorporated with the results when applicable.

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MATERIALS AND METHODS

Seven thoracic and seven pelvic limbs of the domestic pig were dissected for the present study. The animals were sacrificed in the Department of Veterinary Anatomy, College of Veterinary Medicine, Iowa State University of Science and Technology, Ames, Iowa between June, 1964 and December, 1967. Breed, age, sex and body weight of the animals were not taken into consideration in this investigation.

The animals were anesthetized with pentobarbitol sodium and exsanguinated via a cannula from the right carotid artery. The blood vessels were perfused with normal saline solution to remove the blood clots. Later, the specimens were embalmed with the following solution: isopropyl alcohol, 60%; formalin, 4%; phenol, 6%; corn syrup, 2.5%; and water, 27.5%.

The arteries were injected with two parts of 2% ammonia water added to three parts of red latex (Cementex Co.). A pressure of approximately 120 mm mercury was used to inject the arteries. Sometimes the injectable mass was introduced by digital pressure with the help of a metal syringe. The specimens thus prepared were kept in a cooler for two to three days and were later dissected.

In order to evolve a uniform nomenclature for the blood vessels and the nerves supplying these regions and for comparative anatomical reasons the *Nomina Anatomica Veterinaria* (Pars prima), Hannover, 1963; list on *Arteriae Canis* as approved by the World Association of Veterinary Anatomists in Alfort, France in 1967; and the *Nomina Anatomica* (3rd ed.), 1966, have been used.

RESULTS

Part I. Thoracic Limb

A. axillaris

In the pig the thoracic limb was supplied by branches of the axillary artery. Similar to other domestic animals the axillary artery continued the subclavian artery (*A. subclavia*) following the separate origin of the *Ramus ascendens* and the *A. suprascapularis* (*s. A. transversa scapulae*) and extended beyond the first rib in the axillary space. According to Ellenberger and Baum (1943), Nickel and Wissdorf (1964) and Koch (1965) a *Truncus omocervicalis* (*s. A. cervicalis superficialis*) was absent in the pig. Kähler (1960) stated that the *A. transversa scapulae* (*s. A. suprascapularis*) arose as a branch of the *A. thoracica externa* in two cases. It wound around the cranial border of the first rib coursing caudovertrally to the interval between the *Mm. subscapularis* and *teres major*, where it split into three branches; (1) the *Truncus communis* for the *A. subscapularis* and the *A. thoracodorsalis*; (2) the *Truncus communis* for the *A. thoracoacromialis*, the *A. circumflexa humeri cranialis* and the *A. circumflexa humeri caudalis*; (3) the *A. brachialis*. Both (1) and (2) should be considered together as the *Truncus subscapularis* for comparative reasons. Sometimes the *A. thoracoacromialis* was seen to arise from the *A. subscapularis* approximately at the flexor surface of the shoulder joint similar to the observations of Merz (1911). The parent artery gave off the following branch:

1. The *A. thoracica externa* - The external thoracic artery coursed caudoventrally and supplied the *Mm. pectoralis ascendens*, *pectoralis transversus* and *pectoralis descendens*. It also sent a branch cranioventrad between the *Mm. pectoralis ascendens* and *pectoralis transversus* to furnish the *M. brachiocephalicus*. Kähler (1960) observed the *A. transversa scapulae* as arising from the *A. thoracica externa* in two cases.

Truncus communis for the *A. subscapularis* and the *A. thoracodorsalis*

This common trunk arose as one of the terminations of the axillary artery. It proceeded dorsocaudally between the *Mm. subscapularis* and *teres major* and, following a course of approximately 2 cm, split into two terminal branches. Before its division it gave off a slender twig to supply the *M. subscapularis*. This muscular branch arose in one specimen from the *A. subscapularis*, before the origin of the *A. thoracoacromialis* at the level of the *Collum scapulae*.

1. The *A. subscapularis* - The subscapular artery arose together with the *A. thoracodorsalis*. It coursed dorsocaudally between the *Mm. subscapularis* and *teres major* along the caudal border of the scapula. Near the middle of the caudal border of the scapula it released a branch caudally to vascularize extensively the *M. triceps brachii* (*Caput longum*). It continued farther proximally, gradually crossed over the caudal border of the scapula, appeared on the infraspinous fossa, and finally ramified inside the *M. infraspinatus* to the caudal angle of the scapular cartilage. According to Badawi (1959) and Nickel and Wissdorf (1964) it also detached small branches to the *Mm. rhomboideus*, *supraspinatus*, *deltoideus* and *teres minor* during its course. Merz (1911) stated that the *A. nutritia scapulae* also arose from the subscapular artery. During its course the following branches originated from it:

a. The *Rami musculares* - A muscular branch arose near the origin of the parent artery and passed dorsocranially over the medial surface of the *M. subscapularis* to ramify within same. In addition, a few other muscular branches left the parent vessel on its dorsal course to supply the *Mm. teres major*, *latissimus dorsi* and *subscapularis*.

b. The *A. circumflexa scapulae* - The circumflex scapular artery arose from the cranial aspect of the parent artery near the middle of the caudal border of the scapula. It passed between the *Mm. subscapularis* and *triceps brachii* (*Caput longum*) and finally entered the latter muscle. Badawi (1959) described the nutrient artery of the scapula as arising from it.

2. The *A. thoracodorsalis* - The thoracodorsal artery arose together with the *A. subscapularis* as one of the terminations of the axillary artery. It continued caudodorsally over the medial surfaces of the *Mm. teres major* and *latissimus dorsi*. Finally it split into two and disappeared in the interstices of the latter muscle. During its course it released the following branches:

a. The *Rami musculares* - The muscular branches were few in number, supplying the *Mm. teres major*, *latissimus dorsi* and *pectoralis ascendens*. According to Kähler (1960) it also furnished the *Mm. scalenus supracostalis* and *serratus ventralis* and, after piercing the *M. latissimus dorsi*, also the cutaneous muscle and the skin covering the preceding muscle.

Truncus communis for the A. thoracoacromialis, the A. circumflexa humeri cranialis and the A. circumflexa humeri caudalis

This common trunk was very large and arose as one of the terminations of the axillary artery. Following a course of approximately 2 cm between the Mm. teres major and subscapularis at first it gave off the cranial circumflex humeral artery and thereafter divided into the caudal circumflex humeral artery and thoracoacromial artery, at the level of the caudal limit of the head of the humerus.

1. The A. thoracoacromialis - DeVos (1965, p.51) incorrectly quoted Badawi (1959) stating that the latter author did not locate the A. thoracoacromialis in the pig (refer Badawi 1959, p.15). The thoracoacromial artery originated together with the cranial and caudal humeral arteries. In one case, it arose from the A. subscapularis on the flexor aspect of the shoulder joint, similar to the findings of Merz (1911). This artery was very strongly developed, passed dorsocranially along the deep face of the M. subscapularis and the medial surface of the scapula and slightly above the supraglenoid tubercle (s. tuber scapulae) it divided into three branches. The ascending branch coursed dorsocranial, extensively supplying the Mm. subscapularis and supraspinatus. Its descending branch was directed distocranial and furnished the Mm. supraspinatus, subscapularis and pectoralis ascendens. In addition, it also released a few twigs to vascularize the craniomedial aspect of the shoulder joint. The area of supply of the descending branch was taken over by a branch arising from the A. circumflexa humeri cranialis in one specimen. The third branch passed laterad between the Mm. subscapularis and supraspinatus, finally ramifying inside the latter muscle after splitting into ascending and descending branches. Badawi (1959) observed that the A. thoracoacromialis was poorly developed in three cases and ended inside the M. subscapularis.

2. The A. circumflexa humeri cranialis - The cranial circumflex humeral artery arose as the first branch from the parent trunk. Merz (1911) described it as originating from the A. circumflexa humeri posterior, but Martin (1923) and Ellenberger and Baum (1943) stated that it can also come from the A. brachialis. Badawi (1959) described a variable origin of the A. circumflexa humeri cranialis. He observed in four specimens that it arose together with the A. circumflexa humeri caudalis directly from the Truncus subscapularis. In four cases, it arose by a common trunk with the A. circumflexa humeri caudalis and the A. circumflexa scapulae cranialis from the Truncus subscapularis. In another four specimens it separated from the A. brachialis. It was a relatively strong branch, coursed somewhat distocranial between the two portions of the M. coracobrachialis. Here it split into two branches. One of them turned dorsocranially and supplied the Mm. coracobrachialis and pectoralis ascendens. Moreover, it furnished a few twigs to the tendon of the M. supraspinatus and to the cranial and medial aspects of the shoulder joint. The other branch was relatively slender and supplied the Mm. coracobrachialis and biceps brachii. Close to its origin it gave off delicate twigs to vascularize the Mm. subscapularis and teres major close to their insertions. A few twigs were also destined to supply the caudomedial aspect of the shoulder joint. In one case, the A. circumflexa humeri cranialis, before coursing between the two portions of the

M. coracobrachialis, gave off a long slender branch which took over the area of supply of the descending branch of the *A. thoracoacromialis*.

3. The *A. circumflexa humeri caudalis* - The caudal circumflex humeral artery was the other branch of the common trunk which passed laterad between the insertions of the *Mm. teres major* and *subscapularis*. It coursed along the caudal aspect of the shoulder joint and appeared deep to the *M. deltoideus* where it split into two branches. Merz (1911) described it as arising from the axillary artery.

a. The *Ramus proximalis* - The proximal branch split into several strong muscular twigs along the caudolateral aspect of the shoulder joint. On its course it gave off two ascending and two descending twigs. The ascending twigs supplied the *Mm. triceps brachii* (*Caput longum*), *deltoideus*, *teres minor* and *infraspinatus*. Its descending twigs arose 1 cm apart and, after repeated branching, vascularized extensively the *M. brachialis*. Its main continuation proceeded farther and near the rim of the glenoid cavity again split in two. One twig passed deep to the *M. infraspinatus* and ramified inside it, while the other coursed distocranial and supplied the *Mm. deltoideus*, *teres minor* and *infraspinatus*. It also released small twigs to supply the lateral and cranial aspects of the shoulder joint capsule and the *M. subscapularis*.

b. The *Ramus distalis* (*A. collateralis radialis proximalis*) - The distal branch was the direct continuation of the parent vessel. It coursed distocaudally in the space between the *Mm. brachialis* and *triceps brachii* (*Caput longum*). Approximately 1 cm after its origin it released a strong muscular branch which coursed dorsally and entered the *M. triceps brachii* (*Caput longum*). Near the middle of the arm it gave off two branches—the cranial branch was long and slender and mainly supplied the *M. brachialis*, while the caudal branch was relatively strong and coursed caudodorsally inside the *M. triceps brachii* (*Caput longum*). The main branch continued distally and, at the level of the elbow joint, released a few twigs to furnish the *Mm. brachialis*, *anconeus*, *triceps brachii* (*Caput laterale*) and the origin of the *M. extensor carpi radialis*. One of these branches proceeded distocranial between the *Mm. brachialis* and *extensor carpi radialis* and communicated with a branch of the distal collateral radial artery on the flexor surface of the elbow joint, similar to the observations of Badawi (1959), Nickel and Wissdorf (1964) and Koch (1965). According to them a long slender cutaneous branch extended from the *Ramus cranialis* which passed over the elbow joint and reached the cranial aspect of the forearm after coursing between the insertions of the *Mm. brachialis* and *extensor carpi radialis*. Distal to the carpus it opened, according to Badawi (1959) and Koch (1965), in the *A. metacarpica dorsalis* II or III, or according to Nickel and Wissdorf (1964) in the *A. metacarpica dorsalis profunda* II or III and IV.

A. brachialis

The brachial artery was the other terminal branch of the axillary artery. It continued in the region of the arm where it descended accompanying the *N. medianus*. It lay at first between the *M. coracobrachialis* and *triceps brachii* (*Caput mediale*) and then between the *M. biceps brachii* and the flexor surface of the elbow joint, beneath the *Mm. pectoralis descendens* and *pronator teres*. Slightly below the elbow joint it detached

caudally, 1 cm apart, two muscular branches which coursed beneath the *M. flexor carpi radialis*. Both vascularized the *Mm. pronator teres*, *flexor carpi radialis* and *flexor digitorum (digitalis) superficialis*. Approximately 3 cm below the elbow joint the brachial artery gave off the common interosseous artery and continued distally as the median artery. Originating from the brachial artery were:

1. The *Rami musculares* - The muscular branches which were of variable size and origin, departed from the parent vessel to supply the *Mm. coracobrachialis* and *pectoralis ascendens*.

2. The *A. profunda brachii* - The deep brachial artery was of considerable size and left the parent artery from its caudal face. Sometimes this artery was not well developed, similar to the observations of Ellenberger and Baum (1943), and was represented by a few tiny delicate twigs instead. In the latter case, its area of supply was partly taken over by the distal ramus of the *A. circumflexa humeri caudalis*, in agreement with Ellenberger and Baum (1943); Martin (1923) described a twig of the brachial artery as the *A. profunda brachii*. According to Merz (1911) the deep brachial artery was apparently absent and, therefore, the *A. collateralis media* arose directly from the brachial artery. He further stated that the area of supply of the deep brachial artery was taken over by the *A. collateralis radialis* which coursed with the *N. radialis* and was distributed in the *Rete cubiti dorsale*. It coursed caudad for approximately 2 cm and split into at least three twigs. One of them entered the medial head of the *M. triceps brachii*, whereas the rest vascularized the long head of the preceding muscle extensively.

3. The *Ramus muscularis* - A strong muscular branch was constantly seen to leave the cranial aspect of the parent vessel near the middle of the arm. Close to its origin it detached a slender twig to furnish the *M. triceps brachii (Caput mediale)*. The main branch then continued distocranial and entered the belly of the *M. biceps brachii* which it vascularized extensively.

4. The *A. collateralis ulnaris* - The collateral ulnar artery left the caudal aspect of the parent vessel slightly above the level of the olecranon. Following a course of approximately 2 cm it split into three main branches. The proximal branch divided variably and essentially supplied the *M. triceps brachii (Caput mediale)*; the middle branch coursed distocranially and gave off a twig to the *M. tensor fasciae antebrachii* and ulnar and humeral heads of the *M. flexor digitorum (digitalis) profundus*. In addition, it furnished twigs to supply the caudomedial aspect of the elbow joint capsule. A long slender branch continued farther, accompanying the *N. ulnaris*, in the groove bounded by the *Mm. flexor carpi ulnaris* and *flexor digitorum (digitalis) profundus*. Slightly above the accessory carpal bone it opened in the superficial palmar branch of the caudal interosseous artery. The distal branch, soon after its separation, split into several delicate twigs. Some of them supplied the *Mm. tensor fasciae antebrachii* and *pectoralis transversus* and the rest ramified in the fascia and skin on the caudal aspect of the forearm to the carpus.

5. The *A. collateralis radialis distalis* - The distal collateral radial artery originated from the lateral aspect of the parent artery on the flexor surface of the elbow joint. It passed laterad deep to the *Mm. biceps brachii* and *brachialis* where it released a few twigs to supply the

preceding muscles and the *Mm. brachiocephalicus* and *pectoralis transversus*. It also released a few twigs to supply the cranial aspect of the elbow joint capsule. Here it divided into a proximal and a distal branch.

a. The *Ramus proximalis* continued along the flexor surface of the elbow joint and between the *M. brachialis* and origin of the *M. extensor carpi radialis*, where it anastomosed with a branch of the distal branch of the caudal circumflex humeral artery, similar to the findings of Badawi (1959), Nickel and Wissdorf (1964) and Koch (1965). During its course it also furnished twigs to the adjacent muscles.

b. The *Ramus distalis* was of considerable size, coursed distally and soon split in two. One branch extensively supplied the *M. extensor carpi radialis* and the medial belly of the *M. extensor digitorum (digitalis) communis*, while its other branch extended deep to all three heads of the preceding muscle, vascularized them and communicated with the recurrent interosseous artery given off by the *A. interossea cranialis* (*A. interossea dorsalis* of Badawi 1959; Nickel and Wissdorf 1964; Koch 1965).

6. The *Ramus muscularis* - A long slender muscular branch left the parent vessel opposite to the origin of the common interosseous artery before coursing through the interosseous space of the forearm. This branch essentially supplied the *M. pronator teres*. Distally, it split and opened in the median and radial arteries within the middle-third of the forearm.

7. *A. interossea communis* - The common interosseous artery was the last branch of the brachial artery, arising at the level of the upper part of the interosseous space of the forearm. It gave off the following branches:

a. The *A. interossea caudalis* - The caudal interosseous artery was well developed and assumed the distal extension of the parent artery. It coursed distally inside the interosseous space of the forearm, supplied small twigs to the periosteum of the radius, and, at the distal third of the forearm, divided into a dorsal and a palmar branch.

The dorsal branch coursed deep to the *M. abductor primi (pollicis) longus* and appeared superficially slightly above the carpus. On the cranial aspect of the carpus it split in a variable manner and assisted in the formation of the *Rete carpi dorsale*. From this, small twigs extended to the capsule of the carpal joint and the neighboring extensor tendons. From the *Rete carpi dorsale* arose the *A. metacarpea dorsalis III* which coursed distally inside the interval between the 3rd and 4th metacarpals and received the *Ramus perforans proximalis* from the proximal (deep) palmar arch within the proximal third of this region. It continued farther and released twigs to the neighboring extensor tendons and periosteum. Slightly above the fetlock joints of the principal digits, it received the *Ramus perforans distalis* and descended over them as the *A. digitalis dorsalis communis III* which, near the middle of the proximal phalanx, released the dorsal proper digital arteries of the 3rd and 4th digits (*Aa. digitales III et IV dorsales propriae*). It continued inside the interdigital space, split in two and communicated with the *Aa. digitales III et IV palmares propriae*—the terminal branches of the *A. digitalis palmaris communis III* via the *Rami communicantes*. Lechner (1934), Ellenberger and Baum (1943), Bruni and Zimmerl (1951), Sisson and Grossman (1953),

Bourdelle and Bressou (1964), and Dobberstein and Hoffmann (1964) described that Aa. metacarpeae dorsales II, III et IV arose from Rete carpi dorsale. According to them the Aa. metacarpeae dorsales united with the corresponding palmar arteries at the distal end of the metacarpus and gave origin to the Aa. digitales communes II, III et IV. On the other hand, similar to the observations of Badawi (1959) and Koch (1965), we noticed that the Aa. digitales dorsales communes II et IV arose from the Aa. metacarpeae palmares II et IV, respectively. However, Baum (1907) indicated that the A. metacarpea dorsalis II et IV instead of arising from the Rete carpi dorsale may originate from the corresponding volar (palmar) arteries. Similarly, Schwarze and Schröder (1964) mentioned that in many cases the Aa. metacarpicae volares profundae II, III et IV may give rise to the corresponding dorsal branches (Aa. metacarpicae dorsales II, III et IV).

The palmar branch, soon after its separation, again divided into a superficial and a deep branch. The superficial palmar branch gave off some twigs which emerged in front of the tendon of insertion of the M. ulnaris lateralis and supplied the fascia and skin on the palmarolateral aspect of the carpus. The superficial palmar branch continued mediad deep to the preceding muscle to which it furnished some twigs. Near the accessory carpal bone it received an anastomosis with a branch originating from the distal branch of the A. collateralis ulnaris. At this site it released a slender branch to supply the M. flexor digitorum (digitalis) superficialis at the level of the accessory carpal bone and the flexor tendons to which it supplied a few twigs. Approximately 3 cm below the accessory carpal bone it released an anastomotic branch which joined a similar branch from the deep branch of the radial artery to constitute the proximal (deep) palmar arch (Arcus palmaris proximalis profundus). At the level of the anastomotic branch it gave off the A. digitalis dorsalis communis IV which extended through the fourth interdigital space and appeared on the dorsal aspect of the foot, similar to the observations of Badawi (1959) and Koch (1965). The latter vessel, near the fetlock joint of the 5th digit, split into two dorsal proper digital arteries of the 4th and 5th digits (Aa. digitales IV et V dorsales propriae). The main continuation of the superficial palmar branch gave off a long slender twig to furnish the flexors, adductors and abductors of the 5th digit and a Ramus communicans to the A. digitalis palmaris communis IV, close to its origin from the A. digitalis palmaris communis III.

The rest of this branch coursed between the Mm. interossei and the metacarpus as the A. metacarpea palmaris IV and joined the Aa. metacarpeae palmares II et III to form the distal (deep) palmar arch (Arcus palmar distalis profundus).

The deep palmar branch of the caudal interosseous artery passed deep and supplied the caudal aspect of the carpus and the adjoining ligaments.

b. The A. interossea cranialis - The cranial interosseous artery, following division within the interosseous space of the forearm, passed craniodistally deep to the digital extensors. It was a relatively slender vessel and, after coursing over the M. abductor primi (pollicis) longus, contributed in the formation of the Rete carpi dorsale. It gave off the following artery during its passage through the interosseous space of the forearm.

(1) The *A. interossea recurrens* - The recurrent interosseous artery originated from the cranial interosseous artery at the level of the upper part of the interosseous space of the forearm. It passed dorsocranial and immediately divided into two branches. Both of them vascularized the *M. extensor digitorum (digitalis) lateralis*, all the heads of the *M. extensor digitorum (digitalis) communis*, and the *M. abductor primi (pollicis) longus*. One of these twigs stretched deep to the preceding muscles and anastomosed with a branch from the distal branch of the distal collateral radial artery.

A. mediana

The median artery was the distal extension of the brachial artery beyond the origin of the common interosseous artery. It continued distally beneath the *Mm. pronator teres* and *flexor carpi radialis* along the caudomedial aspect of the radius. Within the middle-third of the forearm it received a delicate twig arising from the common interosseous artery before its course through the interosseous space of the forearm. It descended through the carpal canal beneath the *flexor retinaculum*. Here it gave off a slender twig which, after describing an arch around the tendon of insertion of the *M. flexor carpi radialis*, joined the radial artery. It extended farther and, near the middle of the metacarpus received the distal extension of the radial artery, thus constituting the distal (superficial) palmar arch (*Arcus palmaris distalis superficialis*). The resulting arterial trunk continued as the third common palmar digital artery (*A. digitalis palmaris communis III*). Originating from the parent artery were:

1. The *Ramus muscularis* - A muscular branch arose from the caudal aspect of the parent artery, approximately 3 cm above the carpus, and vascularized the *M. flexor digitorum (digitalis) superficialis*.

2. The *A. radialis* - The radial artery originated from the parent vessel near the middle of the forearm and coursed distally between the caudomedial aspect of the radius and the *M. flexor carpi radialis*. Slightly above the carpus it received the slender muscular branch which arose from the brachial artery, opposite the origin of the common interosseous artery. The radial artery descended farther along the palmaromedial aspect of the carpus. Slightly below same it received a branch from the median artery winding around the tendon of insertion of the *M. flexor carpi radialis*. A little below the base of the 2nd metacarpal bone it gave off the *Ramus profundus*, continued farther and, near the middle of the 2nd metacarpal bone, divided into two branches. The lateral branch joined the median artery to form the distal (superficial) palmar arch (*Arcus palmaris distalis superficialis*). The medial branch gave a *Ramus communicans* to the *A. digitalis palmaris communis II* arising from the *A. digitalis palmaris communis III* and then extended as the *A. digiti II palmaris medialis*. Arising from the radial artery were:

a. The *Rami musculares* - Very tiny twigs supplying the *Mm. pronator teres* and *flexor digitorum (digitalis) superficialis*.

b. The *Rami carpei dorsalia* - The branches to the dorsal rete of the carpus were usually two in number. They arose variably quite apart from each other, one above and the other below the carpus.

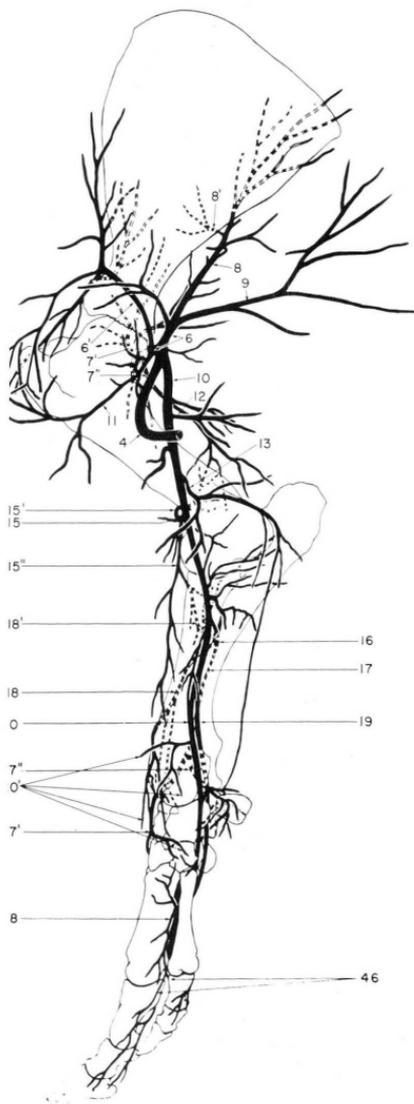
c. The *Ramus profundus* - The deep branch separated from the parent

vessel, slightly below the base of the 2nd metacarpal bone. Approximately 1 cm following its origin it gave off an anastomotic branch which coursed laterad between the Mm. interossei and metacarpal bones where it joined a similar branch from the superficial palmar branch of the caudal interosseous artery to constitute the proximal (deep) palmar arch. Small twigs arose from this arch which supplied the Mm. interossei and the caudal aspect of the carpus by means of an ascending twig. The third palmar metacarpal artery originated from this vascular arch which, after coursing distally, joined the Aa. metacarpeae palmares II et IV to form the distal (deep) palmar arch. From the latter arose the Ramus perforans distalis which traversed the third intermetacarpal space and communicated with the A. metacarpea dorsalis III slightly above the fetlock joint.

The deep branch subsequently split into the A. digitalis dorsalis communis II and the A. metacarpea palmaris II, similar to the findings of Badawi (1959) and Koch (1965). However, Badawi (1959), in two out of twelve specimens, observed the A. metacarpica dorsalis II to arise from the Ramus superficialis of the A. medianoradialis (s. A. radialis). Baum (1907) also mentioned that the A. metacarpea volaris profunda II very often detached from the dorsal arteries. The A. digitalis dorsalis communis II passed through the second intermetacarpal space and appeared on the dorsal aspect of the foot. After emerging it released a few twigs to the Rete carpi dorsale and later continued distally. Near the fetlock joint it divided into two dorsal proper digital arteries of the 2nd and 3rd digits (Aa. digitales II et III dorsales propriae). The second palmar metacarpal artery continued farther and joined the Aa. metacarpea palmares III et IV at the distal deep palmar arch. During its course it furnished a few twigs to the flexors, adductors and abductors of the 2nd digit.

The A. digitalis palmaris communis III

The third common palmar digital artery was the distal extension of the median artery beyond the distal (superficial) palmar arch. It extended distally and on the palmar aspect of the fetlock joint it received the Ramus anastomoticus from the distal deep palmar arch. Slightly below the fetlock joint it gave off a short common trunk which soon split, anastomosed with a slender branch arising from the Ramus communicans of the Aa. digitales III et IV palmares propriae of the respective side and finally supplied the adjoining surfaces. Near the middle of the proximal phalanx it divided into two palmar proper digital arteries of the 3rd and 4th digits (Aa. digitales III et IV palmares propriae). Each of them gave off the Ramus communicans which coursed below the flexor tendons along the flexor surface of the proximal phalanx and joined the A. digiti III palmaris propria and the A. digiti IV palmaris propria. Following their confluence, they continued dorsally and gave reinforcing branches to the A. digiti III dorsalis propria and the A. digiti IV dorsalis propria. From the Rami communicantes slender branches also arose which passed proximally and anastomosed with branches mentioned previously. Each Ramus communicans gave off a branch dorsad and communicated with the branches of the A. digitalis dorsalis communis III inside the interdigital space. Both the Aa. digitales III et IV palmares propriae de-



- 4. A. axillaris
- 6. Truncus subscapularis
- 6'. A. thoracoacromialis
- 7'. Ramus proximalis of A. circumflexa humeri caudalis
- 7''. Ramus distalis (A. collateralis radialis proximalis) of A. circumflexa humeri caudalis
- 8. A. subscapularis
- 8'. A. circumflexa scapulae
- 9. A. thoracodorsalis
- 10. A. brachialis
- 11. A. circumflexa humeri cranialis
- 12. A. profunda brachii
- 13. A. collateralis ulnaris
- 15. A. collateralis radialis distalis
- 15'. Ramus proximalis
- 15''. Ramus distalis
- 16. A. interossea communis
- 17. A. interossea caudalis
- 17'. Ramus dorsalis
- 17''. Ramus palmaris
- 18. A. interossea cranialis
- 18'. A. interossea recurrens
- 19. A. mediana
- 20. A. radialis
- 20'. Rami carpei dorsalia
- 28. A. digitalis dorsalis communis II
- 46. Aa. digitales II et III dorsales propriae

Figure 1. The arterial blood supply to the thoracic limb of the domestic pig via axillary artery (A. axillaris). Medial view (schematic).

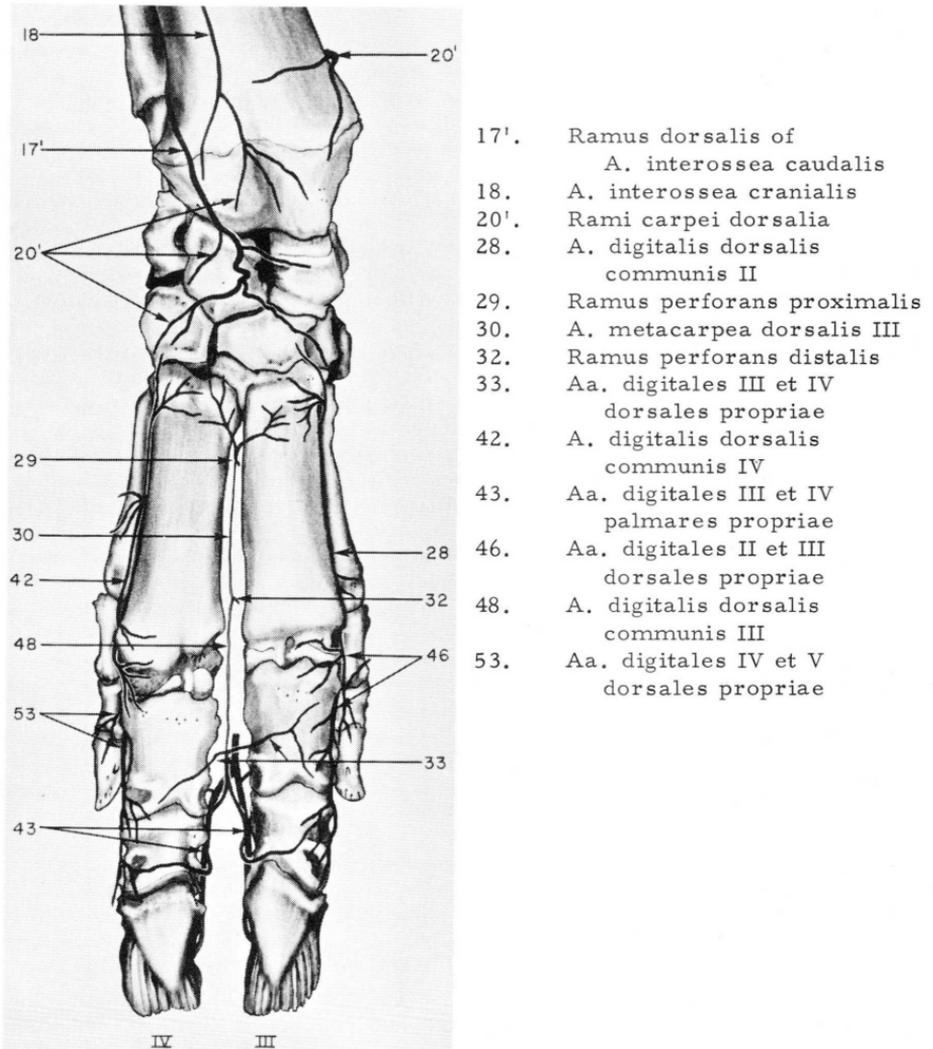
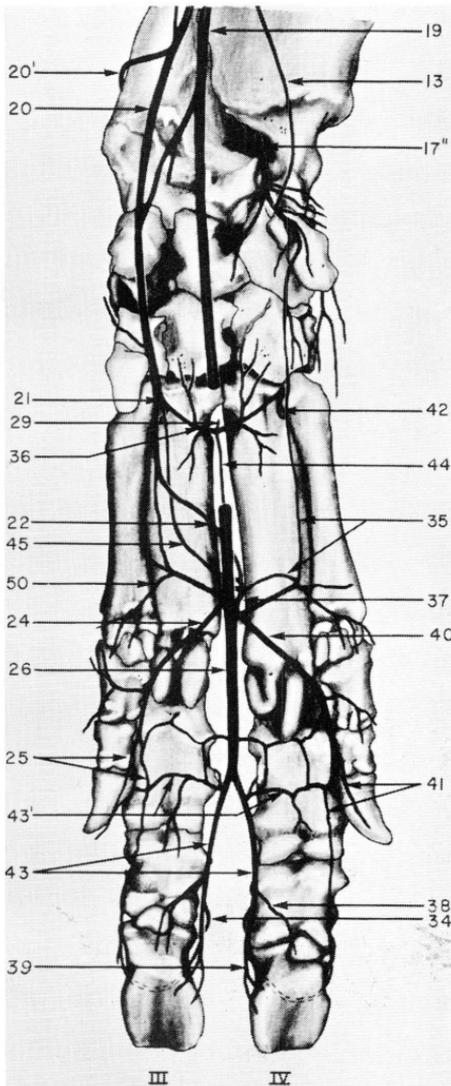


Figure 2. Arteries of the distal part of right thoracic limb of the domestic pig. Dorsal view (schematic).



13. Distal continuation of
A. collateralis ulnaris
- 17''. Ramus palmaris of
A. interossea caudalis
19. A. mediana
20. A. radialis
- 20'. Ramus carpeus dorsalis
21. Ramus profundus
22. Arcus palmaris distalis
superficialis
24. A. digitalis palmaris
communis II
25. Aa. digitales II et III
palmares propriae
26. A. digitalis palmaris
communis III
34. A. coronaria
35. A. metacarpea palmaris IV
36. Arcus palmaris proximalis
profundus
37. Arcus palmaris distalis
profundus
38. Ramus pulvinus distalis
39. Ramus palmaris
40. A. digitalis palmaris
communis IV
41. Aa. digitales IV et V
palmares propriae
42. A. digitalis dorsalis
communis IV
43. Aa. digitales III et IV
palmares propriae
- 43'. Rami communicantes
44. A. metacarpea palmaris III
45. A. metacarpea palmaris II
50. A. digiti II palmaris medialis

Figure 3. Arteries of the distal part of right thoracic limb of the domestic pig. Palmar view (schematic).

scended along the interdigital surface of the main digits and finally divided into three branches: one of them supplied the bulb (Ramus pulvinus distalis), the others supplied the palmar surface and the corium of the distal phalanx (Ramus palmaris). Their continuation passed distally and released the A. coronaria and entered the distal phalanx to form the terminal arch. The A. coronaria extended dorsad along the medial surface of the middle phalanx and furnished the fascia and skin of the neighboring area. Badawi (1959) described a Ramus dorsalis arising from the digital arteries before they entered the distal phalanx. It supplied the corium by means of ascending and descending branches.

On its course the third palmar common digital artery released the following branches:

1. The A. digitalis palmaris communis II - The second palmar common digital artery arose from the parent vessel on the palmar aspect of the fetlock joint. Near its origin it received the Ramus communicans from the radial artery and then divided into two palmar proper digital arteries of the 2nd and 3rd digits (Aa. digitales II et III palmares propriae). The A. digiti III palmaris propria received a Ramus communicans from the axial A. digiti III palmaris propria near the middle of the proximal phalanx.

2. The A. digitalis palmaris communis IV - The fourth palmar common digital artery originated from the parent vessel approximately 1 cm distal to the preceding vessel on the flexor surface of the fetlock joint. Close to its origin it received the Ramus communicans from the superficial palmar branch of the caudal interosseous artery. Later it divided into two palmar proper digital arteries of the 4th and 5th digits (Aa. digitales IV et V palmares propriae). The A. digiti IV palmaris propria received a Ramus communicans from the axial A. digiti IV palmaris propria near the middle of the proximal phalanx.

Part II. Pelvic Limb

The external iliac artery, with its fellow of the opposite side, originated from the abdominal aorta (Aorta abdominalis) just ventral to the last lumbar vertebra approximately 2 cm cranial to the sacral promontory. It coursed caudolaterad paralleling the medial face of the M. iliopsoas to a point 2.5 cm cranial to the origin of the M. sartorius, where it turned ventrocaudad and left the abdominal cavity. Thereafter it proceeded with the deep face of the M. sartorius and continued as the femoral artery. Originating from this artery were:

A. circumflexa ilium profunda

The deep circumflex iliac artery arose ventrolaterad from its parent artery, approximately 2.5 cm following its origin. Close to its origin it furnished twigs to the medial iliac lymph nodes (Lnn. iliaci mediales) and later coursed ventrolaterad retroperitoneally along the ventral face of the M. iliopsoas, dividing into two branches.

The ascending or cranial branch passed cranioventrad on the deep face of the M. transversus abdominis where, after a course of several centimeters, it terminated into numerous branches, supplying the preceding muscle, the Mm. obliquus internus abdominis, rectus abdominis

and the deep face of the cranial aspect of the *M. tensor fasciae latae*. It also supplied the fascia and skin of the flank region by means of superficial branches.

The descending or caudal branch coursed ventrolaterad perforating the abdominal wall, slightly caudal to the *Spina iliaca ventralis* (*tuber coxae*), and appearing on the deep face of the *M. tensor fasciae latae*, where it divided into two branches.

1. The ventral branch proceeded ventrad between the *Mm. tensor fasciae latae* and *rectus femoris*, supplying the preceding muscles and the subiliac lymph nodes (*Lnn. subiliaci*). In addition, it vascularized the fascia and skin of the flank rather extensively.

2. The caudal branch passed caudolaterad to the cranial face of the proximal extremity of the *M. rectus femoris*, supplying the fat between this muscle and the deep face of the *M. tensor fasciae latae*, where it split into three twigs. One of these twigs furnished the *Mm. rectus femoris* and *vastus lateralis*; the other twig coursed beneath the *M. tensor fasciae latae* and across the lateral face of the *M. vastus lateralis* to the deep face of the *M. gluteus medius*. It vascularized all the preceding muscles and finally terminated in the cranial border of the *M. biceps femoris*. In addition, it also contributed twigs to the fascia and skin of the flank during its course. The third twig continued dorsad, supplying the *M. gluteus medius*.

A. profunda femoris

The deep femoral artery arose directly caudad from the parent vessel as it coursed ventrad to leave the abdominal cavity, medial to the caudal head of the *M. sartorius*. It entered a triangular space formed by the *M. iliopsoas* and the ventral face of the *M. obturatorius externus*, somewhat below the *pectin ossis pubis*. It continued through this triangular space to the cranial face of the *M. adductor* where it terminated into several branches. Arising from this vessel were:

1. The *Truncus pudendoepigastricus* - The pudendoepigastric trunk arose from the ventral wall of its parent artery medial to the caudal head of the *M. sartorius*. It coursed ventrad for 2.5 cm and dorsocranial to the deep inguinal ring (*Annulus inguinalis profundus*) where it divided into two branches. Kähler (1960) observed that the *A. pudenda externa* and *A. epigastrica caudalis* arose separately from the *A. profunda femoris* in one specimen.

a. The *A. epigastrica caudalis* - The caudal epigastric artery passed cranial along the deep face of *M. rectus femoris*, supplying this muscle extensively. Finally it anastomosed with the twigs of the *A. epigastrica cranialis*. According to Nunez (1964) the caudal epigastric artery gave off two main vessels during its course. One of them continued laterad to anastomose with branches of the *A. phrenoabdominalis* and the *A. circumflexa ilium profunda*. The other vessel ran mediad to the *linea alba* and gave off ventral branches which anastomosed with the branches of the *A. pudenda externa*.

b. *A. pudenda externa* - The external pudic artery coursed caudoventrad across the inguinal ligament and ran through the inguinal canal to emerge at the medial commissure of the superficial inguinal ring (*Annulus inguinalis superficialis*). It terminated in the subcutaneous fatty

tissue under the superficial inguinal lymph nodes (*Lnn. inguinales superficiales proprii*) and according to Nunez (1964), it terminated in three or four branches. According to Kähler (1960) the lateral branch supplied the external skin and in the female the lateral aspect of the caudal four mammary complexes; the middle branch vascularized the *M. rectus abdominis* and anastomosed with the *A. epigastrica cranialis*. In the remaining animals it furnished the caudal four mammary complexes and the *Lnn. supramammarii* in the female as well as the prepuce in the male. The medial branch, according to him, supplied the medial aspect of the caudal mammary complex and terminated in the skin around the second mammary complex. The caudal branch was most delicate and supplied the skin on the medial surface of the thigh. Kähler (1960) asserted that it supplied the spermatic cord and the scrotum in the male and the perineum in the female. According to Bickhardt (1961) it anastomosed with the *A. pudenda interna* in the perineal region. Arising from this artery was the caudal superficial epigastric artery which arose from the parent trunk near the superficial inguinal ring. It proceeded cranial along the superficial face of the *M. rectus abdominis* and ramified inside it.

2. The *A. circumflexa femoris medialis* - The medial circumflex femoral artery was the continuation of the deep femoral artery following the origin of the pudendoepigastric trunk. It coursed caudodistad, piercing the origin of the *Mm. pectineus* and adductor and supplying them extensively. Near the cranial border of the *M. adductor*, close to its origin, it released a long slender branch which proceeded caudally along the ventral aspect of the ischium and vascularized the *Mm. obturatorius externus, quadratus femoris, gemelli* and *semimembranosus*.

It traversed through the *M. adductor* and descended distolaterally between the apposing surfaces of the *Mm. semimembranosus* and *gluteobiceps*, close to the popliteal lymph nodes (*Lnn. poplitei*) and cranial to the cranial border of the *M. semitendinosus*. Slightly above its termination it gave off a strong branch caudally which ramified inside the preceding muscles. It terminated in two main branches. The lateral branch soon split into several twigs and extensively furnished the *M. gluteobiceps* and the popliteal lymph nodes. Its medial terminal branch, following a short caudodistal course, entered the *M. semitendinosus* and was expended within it.

a. The *Rami musculares* - A few muscular branches arose from the parent trunk approximately 2.5 cm beyond the origin of the pudendoepigastric trunk. They supplied the *Mm. sartorius* and *pectineus*.

b. The *Ramus obturatorius* - The obturator branch originated from the dorsal surface of the parent vessel as it proceeded under the acetabulum through the *M. adductor*. It continued lateral to the *M. obturatorius internus*. Here it released a branch ventrad which extended to the trochanteric fossa accompanying the insertion of the *M. obturatorius internus*. The parent vessel continued through the obturator foramen in the *Canalis obturatorius* where it split into two branches. According to Nunez (1964) one of them, directed cranial, anastomosed with the *A. obturatoria* and the other, after supplying the *M. obturatorius internus*, ran caudad to anastomose with the terminal branches of the *A. urogenitalis* (*s.A. prostatica* in the male or *A. vaginalis* in the female) on the

lateral wall of the urethra, or with the muscular branches of the *M. obturatorius internus* given off by the *A. pudenda interna*. According to him the *Ramus obturatorius*, before reaching the obturator foramen, gave off a caudal branch which passed under the *Ramus acetabularis* of the ischium to end in twigs under the insertion of the *Mm. gemelli*. According to Bickhardt (1961) one of these twigs supplied the *Mm. gemelli*, while the other coursed caudolaterad and anastomosed with the *A. glutea cranialis* on the lateral surface of the *M. gluteus profundus*. Inside the pelvic cavity, the obturator branch also furnished twigs to the *M. coccygeus*.

c. The *Rami musculares* - During its course it released several muscular branches to vascularize the *Mm. pectineus, adductor, gracilis* and *semimembranosus*.

A. femoralis

The femoral artery was the direct continuation of the external iliac artery in the pelvic limb beyond the origin of the deep femoral artery. It passed between the two heads of origin of the *M. sartorius* and descended in the femoral canal between the apposing surfaces of the preceding muscle and the *Mm. pectineus* and *vastus medialis*. It proceeded distally to the insertion of the *M. pectineus*, somewhat dorsal to the dorsomedial border of the *M. semimembranosus*. Here it turned distolaterad between the apposing surfaces of the *Mm. semimembranosus* and *adductor* to the popliteal region, where it continued as the popliteal artery. Bickhardt (1961) and Koch (1965) stated that the femoral artery, immediately after entering the femoral canal, gave off laterally a muscular branch which supplied the *M. iliacus*. Some of its twigs anastomosed with the twigs of the *A. iliolumbalis* and the *A. circumflexa ilium profunda*. Arising from the femoral artery were:

1. The *Truncus communis* - The common trunk, the first and largest branch of the femoral artery, arose from its lateral surface, approximately 1.5 cm from the femoral triangle. It continued laterad for approximately 1.5 cm between the apposing proximal ends of the *Mm. rectus femoris* and *vastus medialis*. Here it divided into the cranial femoral artery and the lateral circumflex femoral artery.

a. The *A. femoris cranialis* - The cranial femoral artery arose as one of the terminal branches of the common trunk. It coursed distocranial inside the *M. rectus femoris* and extensively supplied the preceding muscle and the *M. vastus medialis* to their distal ends. According to Bickhardt (1961) and Koch (1965) it also supplied the cranial head of the *M. sartorius* and the *M. iliacus* by a proximal branch, thereby anastomosing with the *A. circumflexa ilium profunda*.

b. The *A. circumflexa femoris lateralis* - The lateral circumflex femoral artery proceeded laterad as the other termination of the parent trunk. It appeared along the deep face of the *M. vastus lateralis* where it split into several muscular branches. These branches vascularized the *Mm. vastus lateralis, rectus femoris, vastus intermedius, gluteus medius* and *gluteus profundus*. According to Ellenberger and Baum (1943), Bickhardt (1961) and Koch (1965) it also furnished the *Mm. vastus medialis, tensor fasciae latae* and *biceps femoris*. Bickhardt (1961) and Koch (1965) further asserted that one of these branches (*Ramus craniodistalis*)

anastomosed with the A. femoris caudalis and the A. genu^s descendens at the level of its insertion on the patella. According to Bickhardt (1961) the Ramus lateroproximalis anastomosed by its cranial twig with the A. circumflexa ilium profunda and by its caudal twig with the A. glutea caudalis. Koch (1965) stated that the Ramus caudalis gave off the nutrient artery to the femur.

2. The Rami musculares - The muscular branches arose throughout its course. They were usually very small and originated from all sides of the parent vessel. They essentially supplied the Mm. sartorius, pectineus, vastus medialis, adductor and semimembranosus.

3. The A. saphena - The saphenous artery was the most extensive branch of the parent vessel. It arose from the medial aspect of the femoral artery within the middle two-thirds of the thigh. It coursed gradually distocaudad, subcutaneously over the medial aspects of the insertions of the Mm. gracilis, semimembranosus and semitendinosus. Near the middle of the leg, it lay in the fascia in front of the Tendo calcaneus communis and descended farther along the medial aspect of the tuber calcanei. During its course in the region of the thigh and leg it gave off numerous tiny twigs to furnish the fascia and skin on the cranio-medial aspect of the stifle joint and the medial surface of the leg. Near the middle of the leg it released several twigs caudally to supply the Tendo calcaneus communis and the fat and fascia around it. At the level of the tuber calcanei it detached a Ramus articularis which coursed deeply to vascularize the caudal aspect of the tarsus. Approximately 2 cm below the tuber calcanei the saphenous artery split into lateral and medial tarsal arteries.

a. The A. tarsea lateralis - The lateral tarsal artery was one of the terminations of the parent vessel as it approached the tarsus. It arose slightly below and medial to the tuber calcanei and close to its origin split into an ascending and a descending twig. Its ascending twig ramified around the tuber calcanei, while its descending twig was distributed in the fascia and skin on the lateral aspect of the tarsus.

b. The A. tarsea medialis - The medial tarsal artery was the distal continuation of the saphenous artery. During its course it released several twigs which ramified on the mediocranial aspect of the tarsus, where it anastomosed with a few twigs given off by the A. dorsalis pedis. At the level of the sustentaculum tali it divided into two plantar arteries.

(1) The A. plantaris lateralis - The lateral plantar artery was the more slender termination of the parent vessel. It obliquely crossed the tendon of the M. flexor digitorum (digitalis) superficialis and released numerous twigs to the fascia and ligaments on the plantar aspect of the tarsus. Later it descended gradually in the groove bounded by the flexor tendons and the Lig. plantare longum, where it gave off the Ramus perforans proximalis accessorius (A. tarsica perforans proximalis of Bickhardt, 1961 and Koch, 1965) which, after coursing through the tarsal canal, communicated with the A. dorsalis pedis on the flexor surface of the tarsus. The lateral plantar artery passed along the lateral aspect of the flexor tendons to which it gave several twigs during its course. Slightly below the base of the large metatarsal bones it gave off an anastomotic branch which coursed mediad between the metatarsus and the Mm. interossei. It joined a similar branch from the medial branch of

the medial plantar artery to constitute the proximal (deep) plantar arch (*Arcus plantaris proximalis profundus*). Near the middle of the metatarsus it released dorsally the *A. digitalis pedis dorsalis communis IV*, similar to the observations of Bickhardt (1961) and Koch (1965), which after traversing the interosseous space between the 4th and 5th metatarsals, appeared on the distal third of this region. However, Bickhardt (1961) wrongly quoted (p.20) Lechner (1934) by stating that the plantar origin and course of the *Aa. metatarsicae dorsales II* and *IV* were first described by the latter author. On the contrary, Lechner (1934, p.614) stated: "the dorsal vessels originated from the *A. dorsalis pedis*. The *A. metatarsica dorsalis III* was its direct continuation, the *A. metatarsica dorsalis II* its medial branch, which was reinforced by the *A. plantaris medialis*; and the *A. metatarsica dorsalis IV* its lateral branch which received the confluence through the *A. tarsica perforans* and the *A. plantaris lateralis*." Slightly above the fetlock joint it split into the *Aa. digitales IV et V pedis dorsales propriae*. The *A. digiti IV pedis dorsalis propria*, near the middle of the proximal phalanx, received a contribution from the *A. digitalis plantaris communis III* via the *Ramus communicans* and later descended along the dorsolateral aspect of the 4th digit. The lateral plantar artery continued distally and approximately 2 cm above the fetlock joint released the *A. metatarsica plantaris IV* which, after coursing between the metatarsus and the *Mm. interossei*, opened in the distal (deep) plantar arch (*Arcus plantaris distalis profundus*). The extension of the lateral plantar artery emptied in the *A. digitalis plantaris communis IV* behind the fetlock joint of the 5th digit.

(2) The *A. plantaris medialis* - The medial plantar artery was the distal extension of the parent vessel. At the level of the tarsocrural articulation it gave off a medial branch which coursed distally. Near the base of the large metatarsal bones it released an anastomotic branch which coursed laterad between the *Mm. interossei* and metatarsus. It joined a similar branch from the lateral plantar artery to form the proximal (deep) plantar arch. From this vascular arch arose the *Ramus perforans proximalis (A. tarsica perforans distalis* of Bickhardt, 1961 and Koch, 1965) which, after traversing the tarsus, joined the *A. dorsalis pedis* on the flexor surface of the tarsus. Moreover, the *Aa. metatarsicae plantares II et III* also arose from this vascular arch, coursed distally between the metatarsus and the *Mm. interossei* and finally communicated with the *A. metatarsica plantaris IV* at the distal (deep) plantar arch. The *A. metatarsica plantaris III* communicated with the *A. metatarsica dorsalis III* by means of a *Ramus perforans distalis (A. metatarsica perforans* of Bickhardt, 1961 and Koch, 1965) which coursed through the interosseous space between the large metatarsal bones. The *A. metatarsica plantaris II* descended in the groove between the 2nd and 3rd metatarsal bones. Near the middle of this region it gave off the *A. digitalis dorsalis pedis communis II*, similar to the findings of Bickhardt (1961) and Koch (1965), which appeared dorsally through the interosseous space. Slightly above the fetlock joint it divided into the *Aa. digitales II et III pedis dorsales propriae*. The *A. digiti III dorsalis pedis propria* continued along the dorsomedial aspect of the 3rd digit. During its distal course it also received a contribution from the *Ramus communicans* of the *A. digitalis plantaris communis III* near the middle of the proximal phalanx.

The medial branch of the medial plantar artery extended distally and detached numerous twigs to furnish the fascia and skin of the adjoining area. Near the fetlock joint of the 2nd digit it opened in the *A. digitalis plantaris communis II* as it arose from the continuation of the medial plantar artery.

The medial plantar artery proceeded distally along the medial face of the flexor tendons and on the plantar aspect of the fetlock joint formed the distal (superficial) plantar arch (*Arcus plantaris distalis superficialis*) in a zig-zag fashion by the union of its medial branch and the lateral plantar artery. On the plantar surface of the fetlock joints of the principal digits both (superficial and deep) distal plantar arches communicated with each other. Originating from this vascular area were:

(a) The *A. digitalis plantaris communis II* - The second common plantar digital artery arose from the parent vessel behind the fetlock joint of the 2nd digit. Immediately close to its origin it received the distal continuation of the medial branch of the medial plantar artery. After a short course it split into the *Aa. digitales II et III plantares propriae*. The *A. digiti III plantaris propria*, near the middle of the proximal phalanx, received the *Ramus communicans* from the parent vessel or from its axial terminal branch (*A. digiti III plantaris propria*). It later descended along the plantaromedial aspect of the 3rd digit, entered the distal phalanx through a foramen and joined the axial plantar proper digital artery to form the terminal arch within the bone.

(b) The *A. digitalis plantaris communis IV* - The fourth common plantar digital artery originated from the parent vessel approximately 1 cm below the preceding vessel. On its course it received the distal continuation of the lateral plantar artery. Following a short course it divided into the *Aa. digitales IV et V plantares propriae*. The *A. digiti IV plantaris propria* received a *Ramus communicans* from the parent vessel or from its axial terminal branch (*A. digiti IV plantaris propria*) near the middle of the proximal phalanx and then continued distally along the plantarolateral aspect of the 4th digit and entered the distal phalanx through a foramen. Within the bone it assisted in the formation of the terminal arch together with the axial plantar proper digital artery of the respective digit.

(c) The *A. digitalis plantaris communis III* - The third common plantar digital artery continued distally over the flexor tendons along the plantar aspect of the fetlock joints. It gave off tiny twigs to furnish the fascia and skin of this region during its course. Near the middle of the proximal phalanx it released the *Rami communicantes* which coursed deep to the flexor tendons along the plantar surface of the proximal phalanx and communicated with the *A. digiti III plantaris propria* and *A. digiti IV plantaris propria*. Following their confluence the extension of the *Rami communicantes* proceeded to the dorsomedial and dorsolateral aspects of the principal digits, where they finally opened in the *A. digiti III pedis dorsalis propria* and *A. digiti IV pedis dorsalis propria*, respectively. Subsequently, the *A. digitalis plantaris communis III* divided into two plantar proper digital arteries of the 3rd and 4th digits (*Aa. digitales III et IV plantares propriae*) which descended along their interdigital border. The *Rami communicantes* had been observed to arise also from *Aa. digitales III et IV plantares propriae*, close to their origin from the *A. digi-*

talis plantaris communis III. Almost at the same level the plantar proper digital arteries of the 3rd and 4th digits also gave off the *Rami communicantes* to join the *Aa. digitales III et IV pedis dorsales propriae* of the respective digits traversing the interdigital space of the main digits. During their distal course they furnished twigs to the fascia, skin and the tendon sheaths of this region. Approximately at the level of the proximal interphalangeal joint each plantar proper digital artery gave off the *Ramus pulvinus distalis* to supply the region of the bulb. Later it released a slender *Ramus plantaris* for the sole and corium of the distal phalanx and dorsally an *A. coronaria*. The continuation of the plantar proper digital artery entered the distal phalanx of the respective digit through the interdigital foramen and joined the abaxial plantar proper digital artery to constitute the terminal arch (*Arcus terminalis*) inside the bone.

4. The *A. genus descendens* - The descending genicular artery arose from the cranio-lateral aspect of the parent vessel, approximately 0.5 cm below the origin of the saphenous artery. It proceeded cranio-distad along the caudal border of the *M. vastus medialis* and ramified extensively within it extending to the medial aspect of the stifle joint. According to Bickhardt (1961) and Koch (1965) it also supplied the *M. rectus femoris* and lateral to the patellar trochlea anastomosed with the distal branch of the *A. circumflexa femoris lateralis*. Bickhardt (1961) further asserted that they supplied, together, the skin cranial to the knee.

5. The *A. femoris caudalis* - The caudal femoral artery was a strong vessel arising from the caudal aspect of the femoral artery before the latter coursed between the two heads of the *M. gastrocnemius*. After a short course it divided into an ascending and a descending branch.

a. The ascending branch passed laterad between the *Mm. adductor, gastrocnemius* and *gluteobiceps*, and appeared in the space bounded by the *Mm. adductor, vastus lateralis* and *gastrocnemius (Caput laterale)* beneath the *M. gluteobiceps*. Here it split into several twigs and vascularized the *Mm. vastus lateralis, adductor, gluteobiceps* and *gastrocnemius (Caput laterale)*. A long slender twig extended cranio-distad and was destined to supply the lateral aspect of the stifle joint. Bickhardt (1961) and Koch (1965) affirmed that it also anastomosed with the twigs of the *A. circumflexa femoris lateralis* and the *A. poplitea*.

b. The descending branch pursued a very short course distally and vascularized the *M. flexor digitorum (digitalis) superficialis* by means of a slender branch. Its main continuation soon split into two twigs which were entirely expended within the *M. gastrocnemius*. Bickhardt (1961) and Koch (1965) observed one of its superficial branches extending to the lateral aspect of the insertion of the *Tendo calcaneus communis* on the tarsus, where it anastomosed with the proximal twig of the *Ramus articularis* of the *A. saphena*. Bickhardt (1961) further noticed that it furnished the *Ln. popliteus superficialis* in two cases.

A. poplitea

The popliteal artery was the distal extension of the femoral artery beyond the origin of the preceding vessel. It continued through the popliteal region between the two heads of the *M. gastrocnemius*. It coursed distad medial to the origin of the *M. flexor digitorum (digitalis) super-*

ficialis for approximately 2 cm. During its course, according to Bickhardt (1961) and Koch (1965), it gave off the Aa. genus proximales medialis et lateralis at the level of the femoral condyles. They supplied the menisci, joint capsule and the perichondrium. According to them the branches of the lateral proximal genicular artery anastomosed with the A. femoris caudalis, A. poplitea and the A. tibialis anterior. They further described the A. genus media as supplying the fat under the patellar ligaments. It then divided into the caudal and cranial tibial arteries. Before its terminal division it gave off a slender twig to supply the M. gastrocnemius (Caput mediale).

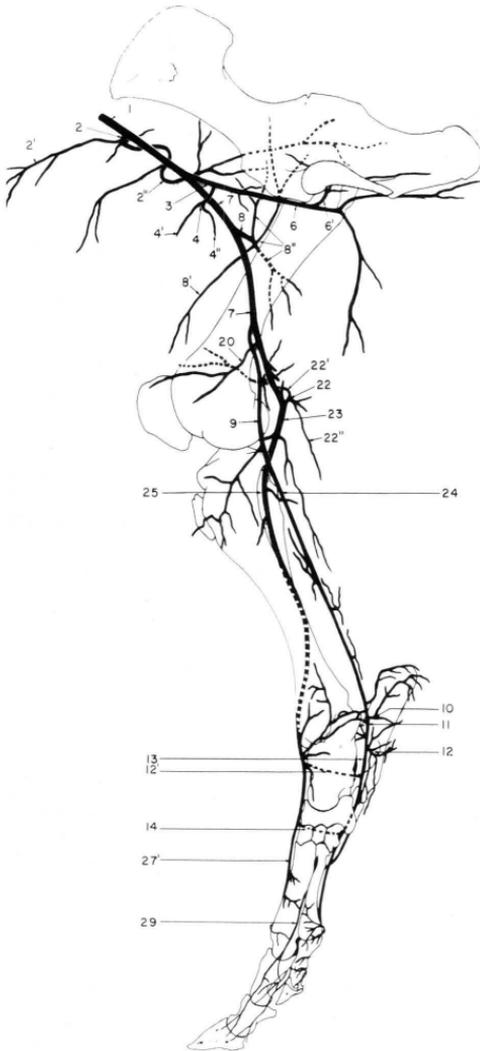
1. The A. tibialis caudalis - The caudal tibial artery arose as one of the end branches of the parent artery. It passed directly distad, at first between the Mm. popliteus and flexor digiti primi (hallucis) longus beneath the M. tibialis caudalis and thereafter between the M. flexor digitorum (digitalis) longus and flexor digiti primi (hallucis) longus. It vascularized all the heads of the M. flexor digitorum (digitalis) profundus.

2. The A. tibialis cranialis - The cranial tibial artery assumed the distal continuation of the popliteal artery. It passed distad and gradually wound around the lateral border of the tibia to appear on the cranial surface of the leg after piercing the Membrana interossea cruris. During this course it gave off two muscular rami for the Mm. gastrocnemius (Caput mediale) and popliteus and the caudal genicular artery to furnish the caudal aspect of the capsule of the stifle joint. After emerging through the interosseous space of the leg it gave off a strong branch which soon divided into an ascending and a descending branch. Both of these branches split variably to vascularize the Mm. peroneus longus, peroneus tertius, tibialis cranialis, extensor digitorum (digitalis) longus (including the M. extensor digiti III), extensor digiti primi (hallucis) longus and extensor digitorum (digitalis) lateralis. Approximately 1 cm below the preceding branch another branch arose from the parent artery. It supplied twigs to the Mm. extensor digitorum (digitalis) lateralis, extensor digiti primi (hallucis) longus and tibialis cranialis. The nutrient artery of the tibia (A. nutritia tibiae) arose from it and entered the bone through the nutrient foramen situated slightly caudad to the lateral border near the middle of the tibia. The cranial tibial artery, during its distal course, gave off several tiny slender twigs to supply the periosteum of the adjoining bones. It obliquely crossed the undersurface of the M. extensor digiti primi (hallucis) longus and gradually attained the cranial aspect as it approached the tarsus. At the level of the tuber calcanei it released a branch laterad to furnish the M. extensor digitorum (digitalis) lateralis and the capsule of the lateral aspect of the tarsus. It descended farther, along with the extensor tendons, beneath the Retinaculum extensorum proximale and became the A. dorsalis pedis opposite the tarsocrural articulation. The A. dorsalis pedis, on the flexor surface of the tarsus, received the Ramus perforans proximalis accessorius from the A. plantaris lateralis at the level of the tarsocrural articulation and the Ramus perforans proximalis from the A. plantaris medialis emerging between the third and fourth tarsals. The Ramus perforans proximalis also contributed twigs to the Rete tarsi dorsale. The A. dorsalis pedis formed an extensive Rete tarsi dorsale on the flexor surface of tarsus between the extensor tendons and the joint capsule. Some of these twigs

also extended to the dorsolateral and dorsomedial aspects of the tarsus. The *A. dorsalis pedis* descended over the tarsus under the *Retinaculum extensorum distale* and continued in the interosseous space between the third and fourth metatarsal bones as the *A. metatarsae dorsalis III* beneath the *M. extensor digitorum (digitalis) brevis*. However, Baum (1907), Lechner (1934), Ellenberger and Baum (1943), Bruni and Zimmerl (1951), Dobberstein and Hoffmann (1964) and Schwarze and Schröder (1964) described that the *A. dorsalis pedis*, at the proximal end of the metatarsus, gave off the *A. metatarsae dorsales II, III et IV*. According to them the *Aa. metatarsae dorsales* united with the corresponding plantar arteries at the distal end of the metatarsus and gave origin to the *Aa. digitales communes II, III et IV*. On the contrary, in our investigation we found, in agreement with Bickhardt (1961) and Koch (1965), that the *Aa. digitales pedis dorsales communes II et IV* arose from the *Aa. metatarsae plantares II et IV*, respectively. Bourdelle and Bressou (1964) did not mention these vessels at all in the pig. During its distal course the *A. metatarsae dorsalis III* released numerous twigs to furnish the *M. extensor digitorum (digitalis) brevis*, the periosteum of the metatarsal bones and the extensor tendons. Slightly above the fetlock joints of the principal digits it communicated with the *A. metatarsae plantaris III* by means of the *Ramus perforans distalis*. Later it extended over the fetlock joints of the principal digits as the *A. digitalis dorsalis pedis communis III* which, near the middle of the proximal phalanx, divided into two dorsal proper digital arteries of the 3rd and 4th digits (*Aa. digitales III et IV pedis dorsales propriae*). Each of them united with the *Aa. digitales III et IV plantares propriae* of the respective digits through a *Ramus communicans*.

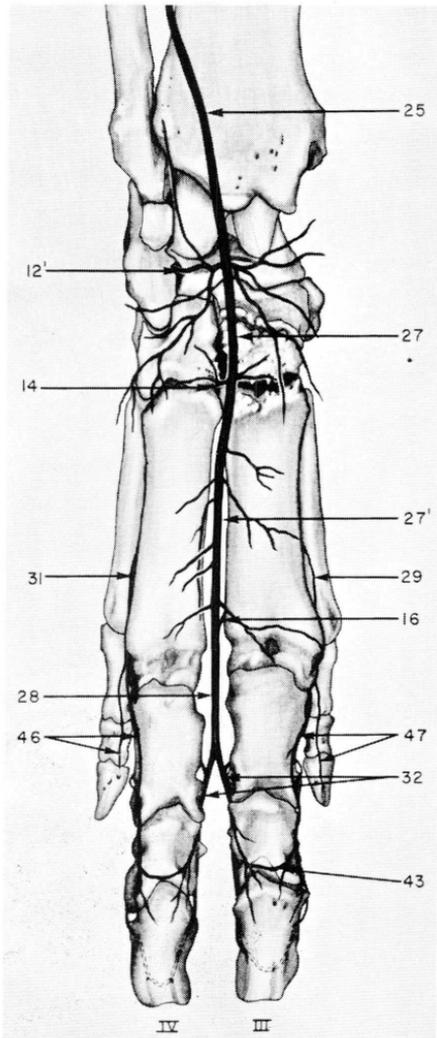
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1. A. iliaca externa
2. A. circumflexa ilium profunda
- 2'. Ramus ascendens
- 2''. Ramus descendens
3. A. profunda femoris
4. Truncus pudendo-epigastricus
- 4'. A. epigastrica caudalis
- 4''. A. pudenda externa
6. A. circumflexa femoris medialis
- 6'. Ramus obturatorius
7. A. femoralis
8. Truncus communis
- 8'. A. femoris cranialis
- 8''. A. circumflexa femoris lateralis
9. A. saphena
10. A. tarsea lateralis
11. A. tarsea medialis
12. A. plantaris lateralis
- 12'. Ramus perforans proximalis accessorius
13. A. plantaris medialis
14. Ramus perforans proximalis
20. A. genu descendens
22. A. femoris caudalis
- 22'. Ramus ascendens
- 22''. Ramus descendens
23. A. poplitea
24. A. tibialis caudalis
25. A. tibialis cranialis
- 27'. A. metatarsa dorsalis III
29. A. digitalis dorsalis pedis communis II

Figure 4. The arterial blood supply to the pelvic limb of the domestic pig via external iliac artery (A. iliaca externa). Medial view (schematic).



- 12'. Ramus perforans
proximalis accessorius
- 14. Ramus perforans
proximalis
- 16. Ramus perforans distalis
- 25. A. tibialis cranialis
- 27. A. dorsalis pedis
- 27'. A. metatarsae dorsalis III
- 28. A. digitalis dorsalis pedis
communis III
- 29. A. digitalis dorsalis pedis
communis II
- 31. A. digitalis dorsalis pedis
communis IV
- 32. Aa. digitales III et IV pedis
dorsales propriae
- 43. A. coronaria
- 46. Aa. digitales IV et V pedis
dorsales propriae
- 47. Aa. digitales II et III pedis
dorsales propriae

Figure 5. Arteries of the distal part of right pelvic limb of the domestic pig. (Dorsal view (schematic)).

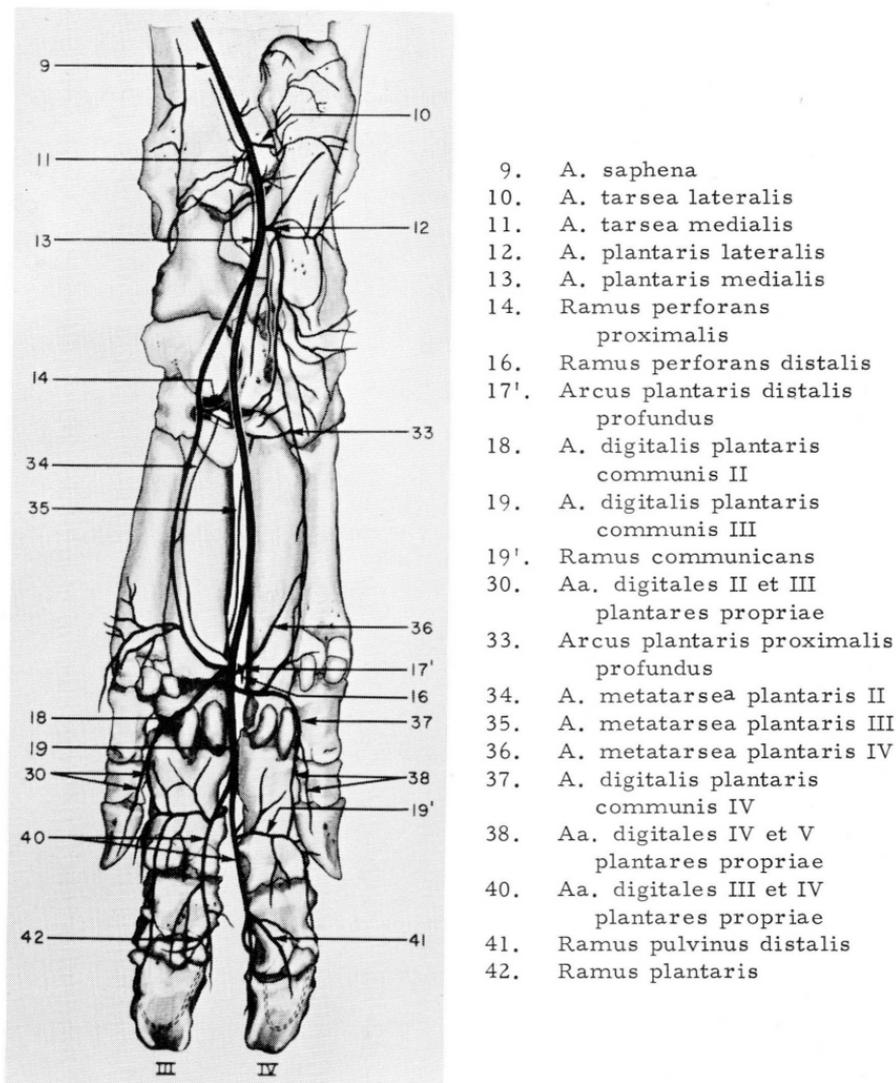


Figure 6. Arteries of the distal part of right pelvic limb of the domestic pig. Plantar view (schematic).

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THE ARTERIAL BLOOD SUPPLY TO THE APPENDAGES
OF THE HORSE (EQUUS CABALLUS)N. G. Ghoshal¹ and Robert Getty²

ABSTRACT. Four thoracic and four pelvic limbs of the horse (Equus caballus) have been dissected to describe the comparative blood supply to the appendages. Breed, age, sex, and body weight of the animals were not considered in this study. Published work in English and foreign literature relative to the blood supply to the appendages was evaluated and the discrepancies existing therein pointed out. An attempt has been made to evolve a uniform nomenclature as consistent as possible with the NAV and with previous articles by these authors for both blood vessels and nerves supplying these areas according to their topography. The findings are represented by composite illustrations.

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INTRODUCTION

The blood supply to the appendages of the horse has been thoroughly described in the existing veterinary anatomy textbooks both in English and foreign languages. However, in these published works many vessels were named differently by various authors, thus causing difficulty in understanding the true phylogenetic significance of the vessels supplying these regions.

This investigation has been undertaken in order to emphasize the comparative significance of the vessels and to evolve a uniform nomenclature as consistent as possible with the NAV and with previous articles by these authors on the blood vessels and nerves supplying these areas.

REVIEW OF LITERATURE

The blood supply of the thoracic and pelvic limbs of the horse has been adequately described in the standard anatomical textbooks and in articles (see bibliography). A detailed literature review will be incorporated with the results when applicable.

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MATERIAL AND METHODS

Four thoracic and four pelvic limbs of the horse were dissected for this investigation. In addition, observations were also made on many limbs during the past several years in the first year dissection class of the professional veterinary curriculum. The animals were sacrificed in the Department of Veterinary Anatomy, College of Veterinary Medicine, Iowa State University of Science and Technology, Ames, Iowa between June, 1966, and April, 1968. Breed, age, sex and body weight of the animals were not considered in this study.

The animals were anesthetized with pentobarbital sodium and exsanguinated via a cannula from the right carotid artery. The blood vessels were perfused with normal saline solution to remove the blood clots. Thereafter, the specimens were embalmed with the following solution: Isopropyl alcohol, 60%; formalin, 4%; phenol, 6%; corn syrup, 2.5%; and water, 27.5%.

The arteries were injected with two parts of 2% ammonia water added to three parts of red latex (Cementex Co.). A pressure of approximately 120 mm mercury was used to inject the arteries. The specimens so prepared were kept in a cooler for two to three days and were later dissected.

In order to evolve a uniform nomenclature for the blood vessels and nerves supplying these regions and for comparative anatomical reasons the *Nomina Anatomica Veterinaria* (Pars prima), Hannover, 1963; list on *Arteriae Canis* as approved by the World Association of Veterinary Anatomists in Alfort, France in 1967; and the *Nomina Anatomica* (3rd ed.), 1966, have been used.

RESULTS

Part I. Thoracic Limb

The subclavian artery (*A. subclavia*) after the origin of the superficial cervical artery (*A. cervicalis superficialis* s. *Truncus omocervicalis*) at the thoracic inlet (medial to the first rib), continued as the axillary artery (*A. axillaris*). The axillary artery wound around the first rib and coursed caudoventrally through the axillary space and at the interval between the *Mm. subscapularis* and *teres major* (medial to the shoulder joint) it divided into two terminal branches—the *Truncus subscapularis* and the *A. brachialis*. During its course it gave off the following branches:

The *A. thoracica externa*

The external thoracic artery arose ventrally close to the origin of the parent vessel. DeVos (1965) stated that the *A. thoracica externa* may arise caudal to the *A. thoracoacromialis*. According to Ellenberger and Baum (1943) its origin was extremely variable; it can originate from the *A. thoracica interna*, *A. axillaris*, *A. subscapularis*, *A. thoracodorsalis* and even from the *A. brachialis*. Near its origin it split into cranial and caudal branches.

1. The cranial branch, following a course of approximately 3 cm, divided into an ascending branch and a descending branch. The ascending

branch passed dorsocranially, supplied twigs to the Mm. pectoralis cleidoscapularis and omohyoideus and finally vascularized the deep face of the M. brachiocephalicus in front of the shoulder joint. Its descending branch coursed distally winding around the M. pectoralis cleidoscapularis to which it furnished several twigs. Later it divided into a few twigs, supplying the Mm. brachiocephalicus, pectoralis descendens and pectoralis transversus.

2. The caudal branch continued along the deep face of the Mm. pectoralis cleidoscapularis and pectoralis ascendens to the lateral wall of the thorax where it supplied the M. cutaneus trunci extensively. On its way it furnished several twigs to vascularize the preceding muscles and the superficial cervical lymph nodes (Lnn. cervicales superficiales).

The A. thoracoacromialis (Suprascapular artery of Sisson and Grossman, 1953; Rooney, 1956; and Rooney et al., 1967).

The thoracoacromial artery arose from the dorsal aspect of the parent vessel approximately 2.5 cm following the origin of the preceding vessel. After coursing approximately 2 cm dorsocranially, it gave off a branch cranially which soon split in two. Its ascending branch vascularized the belly of the M. supraspinatus in front of the shoulder joint. A few of its twigs were also destined to supply the cranio-lateral aspect of the shoulder joint capsule. Its descending branch disappeared inside the M. pectoralis ascendens. The thoracoacromial artery continued farther and attained the septum between the Mm. supraspinatus and subscapularis near the middle of the cranial border of the scapula. Here it split and was expended within the preceding muscles and the M. pectoralis cleidoscapularis. According to Ellenberger and Baum (1943); Sisson and Grossman (1953) and Nickel and Wissdorf (1964) it also supplied the M. brachiocephalicus. In addition, Ellenberger and Baum (1943) alleged that it gave off the nutrient artery to the humerus.

The Ramus muscularis

A slender muscular branch originated approximately 1.5 cm caudal to the preceding vessel. This branch was also seen to arise from the subscapular trunk close to the latter's bifurcation from the parent vessel. The muscular branch coursed dorsocranially and supplied the distal part of the M. subscapularis.

Truncus subscapularis

The subscapular trunk was one of the terminal bifurcations of the axillary artery. Following a course of approximately 0.5 cm it split again into its terminal branches—the A. subscapularis and the A. thoracodorsalis. During its course it gave off:

1. The Ramus muscularis - An inconstant slender muscular branch arose from the parent trunk, close to the latter's origin, passed cranio-dorsad and supplied the M. subscapularis. This branch was seen to arise directly from the axillary artery, slightly behind the origin of the thoracoacromial artery.

2. The A. subscapularis - The subscapular artery continued the parent trunk dorsally, extending between the Mm. subscapularis and teres major, and ramified extensively to the caudal angle of the scapular cartilage. Originating from it were:

a. The *A. circumflexa humeri caudalis* - The caudal circumflex humeral artery arose from the parent vessel, 1 cm following its separation from the thoracodorsal artery. Close to its origin it gave off a small twig to the *M. triceps brachii* (Caput longum) and extended laterad along the flexor surface of the shoulder joint between the *Mm. subscapularis*, *teres major* and *triceps brachii* (Caput longum), accompanying the *N. axillaris*. It appeared laterally beneath the *M. deltoideus* between the long and lateral heads of the *M. triceps brachii*. Here it split in a variable manner and furnished the *Mm. infraspinatus*, *teres minor*, *deltoideus* and *triceps brachii* (Caput longum et laterale). In addition, it also supplied extensively the caudal and cranio-lateral aspects of the shoulder joint capsule. Ellenberger and Baum (1943) and Nickel and Wissdorf (1964) stated that it also vascularized the *Mm. capsularis* and *cutaneus scapulae* and the skin covering this region. In addition, according to Ellenberger and Baum (1943), Sisson and Grossman (1953), Rooney (1956), Dobberstein and Hoffmann (1964), Nickel and Wissdorf (1964), Schwarze and Schröder (1964), Koch (1965) and Rooney et al. (1967) the caudal circumflex humeral artery anastomosed with the *A. circumflexa humeri cranialis* arising from the brachial artery. The area of vascularization of the caudal circumflex humeral artery of the horse corresponded only with the *Ramus proximalis* of other domestic animals.

b. The *A. circumflexa scapulae* - The circumflex scapular artery originated from the parent vessel within the middle-third of the caudal border of the scapula. It coursed for a short distance between the *Mm. subscapularis* and *triceps brachii* (Caput longum) and near the caudal border of the scapula it split in two. The slender medial branch passed between the medial surface of the scapula and *M. subscapularis* and finally disappeared within the preceding muscles. Its strong lateral branch coursed in the infraspinous fossa between the bone and *M. infraspinatus*. During its course it gave off the *A. nutritia scapulae* and ramified inside the *Mm. infraspinatus* and *supraspinatus*.

c. The *Rami musculares* - The muscular branches were numerous and of variable size and origin. They arose from both sides of the parent artery during the latter's dorsal course between the *Mm. subscapularis* and *teres major*. It essentially supplied both the preceding muscles and the *Mm. infraspinatus* and *triceps brachii* (Caput longum). Besides, it gave off delicate twigs to supply the caudomedial aspect of the capsule of the shoulder joint.

3. The *A. thoracodorsalis* - The thoracodorsal artery arose as the other termination of the parent trunk. Ellenberger and Baum (1943) described it as arising from the *A. brachialis* in exceptional cases. It proceeded caudodorsally along the medial surface of the *M. teres major*. Near the caudal border of the preceding muscle it divided mainly into two branches, finally ramifying inside the *Mm. latissimus dorsi* and *cutaneus trunci*.

a. The *Rami musculares* - The small muscular branches were detached on its course to supply the *Mm. teres major* and *tensor fasciae antebrachii* and the axillary lymph nodes (*Lnn. axillares*).

A. brachialis

The brachial artery was the other terminal branch of the axillary

artery which it continued in the region of the arm. It descended over the distal part of the *M. teres major*, lying between the *N. medianus* in front and *V. brachialis* behind. Here it lay between the *Mm. coracobrachialis* and *tensor fasciae antebrachii* and subsequently between the latter muscle and the *M. biceps brachii* in its craniocaudal relationship. Mediolaterally, it was situated between the *Mm. triceps brachii (Caput mediale)* and *pectoralis ascendens*. It proceeded beneath the *M. pronator teres* and approximately 3 cm below the elbow joint it released the common interosseous artery and continued as the median artery. Originating from it were:

1. The *A. circumflexa humeri cranialis* - The cranial circumflex humeral artery arose from the lateral aspect of the parent vessel close to its origin. It was a relatively strong vessel coursing distocranially, accompanying the *Ramus muscularis proximalis n. musculocutanei* between the two portions of the *M. coracobrachialis* and finally ramifying inside the *M. biceps brachii*. During its course it vascularized the *Mm. coracobrachialis*, *subscapularis* and *teres major*. Moreover, a few twigs also furnished the medial aspect of the shoulder joint capsule. As previously mentioned, according to several authors it anastomosed with the *A. circumflexa humeri caudalis*. Sisson and Grossman (1953) and Schwarze and Schröder (1964) mentioned that it supplies the *M. brachiocephalicus* and, according to them and Ellenberger and Baum (1943), Dobberstein and Hoffmann (1964), Nickel and Wissdorf (1964) and Koch (1965), also the *M. pectoralis profundus*.

2. The *A. profunda brachii* - The deep brachial artery arose from the caudal aspect of the parent vessel near the middle of the arm. It was very strongly developed, and soon divided in two branches. The medial branch passed caudad, gave off slender twigs on its way to the *Mm. triceps brachii (Caput mediale)* and entered the *M. triceps brachii (Caput longum)* which it supplied extensively. Its lateral branch, after a course of 0.5 cm divided again into an ascending and a descending branch. The ascending branch split variably and disappeared inside the *M. triceps brachii (Caput longum)*, while its descending branch, accompanying the *N. radialis*, passed laterad between the *Mm. brachialis* and *triceps brachii (Caput longum)* beneath the *Caput laterale* of the latter muscle. During its course through the musculospiral groove of the humerus it furnished twigs to the *Mm. brachialis* and *triceps brachii (Caput laterale)*. Slightly above the origin of the *M. extensor carpi radialis* it split into two branches. The medial twig coursed between the *M. brachialis* and the origin of the *M. extensor carpi radialis* and finally entered the former muscle. The lateral twig extended between the *M. triceps brachii (Caput laterale)* and the origin of the *M. extensor carpi radialis*, supplied the *M. anconeus*, and at the level of the lateral humeral epicondyle, it communicated with both the *A. interossea recurrens* (similar to the observations of Bruni and Zimmerl, 1951; Sisson and Grossman, 1953; Dobberstein and Hoffmann, 1964; Nickel and Wissdorf, 1964; Schwarze and Schröder, 1964; Koch, 1965) and a branch of the distal branch of the *A. collateralis radialis distalis* (also described by Sisson and Grossman, 1953; Schwarze and Schröder, 1964). In addition, the above-mentioned authors reported another anastomosis between the deep brachial artery and the (collateral) ulnar artery. The area of supply of the descending

branch of the lateral branch of the deep brachial artery of the horse corresponded with the Ramus distalis (= *A. collateralis radialis proximalis*) of the *A. circumflexa humeri caudalis* of other domestic animals.

3. The Rami musculares - Several very small muscular branches were released within the region of the arm to supply the *Mm. coracobrachialis* and *triceps brachii* (Caput mediale).

4. The *A. collateralis ulnaris* - The collateral ulnar artery arose from the caudal aspect of the parent vessel within the distal-third of the arm. After a course of 0.5 cm it gave off the *A. nutritia humeri* which immediately entered the humerus. Almost at the same level arose, from the opposite side, another long slender vessel which stretched over the insertion of the *M. biceps brachii* and supplied the *M. pectoralis transversus*. Shortly after, it gave off two delicate twigs to supply the *Mm. triceps brachii* (Caput mediale) and *tensor fasciae antebrachii* and the *Lnn. cubitales*. In addition, it also furnished a slender twig which ramified on the caudomedial aspect of the elbow joint, from which some of the twigs also reached the origins of the *Mm. flexor carpi radialis* and *flexor carpi ulnaris*. It continued farther towards the olecranon and divided into two branches. Its short proximal branch supplied the deep face of the *M. tensor fasciae antebrachii* and the insertion of the *Caput mediale* and *Caput longum* of the *M. triceps brachii*. The distal branch passed distocaudally between the two heads of the *M. flexor carpi ulnaris*, and approximately an inch above the accessory carpal bone it opened in the lateral palmar artery (*A. palmaris lateralis*) (*A. metacarpica volaris profunda lateralis* of Ellenberger and Baum, 1943; Dobberstein and Hoffmann, 1964; Schwarze and Schröder, 1964; Lateral volar metacarpal artery of Sisson and Grossman, 1953; *Ramus volaris profundus* of median artery of Nickel and Wissdorf, 1964; *A. metacarpica volaris* of Koch, 1964). During its course it released muscular twigs for the *Mm. anconeus*, *tensor fasciae antebrachii*, *flexor carpi ulnaris* and the *flexor digitorum (digitalis) profundus* (Caput ulnare). Besides, it also furnished twigs to supply the caudal aspect of the elbow joint capsule. It also formed an anastomosis with a branch of the *A. profunda brachii* as described previously.

5. The *A. bicipitalis* - The bicipital artery originated from the cranial aspect of the parent vessel, opposite to the origin of the *A. collateralis ulnaris*, close to the insertion of the *M. coracobrachialis* on the humerus. For comparative reasons it should be considered as the *Ramus proximalis* of the *A. collateralis radialis distalis*. It passed cranially between the *Mm. coracobrachialis* and *biceps brachii* accompanying the *Ramus muscularis distalis n. musculocutanei*, and soon split into two branches. Its ascending branch stretched laterad and furnished the *Mm. coracobrachialis* and *brachiocephalicus*, while its descending branch pierced the belly of the *M. biceps brachii*.

6. The *A. collateralis radialis distalis* - The distal collateral radial artery arose from the parent vessel at the level of the elbow joint. In comparative anatomy it only corresponded with the *Ramus distalis* of the *A. collateralis radialis distalis*. It extended laterad between the flexor surface of the elbow joint and the *M. biceps brachii*, to which it supplied a twig during its course. It appeared along the deep face of the *M. brachialis* where it released a few twigs to supply same. At this level it also

gave off a few relatively strong twigs which curved upwards and outwards to supply the origin of the *M. extensor carpi radialis*. One of these twigs emerged between the origin of the preceding muscle and the *M. extensor digitorum (digitalis) communis* in front of the lateral humeral epicondyle where it anastomosed with the descending branch of the lateral branch of the deep brachial artery and a branch of the recurrent interosseous artery. The distal collateral radial artery extended at first between the *Mm. brachialis* and *extensor carpi radialis* and later between the latter muscle and the *M. extensor digitorum (digitalis) communis*. Here it split into several strong branches, supplying the *Mm. extensor carpi radialis*, *extensor digitorum (digitalis) communis*, *extensor digitorum (digitalis) lateralis* and *abductor digiti primi (pollicis) longus*. Within the *M. extensor digitorum (digitalis) communis* the muscular twig frequently anastomosed with a similar branch of the *A. interossea cranialis* (*A. interossea dorsalis* of Ellenberger and Baum, 1943; Sisson and Grossman, 1953; Dobberstein and Hoffmann, 1964; Schwarze and Schröder, 1964; and Koch, 1965). Besides, Sisson and Grossman (1953) reported another anastomosis between this vessel and the median artery. In addition they also released tiny twigs to supply the periosteum of the radius, finally extensively contributing branches to the *Rete carpi dorsale*. In one specimen, the branches of the distal collateral radial artery took over part of the area of supply of the *A. interossea cranialis* and its contribution to the *Rete carpi dorsale*. In another specimen, one of the muscular twigs of the distal collateral radial artery descended along the deep face of the *M. extensor digitorum (digitalis) communis* and within the middle third of the forearm opened in the cranial interosseous artery.

7. The *Rami musculares* - Approximately 3 to 4 muscular branches arose from the caudal aspect of the parent vessel below the elbow joint. The most proximal one was slender and communicated with a twig arising from the collateral ulnar artery on the medial surface of the elbow joint; the rest coursed laterad deep to the *M. flexor carpi radialis* and supplied same and the *Mm. flexor carpi ulnaris*, *flexor digitorum (digitalis) profundus* (*Caput humerale*) and *flexor digitorum (digitalis) superficialis*. The remaining muscular branches also supplied, in a variable manner, the preceding muscles.

8. The *A. interossea communis* - The common interosseous artery arose as the last branch of the brachial artery approximately 3 cm below the elbow joint at the level of the interosseous space of the forearm. It was well developed. Close to its origin it gave off a strong muscular branch directed somewhat distolaterally between the radius and flexor muscles, and finally vascularized both bellies of the *Caput humerale* of the *M. flexor digitorum (digitalis) profundus*. The common interosseous artery coursed proximolaterad towards the interosseous space of the forearm and, before reaching the latter space, released a very slender caudal interosseous artery. It then proceeded farther as the cranial interosseous artery.

a. The *A. interossea caudalis* - The caudal interosseous artery was very delicate, coursing distally along the opposing borders of the radius and ulna on their caudal aspect. It released a few tiny twigs on its way and finally entered the *Caput radiale* of the *M. flexor digitorum (digitalis) profundus* near the middle of the forearm. Koch (1965) stated that this vessel can also be absent.

b. The *A. interossea cranialis* - The cranial interosseous artery was the direct continuation of the parent vessel. It continued through the interosseous space of the forearm, and appeared on its craniolateral aspect where it gave off a few muscular twigs for the *Mm. ulnaris lateralis*, *extensor digitorum (digitalis) lateralis* and *extensor digitorum (digitalis) communis*. Inside the latter muscle it frequently anastomosed with a branch of the distal collateral radial artery, similar to the observations of Ellenberger and Baum (1943), Nickel and Wissdorf (1964) and Koch (1965). The cranial interosseous artery proceeded distally along the craniolateral aspect of the forearm between the *Mm. abductor digiti primi (pollicis) longus* and *extensor digitorum (digitalis) lateralis* to which it furnished a few twigs. Near the dorsolateral aspect of the carpus it split in a variable manner, contributing extensively in the formation of the *Rete carpi dorsale*. From the *Rete carpi dorsale* arose the *Aa. metacarpeae dorsales II et III (A. metacarpea dorsalis II (medialis) and IV (lateralis) of Baum, 1907)* which descended along the respective interosseous space on the dorsomedial and dorsolateral aspects of the metacarpus. During their course they released several twigs to supply the extensor tendons, fascia and skin covering the area. Originating from the parent vessel were:

(1) The *Ramus muscularis* - The strong muscular branch arose from the parent vessel before the latter entered the interosseous space of the forearm. This muscular branch stretched laterad between the bones of the forearm and the flexor muscles, where it split and supplied the *Caput ulnare* of the *M. flexor digitorum (digitalis) profundus* and the *M. ulnaris lateralis*.

(2) The *Aa. nutritiae radii et ulnaris* - The nutrient arteries for both the radius and ulna arose by a common trunk from the parent vessel during the latter's course through the interosseous space of the forearm. They entered the nutrient foramen situated at the lower limit of the interosseous space.

(3) The *A. interossea recurrens* - The recurrent interosseous artery arose from the parent vessel after the emergence of the latter from the interosseous space of the forearm. Ellenberger and Baum (1943) and Nickel and Wissdorf (1964) described it as originating from the *A. interossea dorsalis* or from the *A. collateralis radialis (distalis)* or "proximalis" of the latter authors. Here it lay deep to the *M. ulnaris lateralis* to which it supplied a twig. It began to ascend along the lateral aspect of the ulna and split into two slender branches. The caudal branch extended deep to the *Mm. flexor carpi ulnaris* and *ulnaris lateralis* towards the olecranon fossa of the humerus where it supplied the *M. anconeus* and caudal aspect of the elbow joint. Its cranial branch passed between the *Mm. ulnaris lateralis* and *extensor digitorum (digitalis) lateralis* and in front of the lateral humeral epicondyle it anastomosed with the descending branch of the lateral branch of the deep brachial artery (in agreement with other authors mentioned previously) and a muscular branch of the distal collateral radial artery. However, Ellenberger and Baum (1943), Sisson and Grossman (1953), Dobberstein and Hoffmann (1964), Nickel and Wissdorf (1964), Schwarze and Schröder (1964) and Koch (1965) observed an anastomosis between this vessel and branches of the *A. profunda brachii* and *A. collateralis ulnaris*.

A. mediana

The median artery was the distal extension of the brachial artery (A. brachialis) beyond the origin of the common interosseous artery (A. interossea communis). It descended along the caudomedial aspect of the radius, deep to the M. flexor carpi radialis. Approximately one inch above the accessory carpal bone the median artery gave off medially the radial artery and, almost at the same level, divided into medial and lateral palmar arteris. During its course it detached the following:

1. The Rami musculares - The muscular branches were few and of variable size and origin. They arose from either side of the parent vessel and vascularized mainly the Mm. flexor carpi radialis, flexor carpi ulnaris, flexor digitorum (digitalis) superficialis and the Caput humerale and Caput radiale of the M. flexor digitorum (digitalis) profundus.

2. The A. retis carpi caudalis - The artery to the caudal rete of the carpus was strongly developed and left the cranial aspect of the parent vessel. It extended somewhat distocranially, deep to the M. flexor carpi radialis and within the distal third of the forearm, beneath the Caput radiale of the M. flexor digitorum (digitalis) profundus, it split into several branches supplying, essentially, the caudal aspect of the carpus, where it anastomosed with the branches of the lateral palmar and radial arteries to constitute the Rete carpi caudale. Some of its twigs passed distocranially around the distal part of the medial border of the radius and participated in the formation of the Rete carpi dorsale.

3. The A. radialis (A. metacarpica volaris profunda medialis of Baum, 1907; Ellenberger and Baum, 1943; Schummer, 1951; Dobberstein and Hoffmann, 1964; Schwarze and Schröder, 1964; DeVos, 1965; Koch, 1965; A. metacarpea volaris medialis of Sisson and Grossman, 1953; Tagand and Barone, 1957; A. medianoradialis of Nickel and Wissdorf, 1964). - The radial artery separated from the medial aspect of the parent vessel approximately an inch above the accessory carpal bone. According to Ellenberger and Baum (1943) and Sisson and Grossman (1953) it can also originate from a common trunk with the lateral (deep) volar metacarpal artery. It continued distally in company with the medial palmar artery through the carpal canal. At the level of the carpometacarpal articulation it released a small branch which coursed beneath the Lig. accessorium of the M. flexor digitorum (digitalis) profundus and assisted in the formation of the Rete carpi caudale. Slightly below the carpus it gave off two transverse anastomotic branches laterally which joined corresponding branches of the lateral palmar artery to constitute the proximal (superficial) palmar arch (Arcus palmaris proximalis superficialis) between the Lig. accessorium of the M. flexor digitorum (digitalis) profundus and the M. interosseus medius, and the proximal (deep) palmar arch (Arcus palmaris proximalis profundus) between the M. interosseus medius and the large (third) metacarpal bone. The middle palmar metacarpal artery (A. metacarpea palmaris mediana) arose from the proximal (deep) palmar arch and descended between the M. interosseus medius and the large metacarpal bone. It finally opened in the distal (deep) palmar arch or medial articular branch by either arising from a common trunk close to the latter's origin from the A. digitalis palmaris lateralis or from the Ramus anastomoticus, or both. On its way it also supplied a few twigs to the M. interosseus medius. Subsequently, the radial artery

passed deep to the preceding muscle and continued as the second palmar metacarpal artery (*A. metacarpea palmaris II*) along the interosseous space between the second and third metacarpal bones. During its course it communicated with the corresponding dorsal artery by means of several delicate twigs (*Rami perforantes*) traversing the interosseous space. Within the middle two-thirds of the metacarpus it detached the nutrient artery to the third metacarpal bone and also released a few twigs to the *M. interosseus medius*. Ellenberger and Baum (1943) and Schwarze and Schröder (1964) reported that the nutrient artery can also originate from the lateral deep volar metacarpal artery. In one specimen, the middle palmar metacarpal artery (*A. metacarpea palmaris mediana*) arose from the radial artery, following the origin of the nutrient artery of the large metacarpal bone, instead of arising directly from the proximal (deep) palmar arch as stated above. Near the button process (distal end) of the second metacarpal bone the second palmar metacarpal artery joined the middle and third metacarpal arteries, between the third metacarpal bone and *M. interosseus medius*, to constitute the distal (deep) palmar arch (*Arcus palmaris distalis profundus*). Originating from the radial artery were:

a. The *Rami carpei dorsalia* - Two to three slender branches arose from the parent vessel, both above and below the carpus, to furnish twigs to the *Rete carpi dorsale*.

b. The *Rami musculares* - In the metacarpal region it gave off several tiny twigs to supply the *M. interosseus medius* and the *Lig. accessorium* of the *M. flexor digitorum (digitalis) profundus*.

A. palmaris lateralis (*A. metacarpica volaris profunda lateralis* of Baum, 1907; Ellenberger and Baum, 1943; Schummer, 1951; Dobberstein and Hoffmann, 1964; Schwarze and Schröder, 1964; DeVos, 1965; Koch, 1965; *A. metacarpea volaris lateralis* of Sisson and Grossman, 1953; Tagand and Barone, 1957; *Ramus volaris profundus* of *A. mediana* of Nickel and Wissdorf, 1964).

The lateral palmar artery arose as the smaller termination of the median artery approximately an inch above the accessory carpal bone. It passed distolaterad towards the accessory carpal bone, and deep to the *M. flexor carpi ulnaris* it split into three branches. The proximal branch communicated with a branch of the *A. collateralis ulnaris* between the preceding muscle and the *M. ulnaris lateralis*. The middle branch coursed laterad, emerged between the two parts of the tendon of insertion of the *M. ulnaris lateralis* and finally ramified along the caudolateral aspect of the carpus. Some of its twigs were destined to contribute to the *Rete carpi dorsale* as well. In one specimen, it also contributed twigs to the proximal (deep) palmar arch. The distal branch continued the lateral palmar artery between the flexor tendons and the accessory carpal bone. Slightly below the carpus it released two transverse anastomotic branches mediad. These joined similar ones from the radial artery to form both proximal superficial and deep palmar arches. At this place it also gave off a few slender branches which passed upwards medial to the accessory carpal bone. They later stretched beneath the *Lig. accessorium* of the *M. flexor digitorum (digitalis) profundus* and anastomosed with the branches of the radial artery and the *A. retis carpi caudalis* to

form the Rete carpi caudale. Thereafter, the distal branch coursed in the interosseous space between the third and fourth metacarpal bones deep to the M. interosseus medius as the third palmar metacarpal artery (A. metacarpea palmaris III). In one specimen, the third palmar metacarpal artery (A. metacarpea palmaris III) originated from the proximal (deep) palmar arch, instead of being the direct distal extension of the lateral palmar artery. However, during its course it communicated via small twigs (Rami perforantes) with the corresponding dorsal artery through the interosseous space. Slightly below the button process (distal end) of the fourth metacarpal bone it coursed mediad and opened in the distal (deep) palmar arch, and also in the lateral articular branch close to its origin from the A. digitalis palmaris lateralis. The latter vascular arch communicated with the A. digitalis palmaris lateralis near its bifurcation from the medial palmar artery by means of the Ramus anastomoticus coursing through the angle of divergence of the M. interosseus medius. This union constituted the distal (superficial) palmar arch (Arcus palmaris distalis superficialis).

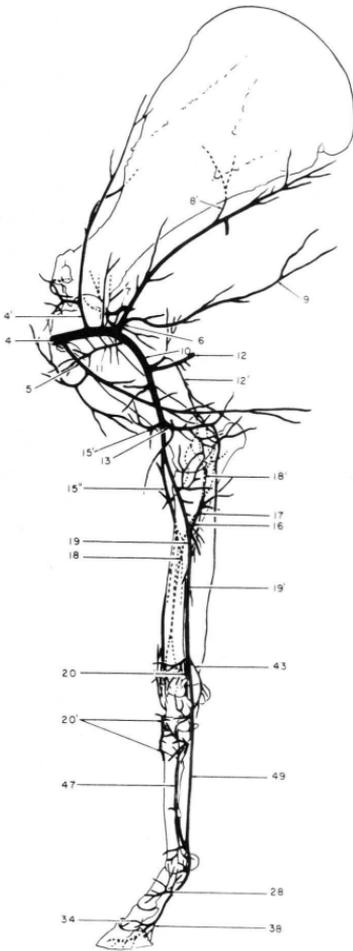
A. palmaris medialis (A. metacarpica volaris superficialis of Ellenberger and Baum, 1943; Schummer, 1951; Dobberstein and Hoffmann, 1964; Schwarze and Schröder, 1964; Koch, 1965; A. digitalis communis s. metacarpea volaris superficialis of Sisson and Grossman, 1953; Tagand and Barone, 1957; A. mediana of Nickel and Wissdorf, 1964; A. metacarpea volaris superficialis III of DeVos, 1954). -

The medial palmar artery was the distal extension of the median artery in the digital region. It descended through the carpal canal below the flexor retinaculum (Retinaculum flexorum) and lay superficially, somewhat medial to the flexor tendons. On its course it released several tiny twigs to furnish the fascia, skin and adjoining tendon sheaths. At the level of the button process of the second metacarpal bone it coursed between the flexor tendons and the M. interosseus medius and divided into two palmar digital arteries.

1. The A. digitalis palmaris medialis (A. digitalis medialis of Ellenberger and Baum, 1943; Schummer, 1951; Dobberstein and Hoffmann, 1964; Schwarze and Schröder, 1964; Koch, 1965; A. digitalis volaris propria medialis of Sisson and Grossman, 1953; A. digiti III volaris medialis of Nickel and Wissdorf, 1964). -

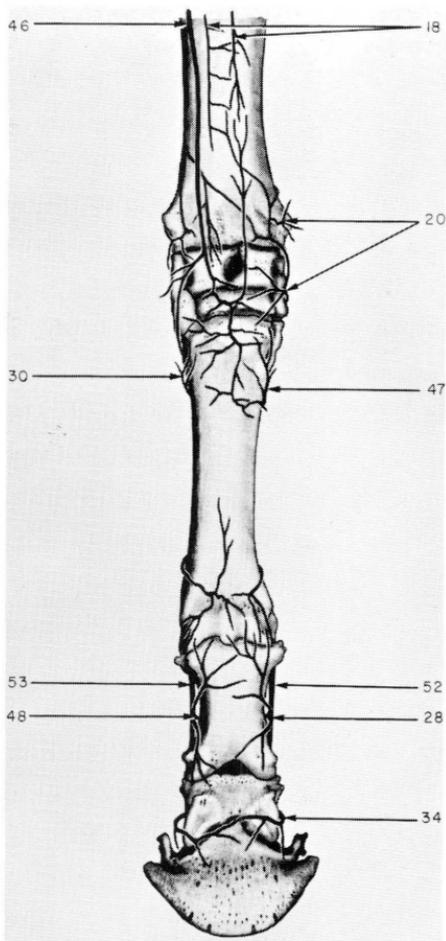
The medial palmar digital artery extended distally in the groove bounded by the abaxial branch of the M. interosseus medius and the flexor tendons along the medial aspect of the fetlock joint with the corresponding vein in front and the nerve behind. On its course it released numerous small slender twigs to vascularize the fascia, skin, tendon sheaths, joint capsules and ergot. It entered the distal phalanx through the Foramen soleare mediale and joined its fellow of the opposite side to form the terminal arch. Small twigs emerged through the foramina and supplied the sole and corium of the distal phalanx. In addition, it gave off the following branches:

a. The Ramus articularis - At the level of the fetlock joint it arose from the dorsal aspect of the parent vessel, from the Ramus anastomoticus, or together with the lateral articular branch from the A. digitalis palmaris lateralis. It furnished twigs to the above-mentioned joint and the fascia and skin around it.



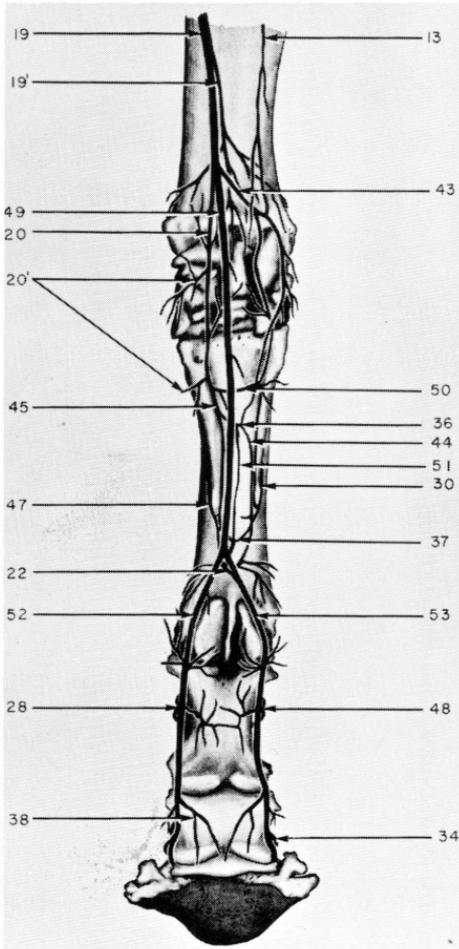
- 4. A. axillaris
- 4'. A. thoracoacromialis
- 5. A. thoracica externa
- 6. Truncus subscapularis
- 7. A. circumflexa humeri caudalis
- 8'. A. circumflexa scapulae
- 9. A. thoracodorsalis
- 10. A. brachialis
- 11. A. circumflexa humeri cranialis
- 12. A. profunda brachii
- 12'. A. collateralis radialis proximalis
- 13. A. collateralis ulnaris
- 15'. A. bicipitalis
- 15''. A. collateralis radialis distalis
- 16. A. interossea communis
- 17. A. interossea caudalis
- 18. A. interossea cranialis
- 18'. A. interossea recurrens
- 19. A. mediana
- 19'. A. retis carpi caudalis
- 20. A. radialis
- 20'. Rami carpei dorsalia
- 28. A. digitalis dorsalis medialis
- 34. A. coronaria
- 38. Ramus pulvinus distalis
- 43. A. palmaris lateralis
- 47. A. metacarpea dorsalis II
- 49. A. palmaris medialis

Figure 1. The arterial blood supply to the thoracic limb of the horse via axillary artery (A. axillaris); medial view (schematic).



- 18. Branches of *A. interossea cranialis*
- 20'. *Rami carpei dorsalia*
- 28. *A. digitalis dorsalis medialis*
- 30. *A. metacarpea dorsalis III*
- 34. *A. coronaria*
- 46. Truncus communis for *A. collateralis radialis distalis* and *A. interossea cranialis*
- 47. *A. metacarpea dorsalis II*
- 48. *A. digitalis dorsalis lateralis*
- 52. *A. digitalis palmaris medialis*
- 53. *A. digitalis palmaris lateralis*

Figure 2. Arteries of the distal part of right thoracic limb of the horse: dorsal view (schematic).



- | | |
|------|---|
| 13. | A. collateralis ulnaris |
| 19. | A. mediana |
| 19'. | A. retis carpi caudalis |
| 20. | A. radialis |
| 20'. | Rami carpei dorsalia |
| 22. | Arcus palmaris distalis superficialis |
| 28. | A. digitalis dorsalis medialis |
| 30. | A. metacarpea dorsalis III |
| 34. | A. coronaria |
| 36. | Arcus palmaris proximalis profundus |
| 37. | Arcus palmaris distalis profundus |
| 38. | Ramus pulvinus distalis |
| 43. | A. palmaris lateralis |
| 44. | A. metacarpea palmaris III |
| 45. | A. metacarpea palmaris II |
| 47. | A. metacarpea dorsalis II |
| 48. | A. digitalis dorsalis lateralis |
| 49. | A. palmaris medialis |
| 50. | Arcus palmaris proximalis superficialis |
| 51. | A. metacarpea palmaris mediana |
| 52. | A. digitalis palmaris medialis |
| 53. | A. digitalis palmaris lateralis |

Figure 3. Arteries of the distal part of right thoracic limb of the horse: palmar view (schematic).

b. The *A. digitalis dorsalis medialis* (*A. phalangis primae* of Ellenberger and Baum, 1943; Sisson and Grossman, 1953; Tagand and Barone, 1957; Dobberstein and Hoffmann, 1964; Schwarze and Schröder, 1964; Koch, 1965; *A. digiti III dorsalis medialis* of Nickel and Wissdorf, 1964).

The medial dorsal digital artery arose from the dorsal aspect of the parent vessel near the middle of the proximal phalanx. Close to its origin it released a transverse branch which anastomosed with a corresponding one from the other side between the *Lig. sesamoidea distale rectum* and *Ligg. sesamoidea distalia obliqua* deep to the flexor tendons. Shortly after, it split and some of its twigs ascended deep to the extensor slip of the *M. interosseus medius* and almost reached the dorsomedial aspect of the fetlock joint.

c. The *Ramus pulvinus distalis* - It arose at the level of the distal extremity of the proximal phalanx from the palmar aspect of the parent vessel. It supplied essentially the bulb of the heel and the adjoining structures.

d. The *A. coronaria* - The coronary artery left the dorsal aspect of the parent vessel near the middle of the middle phalanx. It coursed dorsally and gave off twigs to the proximal interphalangeal articulation and the tendon of the *M. extensor digitorum (digitalis) communis*. It continued farther and anastomosed with its fellow of the opposite side, thereby forming an arterial coronary circle.

2. The *A. digitalis palmaris lateralis* (*A. digitalis lateralis* of Ellenberger and Baum, 1943; Schummer, 1951; Dobberstein and Hoffmann, 1964; Schwarze and Schröder, 1964; Koch, 1965; *A. digitalis volaris propria lateralis* of Sisson and Grossman, 1953; *A. digiti III volaris lateralis* of Nickel and Wissdorf, 1964). -

The lateral palmar digital artery had a course and branching identical to its fellow of the opposite side, except for the following. Close to its origin it usually gave off a common trunk for both medial and lateral articular branches. Both lay between the third metacarpal bone and the *M. interosseus medius* and supplied the palmar aspect of the fetlock joint. Some of their twigs also coursed to the dorsomedial and dorsolateral aspects of the distal end of the third metacarpal bone slightly above the fetlock joint. The medial articular branch was also seen to arise from the *A. digitalis palmaris medialis* or the *Ramus anastomoticus*, connecting the distal deep palmar arch with the *A. digitalis palmaris lateralis*. It received a part of the distal confluence of the *A. metacarpea palmaris II*. It gave off the *A. digitalis dorsalis lateralis* near the middle of the proximal phalanx.

Part II. Pelvic Limb

The external iliac artery (*A. iliaca externa*) arose from abdominal aorta (*Aorta abdominalis*), usually in front of the origin of the internal iliac artery (*A. iliaca interna*), ventral to the body of the fifth lumbar vertebra. According to Tagand and Barone (1957) and Schwarze and Schröder (1964) it can also arise ventral to the last lumbar vertebra. It continued ventrocaudally, along the tendon of the *M. psoas minor* at the side of the pelvic inlet, to the cranial border of the pubis and coursed beyond this limit as the femoral artery (*A. femoralis*), accompanying the

N. saphenus, inside the femoral canal on the medial aspect of the thigh. Originating from it were:

1. The A. circumflexa ilium profunda - The deep circumflex iliac artery arose from the lateral surface of the parent vessel close to its origin or according to Ellenberger and Baum (1943), Sisson and Grossman (1953), Schwarze and Schröder (1964) and Koch (1965), it can occasionally originate from the aorta. It coursed laterad for approximately 5 cm along the medioventral aspect of the Mm. iliopsoas and psoas minor towards the Spina iliaca ventralis (tuber coxae). Under the iliac fascia and near the lateral border of the M. psoas major it divided into an ascending and a descending branch.

The ascending or cranial branch passed craniolaterad, and branched variably to vascularize the sublumbar muscles, the Lnn. iliaci mediales, the Mm. longissimus thoracis, gluteus medius and tensor fasciae latae. It coursed cranially between the Mm. transversus abdominis and obliquus internus abdominis and vascularized them. In addition, it furnished twigs to the M. obliquus externus abdominis and the fascia and skin of the flank region.

The descending or caudal branch passed directly ventrad. Following a course of approximately 2.5 cm it divided again into a cranial and caudal branch. The cranial branch continued distally and ramified extensively inside the M. obliquus internus abdominis, whereas its caudal branch pierced the abdominal wall between the Mm. iliacus and obliquus internus abdominis, accompanying the N. cutaneus femoris lateralis, and descended along the medial face of the M. tensor fasciae latae beyond the subiliac lymph nodes (Lnn. subiliaci). During its distal course it vascularized the preceding muscles extensively and also the M. cutaneus trunci and the fascia and skin on the craniomedial surface of the thigh. According to Ellenberger and Baum (1943), Bruni and Zimmerl (1951), Schwarze and Schröder (1964) and Koch (1965) the caudal branch gave off some mammary branches in the female.

2. The A. cremasterica - The cremaster artery, formerly known as the external spermatic artery, was a small vessel with very variable origin. It was present in the male. It may arise variably from the external iliac artery close to the origin of the deep circumflex iliac artery (Ellenberger and Baum, 1943; Sisson and Grossman, 1953; Tagand and Barone, 1957; Schwarze and Schröder, 1964; Koch, 1965; Rooney et al., 1967). It can also arise either from the deep circumflex iliac artery (Ellenberger and Baum, 1943; Sisson and Grossman, 1953; Schwarze and Schröder, 1964; Koch, 1965) or together with the internal iliac artery (Ellenberger and Baum, 1943; Sisson and Grossman, 1953; Koch, 1965). In some cases it is said to arise from the aorta between the external and internal iliac arteries (Sisson and Grossman, 1953; Tagand and Barone, 1957). It was a flexuous vessel, and ran extraperitoneally to the inguinal canal, accompanying the M. cremaster, between the peritoneum and transverse fascia. It traversed the deep inguinal ring, being situated between the two layers of the mesorchium. It supplied the M. cremaster (Sisson and Grossman, 1953; Schwarze and Schröder, 1964), constituents of the spermatic cord (Sisson and Grossman, 1953; Tagand and Barone, 1957; Schwarze and Schröder, 1964), tunica vaginalis (Ellenberger and Baum 1943; Bruni and Zimmerl 1951; Sisson and Grossman 1953; Schwarze

and Schröder, 1964), and epididymis (Bruni and Zimmerl, 1951; Tagand and Barone, 1957). According to Dobberstein and Hoffmann (1964) it also supplied the scrotum, the skin and prepuce of the penis and, in the horse, in addition, the tip of the penis and glans penis. It anastomosed with branches of the A. ductus deferentis near the tail of the epididymis (Ellenberger and Baum, 1943; Koch, 1965).

3. The A. uterina - The uterine artery, formerly known as the middle uterine artery, arose at the same place as the cremaster artery in the male. It had a large caliber and coursed between the two lamina of the broad ligament (mesometrium). On reaching the lesser curvature or mesometrial border of the uterus it split and supplied the horn and body of the uterus. The uterine artery anastomosed with the Ramus uterinus (cranialis) of the A. ovarica cranially and Ramus uterinus (caudalis) of the A. urogenitalis (A. vaginalis) caudally. Ellenberger and Baum (1943) asserted that it did not correspond to the A. spermatica externa of the male. On the contrary Sisson and Grossman (1953) stated that the A. uterina media was regarded as the homologue of the A. spermatica externa.

A. profunda femoris

The deep femoral artery arose from the medial aspect of the external iliac artery at the level of the cranial border of the pubis, before it coursed between the Mm. iliacus and sartorius. The deep femoral artery was directed caudad ventral to the pubic bone between the Mm. pectineus, iliopsoas and rectus abdominis. On its course it released several twigs to supply the Lnn. inguinales profundi proprii.

1. The Truncus pudendoepigastricus - The pudendoepigastric trunk originated from the parent vessel approximately 2 cm distal near the upper limit of the Lnn. inguinales profundi proprii. The common trunk coursed for approximately 3 cm before bifurcating into two terminal branches of almost equal size—the caudal epigastric and external pudic arteries.

a. The A. epigastrica caudalis - The caudal epigastric artery was one of the terminal branches of the parent vessel. It passed between the Mm. obliquus internus abdominis and rectus abdominis, detached a few twigs to the preceding muscles during its cranial course and then finally entered the belly of the M. rectus abdominis along its deep face.

b. The A. pudenda externa - The external pudic artery left the abdominal cavity through the deep inguinal ring. After emerging at the superficial inguinal ring it supplied a branch to the superficial inguinal lymph nodes and continued as the mammary artery (A. mammaria), from which the slender caudal superficial epigastric artery arose and coursed cranial along the superficial face of the M. rectus abdominis. In the male, the external pudic artery continued as the dorsal artery of the penis (A. dorsalis penis).

2. The A. circumflexa femoris medialis - The medial circumflex femoral artery was the continuation of the deep femoral artery beyond the origin of the pudendoepigastric trunk. It proceeded caudad, ventral to the pubic bone between the Mm. pectineus, iliopsoas and obturatorius externus. It pierced the M. adductor and reached the M. semimembranosus. Its continuation passed at first between the Mm. adductor and

obturatorius externus and subsequently between the latter and the *M. quadratus femoris* to which it furnished a few slender twigs. It finally ramified within the deep face of the *M. biceps femoris*. During its course it gave off the following branches.

a. The *Rami musculares* - Several muscular branches of variable size originated from the parent vessel. They essentially supplied the *Mm. pectineus, iliopsoas, obturatorius externus, adductor, gracilis* and *semi-membranosus*. In addition, it also released a few twigs to the *Lnn. inguinales profundi proprii*.

b. The *Ramus obturatorius* - The obturator branches were slender, usually two in number. They originated from the dorsal aspect of the parent vessel during the latter's course between the *Mm. iliopsoas, obturatorius externus* and *pectineus*. They proceeded towards the obturator foramen. Other investigators state that the vessels anastomose with the obturator artery (*A. obturatoria*) from the internal pudic artery (Ellenberger and Baum, 1943; Schwarze and Schröder, 1964).

A. femoralis

The femoral artery was the distal extension of the external iliac artery in the pelvic limb following the departure of the deep femoral artery. It extended distocaudally at first between the *Mm. sartorius* and *iliopsoas* and then between the *Mm. sartorius, pectineus, vastus medialis* and *adductor*. In the region of the thigh it descended inside the femoral canal along with the *N. saphenus* in front, and the *V. femoralis* behind. As it approached the insertion of the *M. pectineus*, it gradually coursed somewhat distolaterad around the caudal surface of the femur beneath the *M. adductor* to the popliteal surface of the femur. Here it continued as the popliteal artery (*A. poplitea*) between the two heads of the *M. gastrocnemius*. Arising from the femoral artery were:

1. The *Ramus muscularis* - A very delicate muscular twig arose shortly after the origin of the parent vessel to supply the *M. sartorius*.

2. The *A. femoris cranialis* - The cranial femoral artery was of considerable size and arose after 1.5 cm from the beginning of the parent vessel. According to Ellenberger and Baum (1943), Bruni and Zimmerl (1951) and Sisson and Grossman (1953) the cranial femoral artery is sometimes replaced by a strong branch of the *A. circumflexa femoris lateralis*. It passed between the *Mm. sartorius, vastus medialis* and *psoas major* and released twigs to them. It coursed distocranial inside the belly of the *M. rectus femoris* which it supplied extensively to its insertion on the patella. Besides, it also detached a few twigs to the *M. vastus medialis*.

3. The *Rami musculares* - Several muscular branches originated from the parent vessel during its distal course, supplying the *Mm. sartorius, pectineus, adductor, vastus medialis* and *semimembranosus*.

4. The *A. saphena* - The saphenous artery left the medial aspect of the femoral artery near the middle of the thigh. It coursed distocaudally between the *Mm. adductor* and *gracilis* and at the level of the patella it emerged subcutaneously between the aponeurotic insertions of the *Mm. sartorius* and *gracilis*. On its way it vascularized the *Mm. adductor, gracilis* and *sartorius* by means of small twigs. It descended distocaudally behind the medial tibial condyle, lying subcutaneously on the

aponeurotic insertion of the *M. gracilis*. In the region of the leg it proceeded caudad and came to lie in front of the *Tendo calcaneus communis*. It gave off numerous tiny twigs to supply the fascia and skin on the medial aspect of the leg. Finally, it communicated with the medial tarsal artery via the recurrent tibial artery, similar to the observations of Ellenberger and Baum (1943), Bruni and Zimmerl (1951), Dobberstein and Hoffmann (1964), Schwarze and Schröder (1964) and Koch (1965). However, Tagand and Barone (1957) stated that the caudal branch of the saphenous artery anastomosed with a branch of the posterior tibial artery at the level of the tuber calcanei. According to Ellenberger and Baum (1943) and Schwarze and Schröder (1964) sometimes the *A. saphena* was strongly developed and continued as the *A. tarsea medialis* without forming an anastomosis with the *A. recurrens tibialis*. In one instance, it received a twig from the descending branch of the caudal femoral artery approximately 6 cm above the tuber calcanei before opening in the recurrent tibial artery as mentioned above.

5. The *A. nutritia femoris* - The nutrient artery of the femur arose from the caudal aspect of the femoral artery, approximately 1 cm distal to the preceding vessel. According to Ellenberger and Baum (1943) it can also arise from the *A. femoris caudalis*. Tagand and Barone (1957) described the nutrient artery of the femur as originating usually in common with a small muscular branch from the femoral artery. It coursed somewhat upward and backward, released a twig to the *M. vastus medialis* and then entered the nutrient foramen of the femur.

6. The *A. genus descendens* - The descending genicular artery was relatively large. It arose from the cranial aspect of the parent artery at the distal third of the thigh. Close to its origin it gave off a few twigs to the *Mm. sartorius* and *vastus medialis* and passed distocranially between them and the *M. adductor* towards the patella and the medial aspect of the femorotibial joint. On its distal course it also supplied the *Mm. adductor* and *vastus medialis* and the joint capsule, including the adjoining ligaments.

7. The *Rami musculares* - A few muscular branches of variable size originated from the caudal aspect of the parent artery, slightly above the medial supracondyloid crest, to vascularize the *Mm. semimembranosus*, *pectineus* and *adductor*.

8. The *A. femoris caudalis* - The caudal femoral artery was a strong vessel, arising from the lateral aspect of the parent artery. Close to its origin it gave off two relatively large branches to supply the *M. gastrocnemius* (*Caput laterale*) and *M. flexor digitorum* (*digitalis superficialis*). Following a course of approximately 1 cm it divided into an ascending and a descending branch. According to Ellenberger and Baum (1943) and Schwarze and Schröder (1964) these branches can originate separately from the parent vessel. One of these branches extended distally between the lateral head of the *M. gastrocnemius* and the *M. flexor digitorum* (*digitalis superficialis*) and descended along the lateral aspect of the *Tendo calcaneus communis*. Near the distal third of the leg it communicated with the recurrent tarsal artery.

a. The ascending branch coursed dorsolaterad in the space between the origin of the *M. gastrocnemius* (*Caput laterale*) and the insertion of the *M. adductor* under cover of the *M. biceps femoris*. During its course

it furnished small twigs to the preceding muscles. It continued upwards and extensively supplied the *Mm. vastus lateralis*, *semitendinosus*, *semimembranosus* and *biceps femoris* to the third trochanter of the femur. Ellenberger and Baum (1943), Schwarze and Schröder (1964) and Koch (1965) described a slender vessel arising from one of its muscular branches which descended along the *Tendo calcaneus communis* and anastomosed with the *A. tarsea recurrens*. According to Tagand and Barone (1957) the *Ramus ascendens* anastomosed with the ischiatic and obturator arteries.

b. The descending branch was the stronger terminations of the caudal femoral artery. It coursed distally between the two heads of the *M. gastrocnemius* for a short distance before splitting into a few muscular branches. Some of these branches ascended to supply the *Mm. semitendinosus* and *biceps femoris*. Its descending branches vascularized the *Mm. semitendinosus*, *gastrocnemius* (*Caput laterale*) and *flexor digitorum (digitalis) superficialis*. Besides, it released several twigs to the *Lnn. poplitei*. One of these branches continued distally along the deep face of the medial head of the *M. gastrocnemius* and descended on the medial aspect of the *Tendo calcaneus communis*. Near the *tuber calcanei* it communicated with the medial tarsal artery via the recurrent tibial artery, similar to the observations of Ellenberger and Baum (1943), Sisson and Grossman (1953), Dobberstein and Hoffmann (1964), Schwarze and Schröder (1964) and Koch (1965). However, Bruni and Zimmerl (1951) described a small branch of the *Ramus descendens* to anastomose with the recurrent tarsal artery at the level of the tarsus. In addition, Tagand and Barone (1957) and Schwarze and Schröder (1964) mentioned a small branch of the *Ramus descendens* as anastomosing with a descending branch of the *A. obturatoria*. In one case, this descending branch joined the saphenous artery about 6 cm above the *tuber calcanei* before opening in the medial tarsal artery.

A. poplitea

The popliteal artery continued the femoral artery in the region of the leg, beyond the origin of the caudal femoral artery (*A. femoris caudalis*), between the two heads of the *M. gastrocnemius*. It formed a trunk of approximately 10 cm and passed through the intercondyloid fossa of the femur. On its way it gave off a few strong muscular branches to supply both heads of the *M. gastrocnemius* and *Mm. flexor digitorum (digitalis) superficialis* and *soleus*. Some of these branches also furnished the caudal aspect of the stifle joint capsule. One of these branches stretched beneath the lateral head of the *M. gastrocnemius* and at the lateral supracondyloid crest of the femur, divided into an ascending and a descending twig. The ascending twig coursed upwards between the femur and *M. vastus lateralis*, extensively supplying the preceding muscle and the *M. vastus intermedius*. Its descending branch extended distocranially over the lateral aspect of the stifle joint and supplied the adjoining ligaments and joint capsule. While coursing through the intercondyloid fossa it released a few twigs to supply the menisci and the associated ligaments. In addition, it detached a long slender superficial vessel coursing distomedially over the *M. popliteus* within which it expended entirely. It passed through the popliteal notch of the tibia, deep to the *M. popliteus*

to which it gave off a few twigs. Approximately 2.5 cm below the tibial condyles the popliteal artery divided into its terminal branches—the cranial and caudal tibial arteries.

A. tibialis caudalis

The caudal tibial artery was the smaller termination of the popliteal artery. While coursing deep to the M. popliteus it released several twigs to vascularize the preceding muscle and all heads of the M. flexor digitorum (digitalis) profundus. Within the proximal third of the leg it gave off a strong branch medially which split into several small branches. One of them proceeded as the A. nutritia tibiae and the rest ramified inside the M. flexor digiti primi (hallucis) longus. Within the middle two-thirds of the leg it gave off a strong branch on either side. The proximolateral branch stretched between the M. flexor digitorum (digitalis) longus and M. flexor digiti primi (hallucis) longus and ramified inside the latter muscle and the M. tibialis caudalis. The distomedial branch also maintained a similar relationship but was essentially distributed in the fascia and skin of the neighboring region. The continuation of the caudal tibial artery further released a few delicate twigs to the M. flexor digiti primi (hallucis) longus and, slightly above the tuber calcanei, it divided into medial and lateral tarsal arteries.

1. The A. tarsea lateralis - The lateral tarsal artery was the smaller termination of the caudal tibial artery. It passed laterad between the tibia and the tendon of the M. flexor digiti primi (hallucis) longus. It was mostly distributed on the lateral side of the tarsus and tuber calcanei.

a. The A. tarsea recurrens - The recurrent tarsal artery was a very delicate vessel which originated from the lateral tarsal artery. It ascended along the lateral aspect of the Tendo calcaneus communis and anastomosed with a branch of the caudal femoral artery, similar to the observations of Sisson and Grossman (1953) and Schwarze and Schröder (1964). But Ellenberger and Baum (1943), Dobberstein and Hoffmann (1964) and Koch (1965) described it as anastomosing with a branch of the Ramus ascendens of the A. femoris caudalis. According to Sisson and Grossman (1953), in some cases, an arch is formed by junction with the peroneal artery on the lateral surface of the deep flexor at the distal fourth of the leg.

2. The A. tarsea medialis - The medial tarsal artery was the stronger of the two end branches of the caudal tibial artery. Following its origin it described an S-shaped bend on the medial aspect of the tuber calcanei where it received the confluence of the saphenous artery and a branch of the descending branch of the caudal femoral artery via the recurrent tibial artery (A. tibialis recurrens), similar to the findings of Ellenberger and Baum (1943), Sisson and Grossman (1953), Schwarze and Schröder (1964) and Koch (1965). According to Schwarze and Schröder (1964) the A. tarsea medialis is double and united with the A. poplitea. During its distal course the medial tarsal artery detached numerous twigs to supply the Tendo calcaneus communis close to its insertion on the tuber calcanei, the flexor tendons, Ligamentum plantare longum and the ligaments and joint capsule on the caudomedial aspect of the tarsus. At the level of the sustentaculum tali it divided into two plantar arteries.

a. *A. plantaris lateralis* - The lateral plantar artery was one of the end branches of the medial tarsal artery. It passed deep between the *Ligamentum plantare longum* and the tendon of the *M. flexor digitorum (digitalis) profundus*. Here it released a few twigs to supply the tendon of the *M. flexor digitorum (digitalis) superficialis*, *Ligamentum plantare longum* and the plantar aspect of the tarsus. Slightly below the tarsus it participated in the formation of proximal superficial and deep plantar arches (*Arcus plantaris proximalis superficialis et profundus*) between the tendon of the *M. flexor digitorum (digitalis) profundus* and the *M. interosseus medius* and the latter and the large metatarsal bone, respectively. Later it descended along the lateral edge of the flexor tendons and opened in the *A. digitalis plantaris lateralis* slightly above the fetlock joint, constituting a part of the distal (superficial) plantar arch (*Arcus plantaris distalis superficialis*) between the tendon of the *M. flexor digitorum (digitalis) profundus* and the *M. interosseus medius*, in agreement with Baum (1907), Ellenberger and Baum (1943), Sisson and Grossman (1953), Schwarze and Schröder (1964) and Koch (1965). According to Ellenberger and Baum (1943) and Schwarze and Schröder (1964) it may also open in the *A. digitalis communis*. On its way it gave off a few twigs to furnish the fascia and the tendon sheaths.

b. *A. plantaris medialis* - The medial plantar artery was the distal extension of the medial tarsal artery. Following its separation from its fellow of the other side it continued distally along the plantaromedial aspect of the tarsus where it released a few twigs to vascularize the neighboring structures. Subsequently, below the tarsus it wound around the tendon of the *M. flexor digitorum (digitalis) profundus* and assisted in the formation of the proximal (superficial) plantar arch, as mentioned before, together with the lateral plantar artery and the *Ramus perforans proximalis* arising from the *A. dorsalis pedis*. From the proximal plantar arches arose the *Aa. metatarsae plantares II et III*. They continued distally between the large metacarpal bone and the *M. interosseus medius* and emptied in the *A. metatarsae dorsalis III* near the distal third of the metatarsus, thereby forming the distal (deep) plantar arch (*Arcus plantaris distalis profundus*), similar to the findings of Baum (1907) and Sisson and Grossman (1953). During their course the plantar metatarsal arteries gave off twigs to the *M. interosseus medius* and the periosteum of the large metatarsal bone. The medial plantar metatarsal artery (*A. metatarsae plantaris II*) was the stronger of the two and appeared to assume the distal extension of the *Ramus perforans proximalis* beyond the proximal plantar arches. The *A. metatarsae plantaris II* detached the nutrient artery to the large metatarsal bone within its middle two-thirds.

The medial plantar artery proceeded along the edge of the flexor tendons and, at the level of the fetlock joint, it opened in the *A. digitalis plantaris medialis* between the tendon of the *M. flexor digitorum (digitalis) profundus* and the *M. interosseus medius*, constituting a part of the distal (superficial) plantar arch (*Arcus plantaris distalis superficialis*), similar to the observations of Baum (1907), Ellenberger and Baum (1943), Sisson and Grossman (1953), Schwarze and Schröder (1964) and Koch (1965). According to Ellenberger and Baum (1943) and Schwarze and Schröder (1964) it can also open in the *A. digitalis communis*.

A. tibialis cranialis

The cranial tibial artery assumed the distal continuation of the popliteal artery. It coursed deep to the Mm. popliteus and flexor digitorum (digitalis) profundus. It gradually proceeded towards the caudolateral border of the tibia where it pierced the Membrana interossea cruris and appeared on the lateral surface of the tibia. After emergence it gave off several strong muscular branches to vascularize the Mm. tibialis cranialis, peroneus tertius, extensor digitorum (digitalis) longus and extensor digitorum (digitalis) lateralis. One of these branches coursed upwards between the latter muscle and the M. tibialis cranialis and finally ramified around the lateral meniscus and adjoining ligaments.

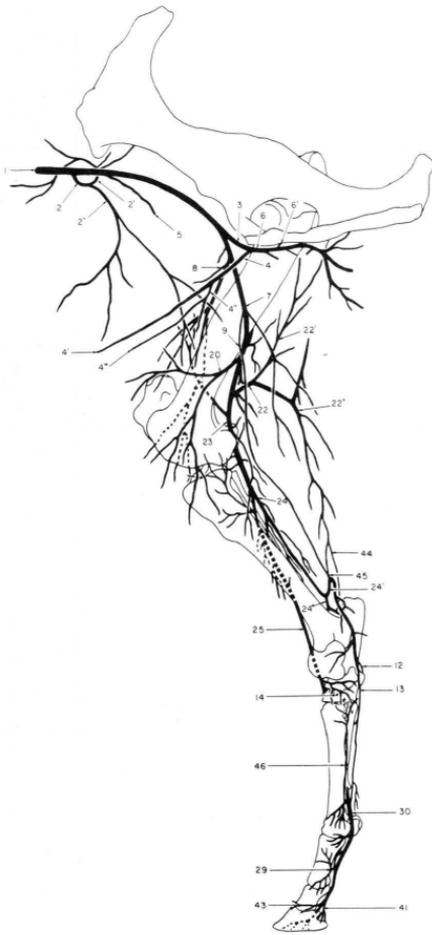
The cranial tibial artery descended farther along the flexor surface of the tarsus, beneath the Retinaculum extensorum proximale and the tendon of the M. extensor digitorum (digitalis) longus as the A. dorsalis pedis. Here it gave off a few twigs to form the Rete tarsi dorsale and to supply the M. extensor digitorum (digitalis) brevis and the cranial aspect of the tarsal joint capsule. From the Rete tarsi dorsale arose the A. metatarsa dorsalis II which descended in the dorsomedial groove between the second and third metatarsal bones.

The A. dorsalis pedis gave off a strong Ramus perforans proximalis which coursed beneath the M. extensor digitorum (digitalis) brevis and entered the tarsal canal. It emerged on the plantar aspect of the tarsus and joined the medial and lateral plantar arteries to form the proximal plantar arches. The A. dorsalis pedis, after giving off the Ramus perforans proximalis, became the A. metatarsus dorsalis III which extended along the dorsolateral aspect of the metatarsus in the groove bounded by the third and fourth metatarsal bones. It gradually coursed between the latter bones and appeared on the plantar surface of the third metatarsal bone between the latter and the M. interosseus medius. Within the distal third of the metatarsus it received the Aa. metatarsae plantares II et III, forming the distal (deep) plantar arch. It coursed distally between the angle of divergence of the M. interosseus medius and immediately split into two plantar digital arteries.

1. The A. digitalis plantaris medialis - The medial plantar digital artery continued distally in the groove bounded by the abaxial branch of the M. interosseus medius and the flexor tendons along the medial aspect of the fetlock joint with the accompanying vein in front and the nerve behind. Close to its origin it received the A. plantaris medialis and formed a part of the distal (superficial) plantar arch. On its course it released several tiny twigs to supply the fascia, skin, tendon sheaths, joint capsules and the ergot. It entered the distal phalanx through the Foramen soleare mediale and united with its fellow of the opposite side to form the terminal arch inside the bone. Small twigs emerged through the foramina and supplied the sole and corium of the distal phalanx. Besides, it gave off the following branches.

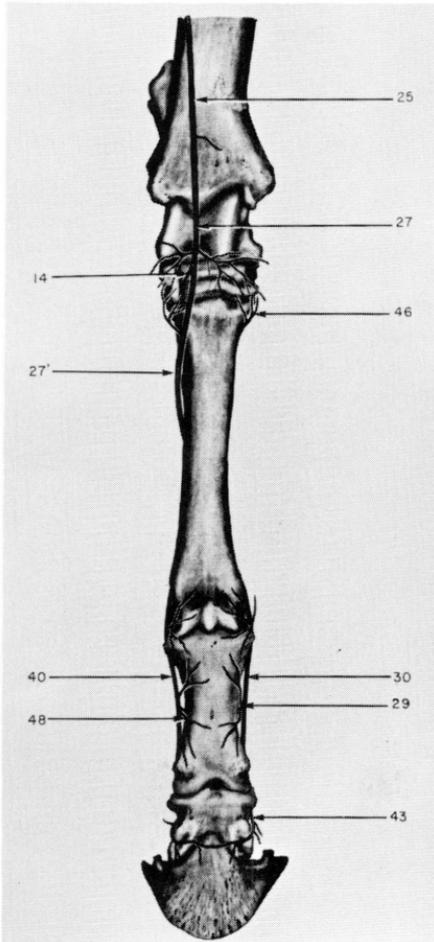
a. The Ramus articularis - At the level of the fetlock joint it arose from the dorsal aspect of the parent vessel and extended between the large metatarsal bone and the M. interosseus medius. It supplied twigs to the fetlock joint and the fascia and skin around it.

b. The A. digitalis pedis dorsalis medialis - The medial dorsal pedal digital artery arose from the dorsal aspect of the parent vessel near the



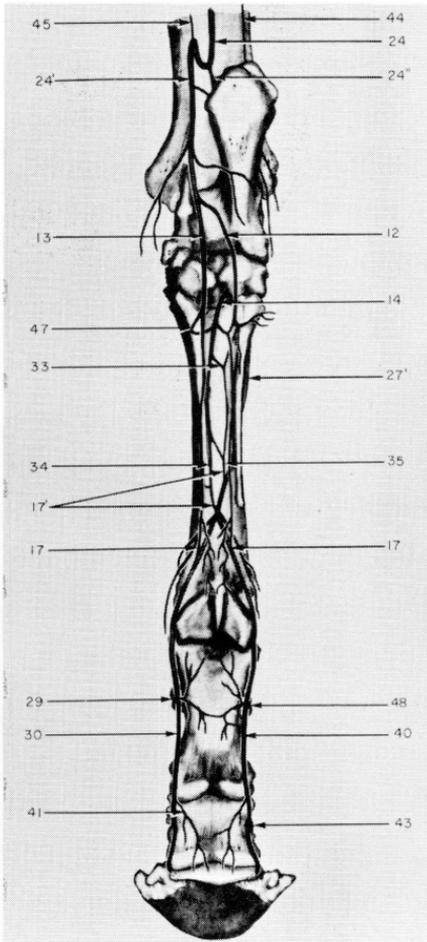
1. A. iliaca externa
2. A. circumflexa ilium profunda
- 2'. Ramus ascendens
- 2''. Ramus descendens
3. A. profunda femoris
4. Truncus pudendoepigastricus
- 4'. A. epigastrica caudalis
- 4''. A. pudenda externa
- 4'''. A. epigastrica caudalis superficialis
5. A. cremasterica or A. uterina
6. A. circumflexa femoris medialis
- 6'. Ramus obturatorius
7. A. femoralis
- 8'. A. femoris cranialis
9. A. saphena
12. A. plantaris lateralis
13. A. plantaris medialis
14. Ramus perforans proximalis
20. A. genus descendens
22. A. femoris caudalis
- 22'. Ramus ascendens
- 22''. Ramus descendens
23. A. poplitea
24. A. tibialis caudalis
- 24'. A. tarsea medialis
- 24''. A. tarsea lateralis
25. A. tibialis cranialis
29. A. digitalis pedis dorsalis medialis
30. A. digitalis plantaris medialis
41. Ramus pulvinus distalis
43. A. coronaria
44. A. tarsea recurrens
45. A. tibialis recurrens
46. A. metatarsea dorsalis II

Figure 4. The arterial blood supply to the pelvic limb of the horse via external iliac artery (A. iliaca externa); medial view (schematic).



- 14. Ramus perforans proximalis
- 25. A. tibialis cranialis
- 27. A. dorsalis pedis
- 27'. A. metatarsea dorsalis III
- 29. A. digitalis pedis dorsalis
medialis
- 30. A. digitalis plantaris
medialis
- 40. A. digitalis plantaris
lateralis
- 43. A. coronaria
- 46. A. metatarsea dorsalis II
- 48. A. digitalis pedis dorsalis
lateralis

Figure 5. Arteries of the distal part of right pelvic limb of the horse: dorsal view (schematic).



- 12. A. plantaris lateralis
- 13. A. plantaris medialis
- 14. Ramus perforans proximalis
- 17. Arcus plantaris distalis superficialis
- 17'. Arcus plantaris distalis profundus
- 24. A. tibialis caudalis
- 24'. A. tarsea medialis
- 24''. A. tarsea lateralis
- 27'. A. metatarsea dorsalis III
- 29. A. digitalis pedis dorsalis medialis
- 30. A. digitalis plantaris medialis
- 33. Arcus plantaris proximalis profundus
- 34. A. metatarsea plantaris II
- 35. A. metatarsea plantaris III
- 40. A. digitalis plantaris lateralis
- 41. Ramus pulvinus distalis
- 43. A. coronaria
- 44. A. tarsea recurrens
- 45. A. tibialis recurrens
- 47. Arcus plantaris proximalis superficialis
- 48. A. digitalis pedis dorsalis lateralis

Figure 6. Arteries of the distal part of right pelvic limb of the horse: plantar view (schematic).

middle of the proximal phalanx. Close to its origin it detached a transverse branch which anastomosed with a corresponding one from the other side between the Lig. sesamoidean distale rectum and Ligg. sesmoidea distalia obliqua deep to the flexor tendons. Shortly after it split and some of its twigs ascended deep to the extensor slip of the M. interosseus medius and almost reached the dorsomedial aspect of the fetlock joint.

c. The Ramus pulvinus distalis - It originated at the level of the distal end of the proximal phalanx from the plantar aspect of the parent vessel. It mainly supplied the bulb of the heel and the adjoining structures.

d. The A. coronaria - The coronary artery left the dorsal aspect of the parent vessel near the middle of the middle phalanx. It coursed dorsally and detached twigs to the proximal interphalangeal articulation and the tendon of the M. extensor digitorum (digitalis) longus. It continued farther and anastomosed with its fellow of the opposite side, constituting an arterial coronary circle.

2. The A. digitalis plantaris lateralis - The lateral plantar digital artery had an identical course and branching as its fellow of the opposite side. It also released the A. digitalis pedis dorsalis lateralis near the middle of the proximal phalanx.

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OUTDOOR RECREATION OF IOWANS—AT HOME¹Glenn H. Manning and Frederick S. Hopkins, Jr.²

ABSTRACT. Results of a survey of Iowa outdoor recreation are discussed. At-home recreation is a major component of Iowa outdoor recreation. Projections of at-home and away-from-home Iowa outdoor recreation are made. Implications of at-home outdoor recreation to recreational and regional planning are discussed.

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INTRODUCTION

Outdoor recreation at home seems a very important part of the total recreational picture. At-home recreation may constitute the major portion of recreational participation in many activities. Information concerning such recreation is not generally available. The National Recreational Survey and report of the Outdoor Recreation Resources Review Commission, published in 1962, and the National Recreation Survey of 1965, conducted by the Bureau of Outdoor Recreation, do not mention at-home recreation activities. Such information is needed for a complete picture of outdoor recreation for the nation as a whole as well as for Iowa. This report is made to provide information concerning at-home outdoor recreation to researchers concerned with outdoor recreation, and secondarily, to planners concerned with providing outdoor recreation to Iowans.

The principal source of information was a survey of outdoor recreation activity in Iowa conducted by the Department of Forestry, Iowa State University, in cooperation with the Statistical Laboratory and the Iowa Conservation Commission. The study covers participation in outdoor recreation during a 1-year period beginning with Labor Day, 1965. This survey provided estimates of participation of Iowans in various outdoor recreational activities and their preferences for such activities. The data derived provides a base for projections of outdoor recreational activity in future years.

As a portion of the survey, respondents were asked to indicate the activities engaged in both away from home and at their own residences. The at-home activities of Iowans are the major subject of this report.

This report concerns only the portion of the study dealing with recreation activities engaged in from June 1, 1966, to Labor Day, 1966. June to early September is the major outdoor recreation period for Iowans,

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since the weather most favorable to outdoor recreation occurs during this period. The outdoor activities not enjoyed during this period are the traditional winter sports, such as sledding, snow skiing, and ice skating. Even hunting varmints is to some extent enjoyed during the summer. For this reason, summer seemed the appropriate period to investigate.

DETAILED OBSERVATIONS

The data on which this report is based were collected in the fall of 1966. A sample design was used in selecting the actual sample such that every person 12 years old and older in the state had a chance of being selected. The sampling unit was the household. The sample was stratified by a 2-way geographic-population-density stratification. Five population densities were defined, ranging from large cities to open country. Counties or pairs of counties formed 77 geographic breakdowns. An arbitrary proportion of the total desired sampling units was assigned to the highest population-density strata. The remainder was allocated to the other strata in proportion to the number of housing units in each. In each sampling unit, every person 12 years old and older was listed, and a 2-of-5 systematic sample was drawn for complete interview. The number of persons interviewed was 812.

At-home outdoor recreation was defined as that occurring at the principal place of residence, whether urban or rural. Vacation homes and farms not occupied as residences were not included. All activities other than those at home are classified as away from home.

Several of the activities reported were also defined. Gardening was the noncommercial growing of flowers, fruit, and vegetables. It included yard maintenance, such as lawn mowing and leaf raking, if the participant indicated that he got pleasure from it. Picnicking (at home) was considered to mean a backyard barbecue or when meals prepared indoors were eaten in the yard. Relaxing was defined as any backyard activity that did not fit into one of the commonly accepted activities. Sunbathing, playing with children, playing cards, etc., were included in this category.

Table 1 summarizes the main variables in relation to at-home and away-from-home outdoor recreational activities for the relevant period.

At-home participation was reported for most activities. Activities lacking participation, and thus not reported, require specialized facilities (e.g., golf, tennis, driving for pleasure) or specialized resources (e.g., canoeing, water skiing) not commonly available on an urban residential property, or even on farms.

Because of physical differences between urban and residential properties, it might be anticipated that the activities and rates of participation for urban residents would differ appreciably from those of the rural population. The survey, however, did not indicate such a difference. Except for such resource-based activities as fishing, no significant difference was found between activities undertaken at home by urban Iowans or by rural residents.

Table 1. Location and Rates of Participation of Iowans 12 Years Old and Older in Outdoor Recreation Activities, June 1 through September 5, 1966.

Activity	Iowa Participants		Percentage of Iowans participating		Days of Participation		Mean days/participant	
	Number participating	Number participating	At-home	Away-from-home	Total days	At-home		
								Total days
Gardening	817	160	40.5	5.3	21,367	1,473	26.2	13.9
Picnics	876	1,520	43.6	75.8	7,687	9,162	8.8	6.0
Playing outdoor games	486	785	23.4	36.8	6,885	8,750	14.2	12.7
Badminton	143	173	7.1	8.6	1,581	804	11.1	4.7
Basketball	86	101	4.3	5.0	1,044	703	12.1	7.0
Baseball or softball	257	387	12.8	19.2	3,385	3,633	13.2	9.5
Archery	30	59	1.5	3.0	269	217	9.1	3.7
Horseshoes, croquet	121	155	6.0	7.8	688	836	5.7	5.4
Football, volleyball	64	212	3.1	10.5	649	1,108	10.1	5.3
Bird watching	118	190	5.8	9.1	3,543	1,071	29.9	6.1
Walking for pleasure	160	1,103	8.0	54.9	3,291	13,036	20.5	11.9
Horseback riding	64	202	3.2	10.1	1,258	1,628	19.6	8.0
Relaxing	25	99	1.2	4.9	693	274	28.1	2.8
Fishing	39	760	2.0	37.8	469	6,424	11.9	8.5

(thousands) (thousands) (thousands) (thousands) (thousands) (thousands) (thousands) (thousands)

RANKING OF PARTICIPATION

Among at-home activities, gardening is the most popular activity in terms of days of participation, but picnicking is the most popular in terms of number of participants. For away-from-home activities, driving for pleasure is first in popularity, with regard to both days of participation and number of participants.

The five most popular activities are in Table 2, both by number of days of participation and number of participants.

Table 2. Relative importance of various at-home and away-from-home recreational activities in Iowa, June 1 to September 5, 1966, by days of participation and number of participants.

At-home activities	Away-from-home activities
<u>Days of Participation</u>	
1. Gardening	1. Driving for pleasure
2. Picnicking	2. Walking for pleasure
3. Bird watching	3. Swimming
4. Playing baseball or softball	4. Bicycling
5. Walking for pleasure	5. Picnicking
<u>Number of Participants</u>	
1. Picnicking	1. Driving for pleasure
2. Gardening	2. Walking for pleasure
3. Playing baseball or softball	3. Sightseeing
4. Walking for pleasure	4. Attending outdoor games
5. Playing badminton	5. Fishing

RELATIVE INTENSITIES OF PARTICIPATION

Among recreational activities engaged in both at home and away from home, more Iowans participate away from home than at home. Gardening is the single exception among the activities identified in this study. Reasons for participation by greater numbers of people away from home are varied and relate to the specific activity, the opportunity for participation, and the characteristics of the people involved. In general, participation away from home may be attributed to limited opportunity and inadequate facilities at home, a more attractive environment elsewhere, a search for variety, or simply the desire to "get away."

Figure 1 compares participation in four representative activities in terms of the proportion of Iowa residents engaging in each activity at home or away from home. Participation in the same four activities depicted in Figure 1 is represented in Figure 2 in terms of the average number of days of participation per participant for each activity at home and away from home.

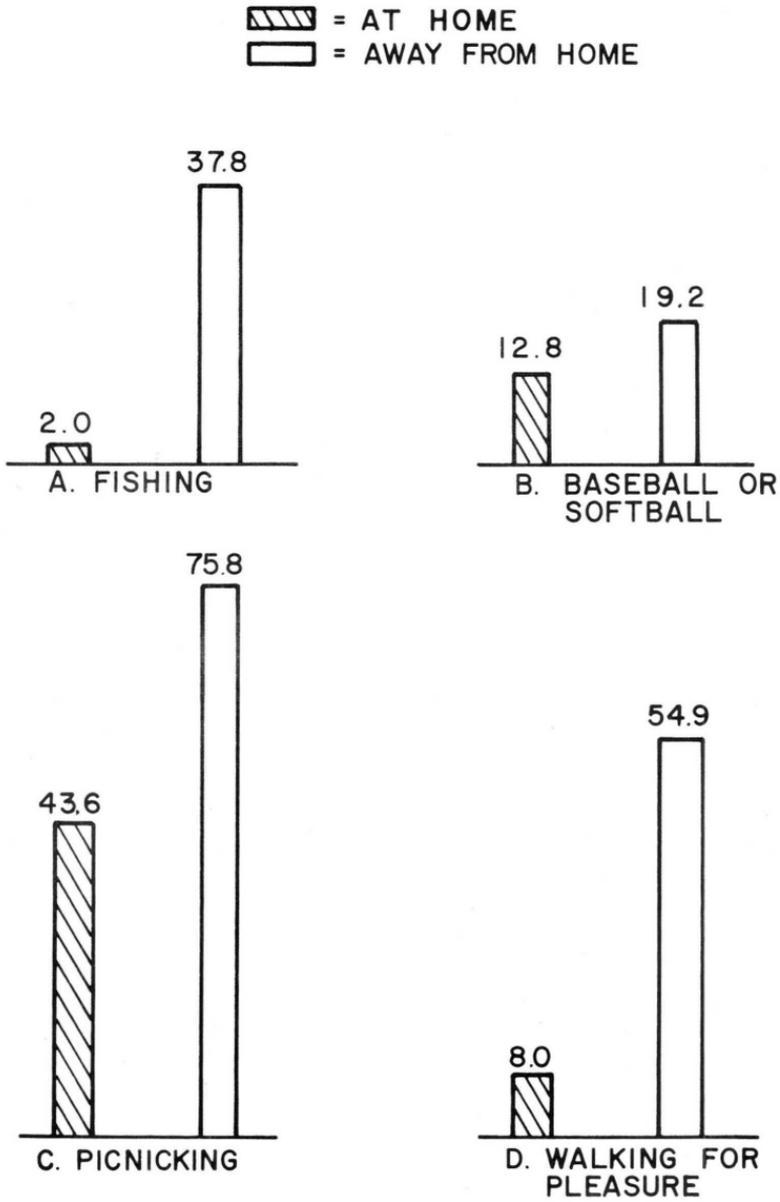


Figure 1. Comparison of at-home and away-from-home activity intensity by percentage of Iowans participating.

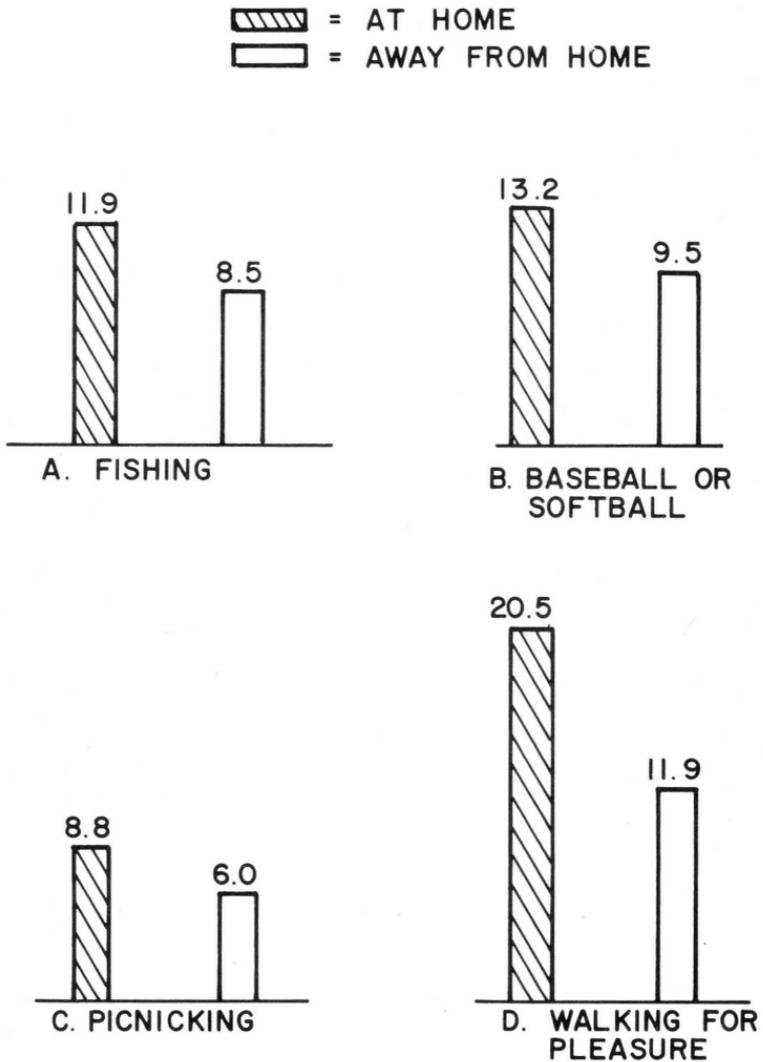


Figure 2. Comparison of at-home and away-from-home activity intensity by days of participation per participant.

In six activities, the total participation at home exceeded that away from home. The ratio between the days of participation at home and the days of participation away from home in four of these activities is: gardening, 14.5:1; bird watching, 3.3:1; relaxing, 2.5:1; and badminton, 2.0:1. The frequency with which some activities are undertaken is appreciably greater at home than away from home.

Where there is opportunity to participate in certain activities at one's residence, the advantages of participation at home are obvious. Foremost among these are convenience and minimal cost in time and money. For many individuals, transportation is not readily available, and the presence of opportunities for outdoor recreation at home eliminates the need to rely on others for transportation. Also the home allows spontaneous participation and minimizes the need for planning and coordination with others.

Two alternative hypotheses concerning the relationship between participation in outdoor recreational activities at home and participation away from home warrant consideration. One is that participation at home is a substitute for similar activity at other locations. Confirmation of this hypothesis would indicate greater need for public outdoor recreational facilities in the absence of substantial participation in outdoor recreational activities at home. An optimum expansion rate for public facilities would tend to be reduced if the rate of growth in at-home activity is expected to exceed that for activity away from home. In any event, opportunities for outdoor recreation at home would tend to reduce dependence on public outdoor recreational facilities. People having such opportunities would tend to substitute activity at home during periods in which public facilities are less attractive because of adverse conditions such as crowding or unfavorable weather. Thus, opportunities for outdoor recreation at home tend to improve distribution in the use of public facilities over time.

The second hypothesis is that participation in outdoor recreation activities at home may tend to increase demand for outdoor recreation away from home and for public facilities. With greater participation at home, interest and preferences are stimulated and strengthened. Equipment may be acquired that is useful in recreational activities at home or away from home. Skills may be developed that would enhance recreational experiences away from home, making them more attractive.

The critical question arising from the first hypothesis has a number of parts. The most important is: Assuming there is indeed substitution, what factors influence substitution of at-home activity for away-from-home activity? Are these factors likely to change over time?

An example of the problem involved here may be given by this hypothetical situation: Suppose it is determined that, all other things being equal, an increase in multi-family dwellings decreased at-home recreation. The questions that occur are: 1) Will there be an increase in multi-family dwellings as compared with single family dwellings? 2) Will the type of multi-family dwellings change (i. e., will the "planned community" concept with its attendant recreation areas and playgrounds become more prevalent)?

The first question can be answered rather easily. The percentage of total authorized housing starts in multi-family units increased from 10%

to 34% between 1961 and 1966. This is consistent with the increasing urbanization of Iowa.

The second question, however, cannot be answered now. But assume for the moment that new multi-family dwellings will not have recreational facilities attached. With this development, it can easily be seen that, if the first hypothesis is correct, the proportion of at-home recreation to away-from-home recreation will decrease. And if a constant level of recreational availability is to be maintained in the future, more public recreational facilities will have to be built or otherwise acquired.

In relation to the present study, however, the hypothesis of substitution and change as just outlined was not supported. In the first instance, investigation of several important activities did not show any significant relationship between intensity of recreation at home and intensity away from home. Secondly, there was no information available in the study to indicate whether at-home recreation occurs with less intensity in multi-family dwellings than in single family dwellings. Thus, determination of the true relationship between at-home and away-from-home recreation must await further investigation.

PROJECTIONS

Estimates of future consumption or participation in outdoor recreational activities are of interest to agencies responsible for making opportunities for such recreation available to the public. A variety of socioeconomic factors (such as population, income, mobility, leisure time) may affect this future consumption. On the supply side, the availability of opportunities for outdoor recreational activity and the quality of such opportunities also determine future outdoor recreational activity. In addition, the interrelationships between activity at home and that away from home will affect future use of public outdoor recreational facilities.

Projections of participation in selected activities at home and away from home for the years 1970 and 1975 are shown in Table 3. These estimates are based on population projections for Iowa. It is assumed that the proportion of the Iowa population participating in such activity will remain constant, as will the mean days of participation per participant. Because of the omission of factors other than population, these estimates may tend to be conservative. A reduction in the anticipated rate of increase in the Iowa population is reflected in a tendency for participation in outdoor recreation to level off by 1975.

CONCLUSIONS

At-home outdoor recreational activities may readily be summarized. It can be seen that they are quite varied in scope, with those activities not occurring at home requiring specialized resources or facilities. The most popular at-home activities do not generally correspond to those that are most popular away from home. In some activities, even though more people participate away from home than at home, the intensity of participation is greater at home. Lastly, a decreasing rate of increase of participation in several outdoor recreation activities has been projected, both at home and away from home.

Table 3. Current and Projected Summer Outdoor Recreation Activity of Iowans, At-Home and Away-from-Home, 1970 and 1975¹

Activity	1966		1970		1975	
	Number of participants	Days of participation	Number of participants	Days of participation	Number of participants	Days of participation
At-home		(thousands)	(thousands)	(thousands)	(thousands)	(thousands)
Playing outdoor games	486	6,885	498	7,076	505	7,169
Baseball or softball	257	3,385	273	3,598	276	3,645
Walking for pleasure	160	3,291	170	3,492	173	3,538
Picnics	876	7,687	928	8,138	941	8,278
Away-from-home						
Playing outdoor games	785	8,750	789	9,953	794	10,084
Baseball or softball	387	3,634	409	3,884	414	3,935
Walking for pleasure	1,103	13,036	1,169	13,912	1,185	14,096
Picnics	1,520	9,162	1,614	9,685	1,635	9,813

¹Based on the assumption that mean days of participation per participant and percentage of population participating are constants. Population projections from: Doerflinger, J., and R. Klimek. Iowa's population: recent trends, future prospects. Agr. and Home Econ. Expt. Sta., Cooperative Extension Service, Ames, Iowa. Special Report 47. 1966.

²12 years of age and older.

³By participants 12 years of age and older.

The information presented here should give recreational planners and researchers some indications of the information needed to decide the rate and intensity of facility development by pointing out:

1. The amount of recreational demand presently absorbed by at-home recreation.
2. The activities not carried on at home.
3. The change in participation predicted for the next few years, based on some rather restrictive assumptions.

This information is, however, only for the state as a whole. Nothing has been said about individual facilities. Such information is beyond the scope of a statewide recreational study. Justification for each individual proposed recreational project must be accomplished by individual studies related to the specific project in question.

Outdoor recreation undertaken at home made up a very substantial portion of the total participation in outdoor recreational activities in Iowa. Relationships between outdoor recreation at home and involvement in the same activities away from home warrant further investigation. Data provided in this study will serve as a base point with reference to which future comparisons may be established. Information concerning trends in participation in outdoor recreation at home relative to that away-from-home participation will be useful and significant to researchers and planners. For example, suppose that further research shows that at-home recreation does indeed substitute for away-from-home outdoor recreation and that it is growing faster. If this were true, simple trends in growth of away-from-home recreation would overestimate future needs for facilities. No such conclusion would be reached if at-home recreation complements rather than substitutes for away-from-home recreation.

Further insight is required into the ability of at-home recreation to substitute for away-from-home recreation, and vice versa, as well as how the two complement each other. Improved information concerning the relationships between outdoor recreation at home and away from home is essential to effective planning and development of public outdoor recreational areas.

A COMPARISON OF TWO MUSKRAT POPULATIONS¹

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ABSTRACT. Two muskrat (Ondatra zibethicus) populations in northwestern Iowa were compared during the summer of 1967. A decreasing population was associated with less dense vegetation, lighter average weight, shorter breeding season, fewer and smaller litters, and larger home-range size compared with an increasing population. There were no apparent differences in mortality between the 2 populations except that the increasing population was heavily trapped and the decreasing population was not trapped. In the decreasing population, 18 adults produced about 54 young, while 17 adults produced 146 young in the increasing population. Males predominated among young animals but not among adults. There was a significantly larger percentage of young males in the decreasing population and a significantly larger percentage of males in April litters compared with litters born in May, June and July.

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INTRODUCTION

Dense emergent vegetation, combined with moderate to relatively high water levels, usually results in an increasing muskrat (Ondatra zibethicus) population (Weller and Spatcher 1965). As food resources are consumed, however, muskrat populations decline. Several factors seem involved in this reduction. Errington (1963) found that increased predation on muskrats was common when habitat conditions were poor. Errington, Siglin, and Clark (1963) found that both litter size and number of litters per female were reduced in animals living in very poor habitat. They also found that the peak of breeding was related to food supply.

In an attempt to appraise the relationship between muskrats and their environment, a study of home range, reproduction, food habits and activity patterns was initiated in the summer of 1966. In the summer and fall of 1967, the study was broadened to include 2 muskrat populations living under grossly similar habitat conditions, but with one population increasing while the other was decreasing. The objectives were to discover what differences, if any, existed between a decreasing and an increasing population, and how these differences were related to habitat

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and to population density. Factors such as condition, chronology of litter production, age and sex ratios, and home range size and movement were studied in relation to differences in population density and habitat between the two populations.

STUDY AREAS

The 2 marshes chosen as study areas were similar in most respects. Both were semipermanent, freshwater glacial marshes near Ruthven in northwestern Iowa. The 2 marshes are about the same size; Rush Lake is 460 acres, and Round Lake is 425 acres. Both were shallow; the water depth was 1-1.5 feet at Round Lake and 1.5-2 feet at Rush Lake. The dominant emergent vegetation in both marshes was cattail (*Typha* spp.).

Round Lake has not been completely dry since the mid-1950's, but Rush Lake was drained in the winter of 1962-63 to stimulate growth of emergent vegetation. It was refilled in late summer of 1964 after emergent vegetation had become established.

A circular study area 400 feet in diameter was selected in each of these two marshes. These 2 plots had comparable water depths, emergent vegetation and areas of open water. The density of the cattail, however, was nearly twice as great in the Rush Lake study area as in the Round Lake study area.

METHODS AND MATERIALS

Vegetation Sampling and Mapping

Distribution and density of vegetation were mapped for both study areas. Individual areas of emergent vegetation were qualitatively classed in categories of 0 to 4: 0 = open water, 1 = sparse, 2 = moderately dense, 3 = dense, and 4 = very dense. As a more precise measure of the density of vegetation in the two study areas, point counts were made of emergent vegetation.

Lodge Counts and Harvest

In both marshes, several observers walked systematic transects on the ice and counted all lodges considered capable of housing a muskrat above the water level. Dozier (1948) estimated muskrat populations on the basis of dwelling houses only. He found, however, that the ability to differentiate between dwelling houses and feeding houses depended upon experience of the observers. No attempt was made in the present study to distinguish between these types, and it is believed that this total count can be used from year to year with little error due to experience of the observers.

Because all trappers on state-owned areas are required to report their yearly catch of furbearers, the total of these reports was used as an estimate of the muskrat harvest for each marsh. Harvest data were obtained from Mr. Glenn Jones of the Ruthven Game Management Unit, Iowa State Conservation Commission.

Traps and Trapping

During the summer of 1966, 12 "National" live-traps were set throughout the summer, primarily within a 200-foot radius of an observation blind at Round Lake. The first summer of the study was designed primarily to perfect methods of trapping and ear-tagging muskrats and to back-tag muskrats for sight observations. In addition, information on home-range size and reproduction was obtained.

During the summer and fall of 1967 (June 1 to October 19), a comparison was made of 2 study areas. A round study area 400 feet in diameter was selected in each of the 2 marshes. On the basis of home-range studies of other authors, as well as home-range and trapping data from 1966 at Round Lake, it was believed that study areas of this size could be adequately trapped and still be large enough to yield realistic home-range data. Study areas were located in areas of good muskrat populations and representative stands of emergent vegetation. The circular area was divided into 4 concentric rings of equal area (31,430 square feet).

Twenty National live-traps were used concurrently in each study area in 1967. Because study areas were 25 miles apart and it was necessary to remove trapped animals before the hottest part of the day, time did not allow simultaneous trapping of both study areas. Trapping 2 days in one study area, followed by 2 days in the other, did permit fairly close synchronization of trapping periods.

The twenty traps were first set in the central one-fourth of the study area and were moved to the next outer ring during successive trapping periods. When the four rings each had been trapped for 2 nights, traps were returned to the central ring and the process was repeated. Traps were placed at locations at which muskrats were most active, such as feeding sites or the edges of active dwelling lodges.

Marking Methods

In 1966, muskrats were marked with individually identifiable strips of plastic (Armortite). These strips were attached to the skin on the back with a small safety pin. Although the plastic was readily visible on swimming muskrats, it was frequently chewed off, probably by the muskrat bearing the tag. The safety pins were retained for longer periods, and it is possible that this means of attachment would be suitable for future studies if a material could be found that would not be destroyed by the muskrats.

In 1966 and 1967, muskrats were marked by placing a numbered, metal fish opercle tag in the right ear. In 1967, only 6 animals (2%) were believed to have lost their tags over a 5-month trapping period.

Handling

Trapped animals were removed from the trap by grasping the tail and pulling them out. They then were thrust head-first into a gallon jar containing a cloth soaked in ether. Because prolonged contact with the ether caused some mortality, animals were removed from the jar as soon as

they lost consciousness. A numbered, metal fingerling fish tag was placed in the right ear, and the animal was weighed to the nearest 1/2 ounce, measured to the nearest centimeter and sexed. Muskrats were released at the trapping site as soon as they were able to swim.

Age Criteria

Birth dates of all young muskrats were calculated by comparing the total length of animals caught during this study with the total length of known age animals in Errington's (1963) and Erickson's (1963) data. A combination of data from both of these authors was used to age muskrats less than 50 days old, and Errington's (1963) data were used to age muskrats between 50 and 100 days old. Birth dates of animals over 100 days old could not be estimated with this method. However, because only 15 (7%) were over 100 days old when first captured, peaks of production would be little changed even if these few muskrats could have been aged exactly.

RESULTS

Vegetation Sampling and Mapping

The percentages of each study area occupied by each of the classes of vegetation are summarized in Table 1.

Table 1 demonstrates that the percentage of each study area that was bare of vegetation was about equal but that emergent vegetation at Round Lake ranged from sparse to moderately dense, while most of the Rush Lake vegetation was dense to very dense. Point-counts provided a similar but more quantitative indication of the higher density of emergent vegetation in the Rush Lake study area. Emergent stems occurred at 18% of 1600 points in the Rush Lake study area and at only 10% of 1600 points in the Round Lake study area.

Behavior

Observations on the feeding habits of both captive animals and those in natural situations indicated that muskrats fed readily on most marsh emergent plants available in the vicinity. Twenty feeding sites were checked in 1966 in a pothole near Round Lake that contained a variety of emergent species including river bulrush (Scirpus fluviatilis), cattail, arrowhead (Sagittaria sp.), burreed (Sparganium sp.), hardstem bulrush (Scirpus acutus), and softstem bulrush (Scirpus validus). Twelve (60%) of the sites contained remains of 2 or more species of plants. Five of the 6 emergent species were represented in at least one of the 20 feeding sites. There was no apparent selection of one species over another, and those species eaten most often were the ones most abundant.

The only emergent vegetation available in either study area was cattail, and it was the only food item known to be utilized by undisturbed animals. Of 100 feeding sites checked on July 4, 1966, in Round Lake, the only food remains found were cattail. Basal portions of stems had been eaten at 95% of the sites; rhizomes had been eaten at 27% and leaves

at 8% of the sites. By mid-August feeding habits had changed somewhat. Of 32 feeding sites checked on August 17, basal portions of stems had been eaten at only 69% of the sites, but rhizomes had been eaten at 45% and leaves at 16%. Lower parts of cattail plants may be selectively eaten because of their higher food value (Stearns and Goodwin 1941).

Muskrats were seen most commonly in daylight hours both early and late in the summer, although few were observed in the middle of the summer (Table 2). A total of 120 individual observations of muskrats was made from the blind in 1966. Thirty-nine per cent of these were swimming at the time of observation, 39% were feeding, 11% were on lodges or feeders but not feeding, 5% were cleaning themselves, 4% were involved in courtship or copulation, and 2% were carrying building material.

Because feeding was of longer duration than any other activity observed, muskrats were engaged in feeding activity during approximately three-fourths of the time they were under observation.

Muskrats tend to build lodges where some sort of previous substrate exists. Of 114 feeding sites marked at Round Lake in the summer of 1966, 23% had lodges built on them by December 20. L.H. Fredrickson (personal communication), working at Rush Lake in 1966, found that 61% of 46 coot (*Fulica americana*) nests already were being used by muskrats on July 7. Forty-one per cent of these nests were being used as feeding platforms and 20% had lodges built on them. He found that, in some areas of Rush Lake, almost all the newly built muskrat lodges were located on old coot nests.

Lodge Counts and Harvest

Lodge counts and harvest figures have been gathered for the past 4 years. Round Lake is a State wildlife refuge and normally is not open to fur-trapping. However, trapping was allowed in 1964 and 1967, and harvest figures from these 2 years indicate a declining population (Table 3). Lodge counts also suggest that the Round Lake population was declining (Table 3).

Harvest figures are available from Rush Lake for all recent years (Table 3) and indicate an increasing muskrat population. These figures parallel lodge counts quite closely. For example, 1.70 muskrats were trapped per lodge in 1965, 1.89 per lodge in 1966, and 1.82 per lodge in 1967. If the average of these (1.80) was multiplied by the number of lodges in a given year, the harvest for that year could be predicted within + 6% of its actual value in all cases.

Trapping Success

The number of animals captured each month is summarized in Table 4. Sixty-three muskrats were captured at Round Lake during about 500 trap-nights in 1966. Of these, 1 escaped, 5 died in the traps, 1 was killed in handling and 1 was taken captive. Of 55 animals marked and released, 65% later were observed (those identifiable by plastic back tags) or recaptured a total of 92 times. For animals recaptured, the number of times recaptured ranged from 1 to 10 and averaged 2.6. Trap success was about 29%.

Table 1. Percentages of each study area occupied by emergent vegetation

Location	Open water	Sparse	Mod. dense	Dense	Very dense
Round Lake	36	20	44	0	0
Rush Lake	37	3	5	19	36

Table 2. Muskrats observed per hour (Round Lake--1966)

Period	Hours observation	Muskrats seen	Muskrats seen per hour
May 31-June 15	9	19	2.1
June 16-30	12	22	1.8
July 1-15	8.5	10	1.2
July 16-31	3	0	0
Aug. 1-15	8	2	0.3
Aug. 16-24	10.5	9	0.9

Table 3. Muskrat lodge counts and harvest figures (1964-1967)

	1964	1965	1966	1967
Round Lake harvest	2073	closed	closed	36
Rush Lake harvest	0	640	4491	5509
Round Lake lodges	--	2217	2529	376
Rush Lake lodges	24	376	2374	3027

TWO MUSKRAT POPULATIONS

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Table 4. Number of muskrats captured each month

		June	July	August	September	October	Total
Round Lake (1966)	Adults	31	9	10	-	-	50
	Young	1	2	10	-	-	13
	Cumulative young/adult	.03	.08	.26	-	-	
	Recaptures	41	13	18	-	-	72
	Trap success	31%	20%	26%	-	-	29%
Round Lake (1967)	Adults	4	11	2	1	0	18
	Young	2	21	22	5	4	54
	Cumulative young/adult	.5	1.5	2.6	2.8	3.0	
	Recaptures	0	30	38	25	20	113
	Trap success	5%	31%	31%	26%	30%	26%
Rush Lake (1967)	Adults	7	7	2	1	0	17
	Young	30	38	46	29	3	146
	Cumulative young adult	4.3	4.3	7.1	8.4	8.6	
	Recaptures	20	34	75	62	56	247
	Trap success	48%	40%	68%	66%	74%	57%

In 1967, 720 trap-nights at Round Lake yielded 185 captures for a trap-success of 26%. Seventy-two of these animals were original captures (39%) and 113 (61%) were recaptures. For animals recaptured, the number of times recaptured ranged from 1 to 16 and averaged 2.6. It is believed that almost the entire study area population was captured at least once at Round Lake. A Lincoln population estimate of 79 was made by using a final sample of animals caught in October. In reality, 72 different animals were trapped in the study area.

Seven-hundred-and-twenty trap-nights at Rush Lake yielded 409 captures for a trap-success of 57%. One-hundred-sixty-two of these were original captures (40%) and 247 (60%) were recaptures. On 8 different occasions, 2 muskrats were captured in 1 trap, a situation that never occurred at Round Lake. For animals recaptured, the number of times recaptured ranged from 1 to 11 and averaged 2.8. By using those animals caught in October as a final sample for a Lincoln population estimate for the Rush Lake study area, an estimate of 165 was obtained. One-hundred-sixty-two animals actually were caught in the study area.

Susceptibility to Trapping

Table 5 summarizes the percentages of all muskrats captured with various frequencies. There was no difference in susceptibility to trapping between the 2 areas, or between the 2 years. It is not likely that animals became trap-shy on either area because trap success (Table 4) did not decrease as the season progressed. Because similar numbers of adults were present in both study areas in 1967 (Table 4) and because large percentages of both populations were captured, the difference in total numbers captured can be attributed to differences in reproduction between the 2 areas.

Table 5. Frequency of capture of all muskrats

Location	Number of times captured				
	1	2	3	4	5 or more
Round Lake-1966	43%	32%	12%	3%	10%
Round Lake-1967	45%	24%	14%	8%	9%
Rush Lake-1967	42%	22%	14%	7%	15%

Mortality

Trapping mortality occurred in about 4% of the total captures made, and was approximately equal between the 2 study areas (14 killed at Rush Lake, 10 killed at Round Lake). There were no conspicuous differences noted in natural mortality between the 2 study areas during the summer and fall.

Length and Weight

To determine whether there was any difference in condition or relative growth rate of the muskrats between the 2 study areas, all animals captured were weighed and measured. Average weights for given length intervals are summarized in Table 6. There was no difference in weight between the sexes, but there was a difference between the 2 study areas in the average weight of muskrats taken.

Table 6. Average weight in ounces for each size class caught during summer and fall, 1967 (sample size in parentheses)

	Length in cm. (Young animals)					All Young 29-60	Adults 54-63cm
	29-36	37-44	45-48	49-52	53-60		
Males	8 (13)	14 (37)	18 (23)	24 (19)	28 (20)	18 (112)	42 (21)
Females	8 (12)	14 (22)	18 (33)	24 (13)	29 (11)	18 (91)	43 (18)
Rush Lake	8 (15)	14 (46)	19 (38)	24 (24)	30 (25)	19 (148)	44 (19)
Round Lake	8 (10)	13 (14)	17 (18)	23 (8)	27 (6)	16 (56)	42 (20)

Muskrats from Round Lake averaged lighter weights of all lengths when compared with the Rush Lake muskrats. Round Lake adults, in addition to being lighter in weight, also averaged 1.3 centimeters less in length than the Rush Lake adults. The difference in mean weights of adults was not statistically significant, however. The mean weight of young muskrats from Rush Lake was significantly larger (at the 5% level) than the mean weight of young muskrats from Round Lake. This may be interpreted as poorer condition or slower growth rate in the muskrats from poorer habitat (Round Lake).

Chronology of Reproduction

Birth dates of individual animals were calculated by estimating their age from the total length and then back-dating the indicated number of days to arrive at the birth date. In 1966, muskrat reproduction at Round Lake did not start until May 1 and ended June 30 (Figure 1). Round Lake reproduction was very poor in 1966; although there were 50 adults caught, only 13 young were caught during the summer.

In 1967, reproduction did not begin at Round Lake until April 20, and only one peak in reproduction occurred (Figure 1). This peak occurred at the same time as the second Rush Lake peak (May 10-June 8); 50% of the Round Lake young were born in this period.

Figure 1 shows that reproduction at Rush Lake extended over a longer period than did reproduction at Round Lake. Births of litters began at

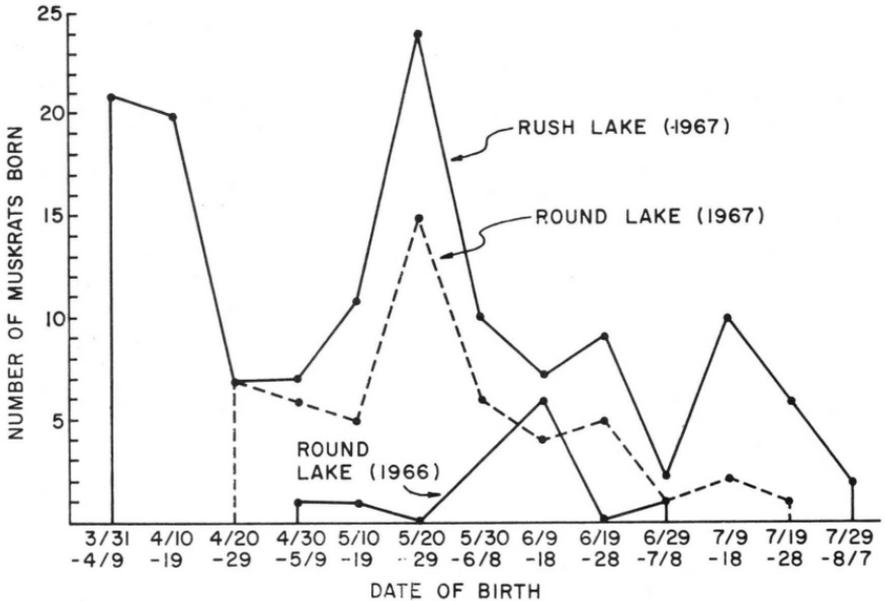


Figure 1. Muskrats born per 10-day interval.

Rush Lake on March 31, 1967 (3 weeks earlier than Round Lake), and rapidly reached a peak in the period of March 31 to April 19. A second peak of production occurred between May 10 and June 8 when 48% of the young were born.

Production

Because similar numbers of adults were present on the two study areas in 1967 (18 trapped on Round Lake, 17 on Rush Lake), it is believed that the difference in total production between the study areas can be attributed to a difference in reproduction per female.

One-hundred-forty-six young muskrats were trapped in the Rush Lake study area as opposed to only 54 in the Round Lake study area. There are several factors that may have contributed to the difference in total reproduction between the two areas. A large number (30%) of the Rush Lake young were produced before production began at Round Lake (Figure 1). This difference in length of the reproductive season could have accounted for an additional litter of young being produced at Rush Lake. It was estimated from groupings of animals having the same birth dates that 7 females gave birth to about 24 litters in the Rush Lake study area, for an average of 3.4 litters per female. In the Round Lake study area, 10 females were estimated to have given birth to only about 12 litters during the summer, for an average of 1.2 litters per female.

Limited data indicate that, in addition to fewer litters being born at Round Lake than at Rush Lake, the litter size also was smaller at Round Lake. Three complete litters, found by opening lodges at Round Lake, averaged 4 young each; 2 complete litters, found by opening lodges at

Rush Lake, averaged 7.5 young each. Litter sizes also were calculated by mapping the location of muskrats with certain birth dates. Concentrations of young animals having the same or nearly the same birth dates were considered to comprise individual litters. Litter sizes indicated by birth date groupings (Table 7) were also larger at Rush Lake than at Round Lake. Litter size at Round Lake at the time of trapping ranged from 2 to 4 young per litter and averaged 2.8. Rush Lake litters ranged from 2 to 7 and averaged 4.2 young per litter.

Further evidence of a difference in production per female was provided by placental scar counts made during the fall 1967 trapping season. Six placental scar counts from Rush Lake averaged 18.3, and 2 placental scar counts from Round Lake were only 15 and 9. Results of several methods of calculating reproduction are summarized in Table 7.

Table 7. Results of several methods of calculating reproduction

	Litter size		No. of litters/female		Production/female	
	Round Lake	Rush Lake	Round Lake	Rush Lake	Round Lake	Rush Lake
Mapping groups of similar birth dates	2.8	4.2	1.2	3.4	3.4	14.3
Summer age ratios	-	-	-	-	5.4	20.9
Winter age ratios	-	-	-	-	5.3	10.5
Placental scars	-	-	2.0	3.0	12.0	18.3
Litters found by opening lodges	4.0	7.5	-	-	-	-
				Average	6.5	16.0

The ratio of young animals to adults can be used as a measure of reproductive success (Tables 4 and 7). The age ratio for animals live-trapped during the summer and fall at Rush Lake was 146 young: 17 adults, or 8.6 young: 1 adult. At Round Lake, the age ratio was 54 young: 18 adults or 3.0:1. The lower number of young per adult at Round Lake is to be expected, since this area had a shorter breeding season and probably fewer and smaller litters (Table 7).

The age ratio for animals trapped for fur in the winter was 5.6 young: 1 adult for 272 animals at Rush Lake. Fewer young per adult present in the winter (5.6) than in the summer (8.6) could indicate slightly poorer survival of the young animals, or movement out of the area. The Round Lake winter ratio (4 young: 1 adult for 20 animals) is slightly higher than would be expected, probably because of the small sample size. Errington (1948) and Beer and Truax (1950) suggested that the percentage of young in the population is inversely proportional to breeding density. This did not appear of primary importance in the current study, however, because similar numbers of adults were present on both study areas.

Sex Ratios

Sex ratios among young animals in this study showed a preponderance of males in both study areas, although the difference was more pronounced in the poor habitat of Round Lake. Errington (1963) found that females usually predominate among adult muskrats, but not among young. Sixty-two per cent of 60 Round Lake young were males, while only 41% of 22 adults were males. This difference was not statistically significant, however. At Rush Lake, males also predominated among young animals but to a smaller degree. Fifty-four per cent of 377 young were males and only 50% of 58 adults were males. At the 10% level, there was a significantly greater percentage of males among the young animals from Round Lake than among the young animals from Rush Lake. Beer and Truax (1950) found that there was a significantly greater proportion of young males in a low-density population than in a high density population of muskrats. They suggested that there is probably some factor that works relatively against immature females in a low density population. This also was the case in the present study. The predominance of males was greater in the young animals from Round Lake which had a decreasing population, than in the young animals from Rush Lake, where the population was increasing.

Sex ratios are summarized for various age groups in Table 8. The sex ratio for adults is not significantly different from a 50:50 ratio. At the 5% level, the sex ratio for young animals had a significantly greater proportion of males than would be expected. Apparently, differential mortality acts against females before the age at which they are susceptible to trapping. There was no apparent sex-related differential mortality between summer and winter (Table 8).

Table 8. Sex ratios of various age groups

Age Group	Males	Females	Males : Females
Summer-trapped yg. (28-100 days old)	113	91	1.24 : 1
Winter-trapped yg. (122-245 days old)	136	111	1.23 : 1
Adults	38	42	0.90 : 1

Gashwiler (1950) and Olsen (1959) found that there was a greater preponderance of males in early-born litters than in those born later in the summer. This was also the case in the present study. Sixty-eight per cent of 57 young born in April were males, 49% of 70 born in May were males, and 51% of 65 born in June and July were males. At the 5% level, April-born young consisted of a significantly larger percentage of males than those born in May, June and July. This suggests that the over-all preponderance of males in the population results from the preponderance of males in April litters, because May, June and July litters consisted of approximately equal numbers of males and females. However, this does not explain the cause of the preponderance of males in early litters, nor does it explain how it may be related to habitat conditions or population level. It is possible that differential mortality acts on females in early litters and not in late litters.

Home-Range

Although absolute home-range size could not be established for many animals, calculated home-ranges averaged consistently larger in the less-dense vegetation of Round Lake than in the dense vegetation of Rush Lake. Apparently habitat conditions are more important in determining home-range size than are interactions between the muskrats themselves (Table 9).

Apparent home-range size increased directly with the number of times an animal was captured until a muskrat had been captured 5 times (Figure 2). Thereafter, home-range size did not get much larger regardless of the number of additional times it was recaptured. Lidicker (1966) found a similar phenomenon in the house mouse (*Mus musculus*). He found that home-range size did not increase significantly after the animals had been recaptured 5 times.

There was no indication during the entire study that territorial defense was occurring on either study area. Only one instance of aggressive behavior was observed. In this case, a cannibalistic adult drove several other adults from the vicinity of a nest of young it was eating. The only animals showing wounds of any kind had been injured in trapping and not from fighting.

This lack of intraspecific strife occurred even though many animals were occupying the same area. For example, 12 different muskrats including 9 adults were captured at one lodge in the summer of 1966.

Home-ranges were characterized by various degrees of overlap and were not mutually exclusive. The limits of most home-ranges did not appear to be set by the actions of neighboring muskrats.

Only a few animals were captured enough times to give an indication of individual home-range sizes. Number 92, a young male, was first caught at Round Lake on July 3. It was recaptured 16 times through the next 4 months and was finally taken by a trapper on December 3. The maximum diameter of its calculated home-range was 217 feet. Number 183 was captured 10 times in 4 months, but never outside a calculated home range having a maximum diameter of 162 feet.

At Rush Lake, a young male was captured 12 times in $2\frac{1}{2}$ months, always within a calculated home-range 145 feet in diameter. Three animals

were captured 10 times within home-ranges of 136 feet, 157 feet, and 174 feet, diameter, respectively. Distances from point of original capture to point of recapture or observation are summarized in Table 10. Apparently most summer and fall home ranges can be enclosed by a circle 150-200 feet in diameter.

Table 9. Average calculated home-range diameter (in feet) for all animals captured (sample size in parentheses)

Location		Number of times captured				
		2	3	4	5 or more	all
Round Lake	Young	94' (14)	113' (7)	81' (4)	183' (6)	114' (31)
	Adults	72' (4)	111' (4)	178' (2)	153' (1)	113' (11)
Rush Lake	Young	62' (32)	103' (18)	104' (10)	146' (20)	97' (80)
	Adults	57' (1)	89' (3)	53' (1)	130' (2)	91' (7)

Table 10. Percent of recaptures made at various distances from the original capture point

Location	Distance from original capture (in feet)					
	0'	1-50'	51-100'	101-150'	151-200'	201' or more
Round Lake-1966 (92 recaptures and observations)	49%	19%	15%	9%	4%	4%
Round Lake-1967 (114 recaptures)	4%	19%	43%	17%	11%	6%
Rush Lake-1967 (241 recaptures)	15%	19%	46%	14%	5%	1%
Total	19%	19%	39%	13%	7%	3%

When the 1967 movement data for Round Lake and Rush Lake are compared (Table 10) fewer Round Lake muskrats were recaptured at their original capture site, and more Round Lake muskrats were captured at distances over 150 feet from the original capture site. Thus, Round Lake muskrats were more likely to move farther from the site of original capture than were Rush Lake muskrats. The reasons for this are unknown.

Calculated home-ranges of adults appeared to be slightly smaller than those of young animals (Table 9), although the difference was not statistically significant. Home-ranges of males appeared to be about the same size as or slightly smaller than those of females (Table 11).

Table 11. Average home-range diameter (in feet) for all animals, by sex (sample size in parentheses)

	Number of times captured					
	2	3	4	5-6	7-17	All
Males	71' (25)	90' (19)	113' (9)	140' (5)	155' (10)	99' (68)
Females	74' (26)	110' (12)	123' (9)	144' (7)	156' (7)	106' (61)

Table 12. Average distance in feet from last capture point for animals recaptured in each month (sample size in parentheses)

Location	Month recaptured				
	June	July	August	September	October
Round Lake	----	48' (29)	74' (34)	85' (21)	94' (20)
Rush Lake	48' (20)	69' (33)	69' (76)	71' (67)	83' (53)

Table 12 shows the average distance from the last capture point for animals recaptured in each month. The distances for June at Rush Lake and July at Round Lake are smaller than the average for the other months because of the preponderance of muskrats 4-8 weeks old, which have small home-ranges. Apparently, a relatively small and constant area constituted the home-range of Rush Lake muskrats during the summer, although its size may have increased slightly in the fall. The Round Lake muskrats' home-range size increased steadily from July on and was soon larger than the home-range size at Rush Lake. It is possible that this increase is a response to the poorer habitat and food conditions at Round Lake, as indicated by the poorer condition of the Round Lake muskrats.

Average home-range diameter is shown for the various age categories in Figure 3. Home-range size increased sharply when the animal became 9 weeks of age, then remained about the same size until 20 weeks of age. After 20 weeks of age, the home-range of young animals was larger than the home-range of adults.

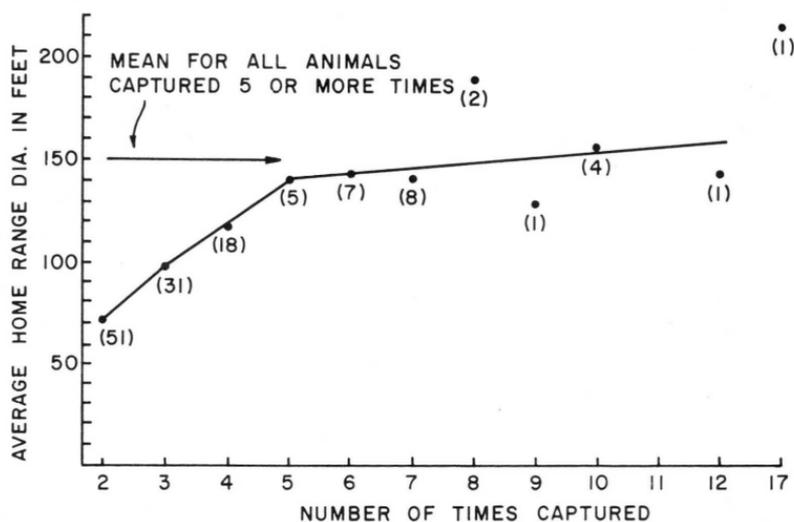


Figure 2. Average calculated home range diameter compared to number of times captured (Sample size in parentheses).

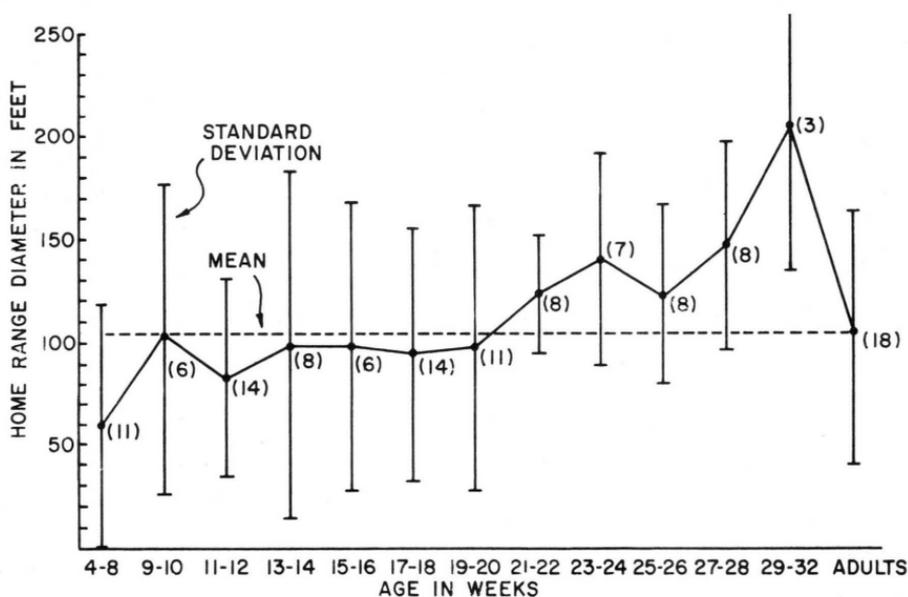


Figure 3. Home range diameter in feet compared to age in weeks (sample size in parentheses).

DISCUSSION

To learn how best to manage muskrat populations, it is necessary to relate productivity to food habits, reproduction, activity patterns, and home-range. It is also necessary to learn how chronology, size, and number of litters, condition, and age and sex ratios are related to habitat and population density.

From this comparison of two muskrat populations, the increasing population was associated with more dense vegetation than was the decreasing population. The decreasing population, although not subject to trapping, continued to decline during the study. The increasing population, on the other hand, continued to increase rapidly in spite of annual harvests averaging 1.8 muskrats per lodge. There were no apparent major differences in natural mortality, so it would be expected that differences in reproduction accounted for the net changes in population. The lower reproduction was probably the result of a shorter breeding season, fewer and smaller litters per female, and possibly poorer survival at Round Lake. However, the environmental influence that produced this reproductive pattern was not isolated.

Sex ratios were strongly unbalanced in poor habitat and only slightly unbalanced in good habitat. The reasons for this unbalanced sex ratio are unknown, but it may be that agents of differential mortality are more pronounced in poor habitat. It is not known precisely what these mortality agents are. Young females are apparently more subject to mortality than are young males, but adult females are less subject to mortality than are adult males.

Condition of the habitat was of some importance in determining home-range size. Larger home-ranges were characteristic of the decreasing population occupying poor habitat. The factors responsible for the larger home-range in poor habitat are not known, but it is possible that sparse vegetation allows easier and more rapid movement and permits larger home-ranges. It also may be that animals in poor habitat are forced to cover a larger area in search of food than are animals in good habitat.

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ABUNDANCE OF CREPIDOSTOMUM AND OTHER INTESTINAL
HELMINTHS IN FISHES FROM POOL 19, MISSISSIPPI RIVER¹

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ABSTRACT. From 1961 through 1963, digestive tracts of 28 species of fishes were examined for helminth parasites. Trematodes were numerically the most important. Adult Crepidostomum ictaluri were identified in seven species, C. cooperi in one, and C. illinoiense in three. The blue catfish, flathead catfish, and white crappie evidently represent new definitive host records, the first species for C. ictaluri, and the other two for both C. ictaluri and illinoiense.

Adult Crepidostomum have little or no significant deleterious effects on the fishes. Rediae and cercariae are harbored by Sphaerium transversum, but the percentage of infection is low. Hexagenia naiads host the metacercariae, but deleterious effects are probably unimportant.

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INTRODUCTION

Fremling (1960) found many metacercariae of allocreadiid flukes, Crepidostomum spp., in mayflies, Hexagenia bilineata, from Pool 19 of the Mississippi River. Mayfly naiads are very abundant in the impounded areas of the Mississippi River and emerging mayflies often interfere with river and highway traffic and are a nuisance in cities along the river (Carlander, Carlson, Gooch, and Wenke 1967). The mayflies are an important food source for many species of fish in the river (Hoopes 1960). Crepidostomum flukes mature in the intestines of a number of species of fish which feed on infected mayflies. This paper reports on the incidence of these and other helminth parasites found in the digestive tracts of fishes collected from the river in 1961 and 1963.

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METHODS

The fish were collected by various gear including seines, hoop nets, basket traps, trot lines, and an electric shocker. They were examined as soon as possible after capture except in instances when they were kept alive for a time. The holding of fish in captivity for several days insured that the digestive tract would be devoid of food, thus simplifying the search for parasites. The entire digestive tract was opened lengthwise, placed in physiological saline, and examined with a dissecting microscope. Whole mounts were made of all trematode parasites except those whose general morphology definitely precluded their being members of the genus Crepidostomum. In instances where large numbers made mounting inconvenient, only a fraction of the total number was mounted and the number of remaining individuals was estimated. Flukes were fixed in alcohol-formalin-acetic acid, stained with Mayer's paracarmine, and mounted in Canada balsam. At times, a fast green counterstain was useful in defining the oral papillae.

For histological study, intestinal tracts of experimentally fed fish were fixed in Zenker's fluid, sectioned serially at 8 or 10 microns, and stained with Maximow's eosin azure II—haemotoxylin.

Lengths of all fishes were recorded as total lengths.

INCIDENCE OF PARASITISM IN FISHES

Digestive tracts of 28 species of fishes were examined for helminth parasites (Table 1). Cestodes, nematodes, acanthocephalans, and trematodes other than Crepidostomum were not identified further but simply enumerated whenever encountered. In the early phases of this study the presence of cestodes, nematodes, and acanthocephalans was not noted; thus, the tabulated numbers of fishes harboring these groups of helminths should be considered minimal.

For all fishes combined, trematodes were numerically the most important intestinal helminth parasites. They occurred in 18 of the 28 species and were particularly abundant in channel catfish, blue catfish, white bass, saugers, and a single mooneye. Members of at least 20 species harbored nematodes, sometimes in large numbers. Cestodes were noted in 10 species, but were most numerous in paddlefish, flathead catfish, and saugers. Acanthocephalans were uncommon both numerically and in frequency of occurrence.

CREPIDOSTOMUM SPP.

Special attention was given to the flukes of the genus Crepidostomum because the project of which this study was one phase was concerned with the abundant mayflies and caddisflies of the Mississippi River. These mayflies serve as intermediate hosts for several species of Crepidostomum. Specific identification of the allocreadiids was often not possible since many specimens were either immature or mounted in such a manner that diagnostic features were not clearly evident. Therefore, some of the tabulated numbers of fish harboring the various groups of trematodes are minimal (Table 2). In some instances, this is also true of the values for maximum numbers in a single individual.

Table 1. Incidence of intestinal helminth parasites in 28 species of fishes from Pool 19 and tailwaters.

Species	Number examined	Number infected	Number harboring					Maximum number of trematodes per fish
			Cestodes	Nematodes	Acanthocephalans	Trematodes	Trematodes other than <u>Crepidostomum</u>	
Paddlefish <u>Polyodon spathula</u>	4	3	3	1	0	0	0	
Shovelnose sturgeon <u>Scaphirhynchus platorhynchus</u>	3	0	0	0	0	0	0	
Shortnose gar <u>Lepisosteus platostomus</u>	3	1	0	0	0	1	1	1
Bowfin <u>Amia calva</u>	2	2	0	1	1	2	1	7
Gizzard shad <u>Dorosoma cepedianum</u>	2	2	1	1	0	0	0	
Mooneye <u>Hiodon tergisus</u>	1	1	0	0	0	1	0	
Bigmouth buffalo <u>Ictiobus cyprinellus</u>	2	1	0	1	0	0	0	
Smallmouth buffalo <u>Ictiobus bubalus</u>	2	2	0	1	0	1	1	1
Northern redhorse <u>Moxostoma macrolepidotum</u>	1	1	0	1	0	0	0	
Carp <u>Cyprinus carpio</u>	15	2	0	1	0	1	1	1
Emerald shiner <u>Notropis atherinoides</u>	2	1	1	0	0	0	0	
Spottail shiner <u>Notropis hudsonius</u>	2	0	0	0	0	0	0	
Channel catfish <u>Ictalurus punctatus</u>	33	27	2	6	0	27	15	116
Blue catfish <u>Ictalurus furcatus</u>	4	4	1	4	1	4	3	17
Black bullhead <u>Ictalurus melas</u>	7	3	0	1	0	2	1	1

Table 1. Incidence of intestinal helminth parasites in 28 species of fishes from Pool 19 and tailwaters. (Cont.)

Species	Number examined	Number infected	Number harboring					Maximum number of trematodes per fish
			Cestodes	Nematodes	Acanthocephalans	Trematodes	Trematodes other than <u>Crepidostomum</u>	
Yellow bullhead <u>Ictalurus natalis</u>	4	3	1	1	0	2	2	23
Flathead catfish <u>Pylodictis olivaris</u>	11	11	7	5	0	9	6	17
Tadpole madtom <u>Noturus gyrinus</u>	16	9	0	0	0	9	6	30
American eel <u>Anguilla rostrata</u>	3	2	0	2	0	0	0	
White bass <u>Roccus chrysops</u>	5	5	0	1	0	5	5	850
Largemouth bass <u>Micropterus salmoides</u>	4	2	0	2	2	2	2	80
Bluegill <u>Lepomis macrochirus</u>	3	2	1	2	1	0	0	
White crappie <u>Pomoxis annularis</u>	7	7	3	3	1	7	6	28
Black crappie <u>Pomoxis nigromaculatus</u>	2	2	0	1	1	1	1	7
Sauger <u>Stizostedion canadense</u>	13	12	6	3	0	11	11	650
Walleye <u>Stizostedion vitreum vitreum</u>	2	1	0	0	0	1	1	4
River darter <u>Percina shumardi</u>	2	0	0	0	0	0	0	
Freshwater drum <u>Aplodinotus grunniens</u>	12	8	0	3	0	6	6	9

Table 2. Incidence of Crepidostomum spp. in fishes of Pool 19 and the tailwaters.

Species	Number examined	Number harboring each species (max. no. per individual host in parentheses)			
		<u>C.</u> <u>ictaluri</u>	<u>C.</u> <u>cooperi</u>	<u>C.</u> <u>illinoiense</u>	<u>C.</u> <u>cornutum</u>
Bowfin	2				1(12)
Mooneye	1			1(68)	
Channel catfish	33	18(290)			
Blue catfish	4	4(1400)			
Black bullhead	7	1(3)			
Yellow bullhead	4	1(25)	1(14)		
Flathead catfish	11	5(57)		1(3)	
Tadpole madtom	16	7(29)			
White crappie	7	1(1)		2(3)	

The white crappie with C. ictaluri also harbored C. illinoiense, and the flathead catfish with C. illinoiense also harbored C. ictaluri.

Adults of the family Allocreadiidae are small to medium-sized flukes, and those found in this study all belonged to the genus Crepidostomum. The most abundant species was C. ictaluri (Surber) (Figure 1). Surber (1928) described the species as possessing four testes and erected the genus Megalogonia to contain it. Further studies of this species by Walz (1933), Hopkins (1934), Van Cleave and Mueller (1934), and Lyster (1939) revealed that they are often bitesticular, each organ divided by a median longitudinal constriction into a right and left lobe. Immature worms were found by Lyster to possess only two testes, thus removing any doubt as to the fundamental nature of these organs. The character on which Surber based his genus Megalogonia was, therefore, considered of specific significance only, and Van Cleave and Mueller declared this genus a synonym of Crepidostomum.

The life cycle was described by Hopkins (1934). Upon hatching, each operculate egg yields a ciliated miracidium. Miracidia penetrate the first intermediate host, a sphaeriid pelecypod, Sphaerium transversum (Say), and develop directly into rediae. A sporocyst stage has not been reported. The site of redial infestation is principally in the digestive gland (hepatopancreas) but also extends into the region of the gonads. Rediae ultimately produce cercariae which emerge from the clam and penetrate Hexagenia naiads. Penetration is mainly through the cuticle of the abdomen or abdominal gills. After penetration, cercariae transform into metacercariae that encyst chiefly in the gills and in the muscles and fat body of the abdomen. When mayflies are consumed by fish, metacercariae excyst and develop into adults. Adults attach to the intestinal epithelium by the acetabulum.

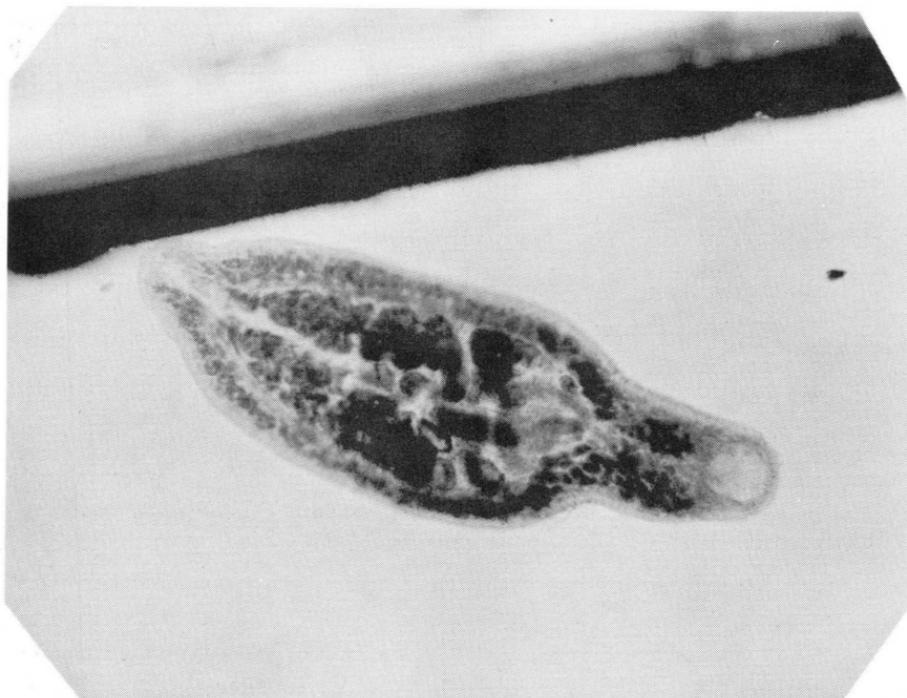


Figure 1. *Crepidostomum ictaluri* (Surber) adult (X 95). Photomicrograph by Louis Facto, Iowa State University Photoservice.

Adult *C. ictaluri* were definitely identified in intestinal tracts of 37 fish representing the following seven species: channel catfish, blue catfish, black bullhead, yellow bullhead, flathead catfish, tadpole madtom, and white crappie. These fish were collected during April, June, July, and August of 1961 through 1963. In each month, most flukes examined were sexually mature.

Eighteen of the 33 channel catfish examined harbored *C. ictaluri*. Three individuals contained more than 100 of these flukes, the maximum number being about 290. The fish harboring this parasite ranged in length from 4.5 to 22.4 inches, but there was no apparent relation between fish size and magnitude of infection. Flukes other than *C. ictaluri*, although frequently encountered, were definitely less numerous. Each of the four blue catfish (14.4 to 18.7 inches) harbored *C. ictaluri*. The estimated 1400 flukes found in the largest fish represented the greatest magnitude of *C. ictaluri* infection that I encountered. Flukes of other species were found in three blue catfish but were numerically insignificant. An 11.6-inch black bullhead harbored three *C. ictaluri* and a 7.0-inch yellow bullhead harbored at least 25 individuals. The five flathead catfish possessing *C. ictaluri* ranged in length from 1.8 to 16.9 inches,

with the heaviest infection (about 57 flukes) occurring in a 5.0-inch fish. The magnitude of other C. ictaluri and other trematode infections was generally light. The same was true in the seven tadpole madtoms harboring C. ictaluri excepting a 2.8-inch fish that held about 29 flukes. The single white crappie with C. ictaluri measured 8.6 inches. Only one of these flukes was definitely identified, but at least 24 others could have been of this species. Flukes not belonging to the genus Crepidostomum were found in six white crappies.

Hopkins (1934), in summarizing the host records for C. ictaluri, listed channel catfish, tadpole madtom, and brindled madtom (Noturus miurus). Fischthal (1956) added margined madtom (N. insignis); Van Cleave and Mueller (1934) added stonecat (N. flavus), yellow bullhead, brown bullhead (Ictalurus nebulosus) and largemouth bass (Micropterus salmoides); Bangham and Hunter (1939) added black bullhead. The bass is the only non-ictalurid definitive host previously listed. The blue catfish, flathead catfish, and white crappie evidently represent new host records.

Fourteen adult C. cooperi (Hopkins) were identified in a 7.3-inch yellow bullhead collected in August. Crepidostomum cooperi (Figure 2) is

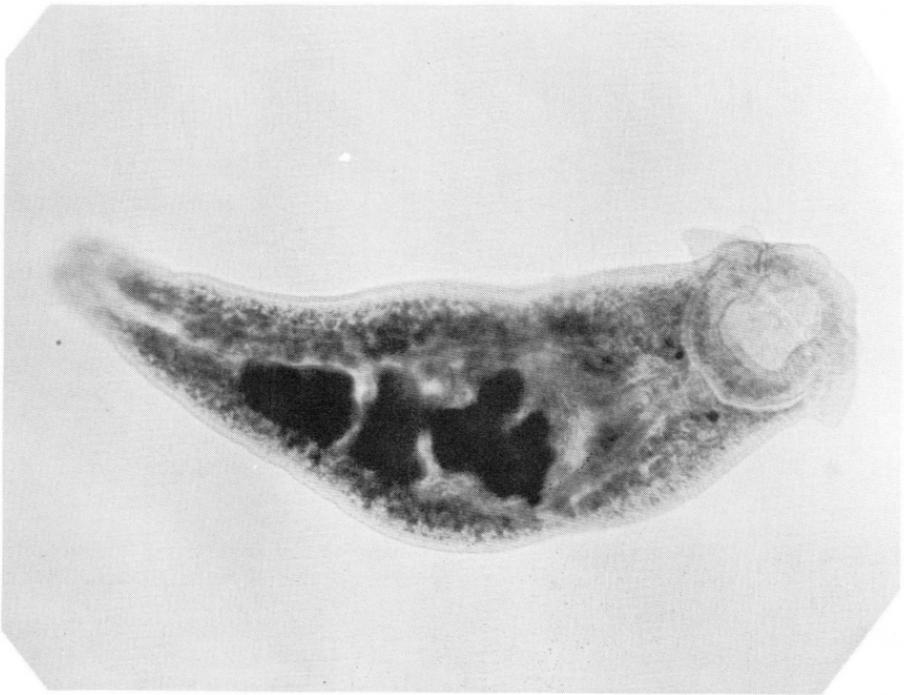


Figure 2. Crepidostomum cooperi (Hopkins) adult (X 95). Photomicrograph by Louis Facto, Iowa State University Photoservice.

similar to C. ictaluri in size and shape but differs most conspicuously in possessing a pair of testes that are usually unconstricted and somewhat spherical. Van Cleave and Mueller (1934), however, reported difficulty in distinguishing between some individuals of these two species. Many species of fish have been reported as definitive hosts of C. cooperi. The life cycle was described by Hopkins (1934) as similar to that of C. ictaluri.

Adult C. illinoiense (Faust) were recovered from one mooneye, one flathead catfish, and two white crappies. The most prominent diagnostic feature of C. illinoiense is the notched condition of the median pair of dorsal oral papillae (Figure 3). The mooneye, captured in June and



Figure 3. Crepidostomum illinoiense (Faust) adult (X 160). Photomicrograph by Louis Facto, Iowa State University Photoservice.

measuring 11.3 inches, harbored nearly 350 flukes. About 68 of these were identified as C. illinoiense but many of the remainder could also have been of this species. The flathead catfish held at least 3 C. illinoiense in addition to several other members of the genus Crepidostomum. It was taken in July and was 1.8 inches in length. Three C. illinoiense were identified in each of the white crappies although more could have been present. Both crappie were taken in July and measured 8.6 and

9.6 inches. I found no previous records for the flathead catfish or white crappie as definitive hosts.

C. illinoiense have been reported from black crappie (Faust 1918), mooneye (Pearse 1924a, 1924b; Hunter and Bangham 1932; and Bangham and Hunter 1939), goldeye, Hiodon alosoides (Self 1954; Peters 1963), and johnny darter, Etheostoma nigrum (Hopkins 1934). The life cycle has not been reported. Seven metacercariae from naturally infected Pool 19 naiads were examined; two from Hexagenia bilineata and five from H. limbata. These metacercariae were of particular interest since the two median oral papillae were distinctly notched, a condition characteristic of adult C. illinoiense. The metacercaria of C. illinoiense is unknown, but no other known species of adult Crepidostomum possesses notched median oral papillae. In view of the occurrence of C. illinoiense in Pool 19 fish, it is probable that these metacercariae were of this species.

Twelve Crepidostomum cornutum (Osborn) were obtained from a 17-inch bowfin. The bowfin was listed as one of the definitive hosts for this species by Bangham and Hunter (1939). Crayfish, rather than mayflies, serve as the second intermediate host (Hopkins 1934; Ameel 1937; Cheng 1957; and Cheng and James 1960).

PATHOLOGICAL EFFECTS OF CREPIDOSTOMUM SPP.

An attempt was made to determine the pathological effects of the flukes on the definitive host. The channel catfish was chosen for this study because of its commercial value and its importance as a host. A group of hatchery-reared fingerling catfish were fed infected Hexagenia naiads, and others were fed commercial pellets. After the feeding period, intestinal tracts from some fish of both groups were examined and whole mounts were prepared of the flukes encountered. The pellet-fed fish were uninfected but the naiad-fed fish harbored varying numbers of parasites. In most cases, specific identification of parasites was not possible. This was due primarily to the immature state of the gonads of many individuals. The others were identified as Crepidostomum ictaluri, and it is highly probable that the undetermined parasites were at least members of this genus.

The intestinal tracts of other naiad-fed and pellet-fed catfish were prepared for histological study. The flukes attached themselves to the intestinal villi by the acetabulum. In no instance had the worms penetrated the submucosa or muscularis. Both mononuclear leucocytes and eosinophils were common in the mucosa and submucosa of the infected fish. However, there was no discernible hematological difference between areas in close proximity to the parasites and areas not invaded. Eosinophils and other leucocytes did not accumulate to a greater degree near the site of infection than elsewhere in the intestine. A comparison with intestinal tissue of the uninfected fish revealed no detectable difference with respect to mononuclear leucocytes. Eosinophils, however, appeared slightly more numerous in the infected fish, but the difference was not striking. On the basis of blood cell analysis, the pathological effects of the flukes in this experiment were slight.

According to Shaw (1933) and Shaw, Simms, and Muth (1934) the poor condition of rainbow trout in certain Oregon waters was probably due to

infections of Crepidostomum cooperi. A closely related species of Crepidostomum (probably farionis) was believed by Wales (1958) to be partially or entirely responsible for several cases of mass mortalities involving brook and rainbow trout in California.

In the Pool 19 area, I found no evidence of poor condition or mortality due to Crepidostomum or other parasites. Tables 1 and 2 illustrate that much of the parasitism is contributed by other groups. Therefore, with respect to deleterious effects, the Crepidostomum parasites themselves are probably of little or no significance. Because they do not invade fish muscles, marketability of commercial species is not affected by their presence.

Crepidostomum spp. rediae and cercariae are harbored by Sphaerium transversum, a species which is exceedingly abundant in the mud flats of lower Pool 19. During a 3-year period, 1166 clams from this area were examined for rediae and cercariae. Six per cent were infected. It is not known if all larvae encountered were of the genus Crepidostomum. Although some were definitely identified as Crepidostomum, cercariae of other genera have been reported from Sphaerium transversum (e.g., Steelman 1939; Dunagan 1957; and Coil 1955). It is probable, therefore, that larvae other than Crepidostomum also infect the Pool 19 clams. The possibility of sterility of clams resulting from Crepidostomum infections is not remote since similar effects of larval trematodes have been reported previously (e.g., Cheng and Snyder 1962). Even if this is true in Pool 19, the low percentage of infection indicates that the effect on the total population is insignificant. In addition, stomach analyses of 46 species of fish during this period demonstrated that these clams are not important sources of food.

I made no attempt to determine possible deleterious effects of Crepidostomum metacercariae on Hexagenia naiads. However, these insects are able to harbor large numbers of parasites, and virtually all larger naiads are infected to some degree. Moreover, since trapping studies performed during 1962 and 1963 demonstrated considerable movement, it is not likely that the naiads are greatly weakened by the parasites. It is possible, however, that a slight weakening may result in instances where infections are heavy, and such a condition could conceivably render the naiads more susceptible to predation by fish. Whether or not mortality may result from the metacercarial infections is not known. Since very large populations of naiads are present in Pool 19, it is likely that mortality, if it does occur, is not limiting.

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BLOOD pH OF CHANNEL CATFISH¹Gerard C. LeTendre²Iowa State University of
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ABSTRACT. Blood pH is easier to measure than blood lactic acid and may be as satisfactory a measure of stress. Mean pH of unexercised channel catfish, Ictalurus punctatus (Rafinesque) was 7.55. Although there was no difference in pH of catfish retained in the river and the laboratory, significant differences were found among collections. Sex did not affect blood pH. Forced exercise dropped pH values to about 7.1.

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INTRODUCTION

Blood lactic acid concentrations frequently have been used as measures of hyperactivity and stress in fish. Caillouet (1968) found blood pH closely correlated with blood lactic acid and suggested that blood pH may be the more practical and reliable indicator of condition in fish subjected to hyperactivity. (This suggestion was available to me in Caillouet's doctoral dissertation, filed 1964.) Blood pH can be more quickly and easily determined electrometrically than blood lactic acid concentration can be determined colorimetrically. Furthermore Jonas, Schdev, and Tomlinson (1962) indicated that the lowered blood pH was more directly related to fish mortality than was lactic acid concentration. The present study was undertaken to study the effect of exercise and activity on the blood pH of channel catfish, Ictalurus punctatus (Rafinesque) and to examine some of the factors related to variability of blood pH determinations.

METHODS

Channel catfish were collected with baited hoop nets and box traps from the Des Moines River, Boone County, in June to September 1964.

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When blood tests were made in the field, the fish were held for over 17 hours in a holding net in slight current (one exception was a group of 9 fish processed after 17 hours). Other fish were taken to the laboratory at Iowa State University, about 20 miles, and held in 60 or 100 gallon tanks, well oxygenated for at least 2 hours before the blood tests.

The blood samples were taken with an external style hypodermic blood electrode assembly (Beckman blood electrode assembly 39022, 1958), and the pH values were determined with a Beckman G.S. pH meter. In drawing blood samples, I inserted the needle through the isthmus between the opercles at such an angle that the needle entered pointing toward the caudal portion of the fish. In this way, I was able to hit the conus arteriosus portion of the heart and obtain satisfactory blood samples. The fish was held ventral surface up in the left hand with the thumb and second finger behind the left and right spines, respectively.

Early in the study I found that humidity affected the pH meter. This was more often a problem in the field than in the laboratory. In each instance, the problem was first noted as a constant drift toward more alkalinity. The null meter was zeroed against the pH 7 buffer between each reading. Drifting was quickly noted, and the pH values concerned were discarded. During the summer I resorted to using a polyethylene bag over the meter and desiccant (CaSO_4) inside and on top of the instrument to eliminate the effects of humidity. On several occasions, this was the only way that readings could be obtained.

COMPARISON OF FIELD AND LABORATORY TESTS

The average blood pH values of unexercised channel catfish in the field and in the laboratory were almost identical; but the standard deviations were greater in the field:

	<u>Field</u>	<u>Laboratory</u>
Number tested	76	51
Mean pH	7.551	7.554
Range	7.28-7.90	7.27-7.77
Standard deviation	0.46	0.26

Haws and Goodnight (1962) reported a range of 7.49 to 7.65 for blood pH of 10 channel catfish, and Caillouet (1968) reported 7.7 to 7.8 for 12 unexercised channel catfish.

Although the mean values were the same in the field and the laboratory, there was some difference on different days when the tests were run (Table 1). Analysis of variance indicated that the differences between days were greater than expected by chance. The F values were 5.58, with 4 and 71 degrees of freedom for the field, and 9.4, with 4 and 46 degrees of freedom for the laboratory tests, both beyond the 0.01 probability level. The reason for differing results on various days are not known. The two days in the field when pH was below 7.5 were the two warmest days, and temperatures of 30 and 31.5°C may have stressed the fish somewhat.

The mean "within sample" squared deviations in the analysis of variance, 0.0173 in the field and 0.0043 in the laboratory, gave a significant

Table 1. Blood pH results on unexercised channel catfish in the Des Moines River and in the laboratory, 1964.

Field tests	Water temperature	Number	Mean pH	Standard deviation
July 26	27.5	9	7.570	0.018
July 27	30.0	5	7.428	0.014
July 28	31.5	25	7.474	0.011
July 29	27.0	10	7.637	0.012
July 30	25.0	27	7.600	0.025
Laboratory				
Aug. 5	26.0	4	7.535	0.003
Aug. 14	20.0	6	7.503	0.006
Sept. 4	22.0	16	7.526	0.003
Sept. 15	—	19	7.624	0.001
Sept. 20	20.0	6	7.472	0.014

F value of 4.0. The greater variance within samples in the field tests is also indicated by the standard deviations (Table 1).

The greater variability in field experiments may be the result of less stable conditions for the pH meter, more variation in exercise of the fish as they were taken from the holding net than when taken from the laboratory tanks, and more variation in conditions within the holding net than in the tanks.

EFFECT OF SEX AND SIZES ON BLOOD pH

After the blood samples were taken on September 15, each fish was killed and opened to determine sex. The 8 males had an average blood pH of 7.61, and the 11 females, 7.63, values so similar that a test of significance was unnecessary. Black *et al.* (1962) found no consistent difference in blood lactic acid levels of male and female rainbow trout. Caillouet (1967) found no difference in blood lactic acid of male and female channel catfish.

When the blood pH values were plotted against weight of the fish, there was a tendency for pH to increase with weight in the laboratory studies (Figure 1), but the variance was too great in the field tests to indicate any trend with size (Figure 2).

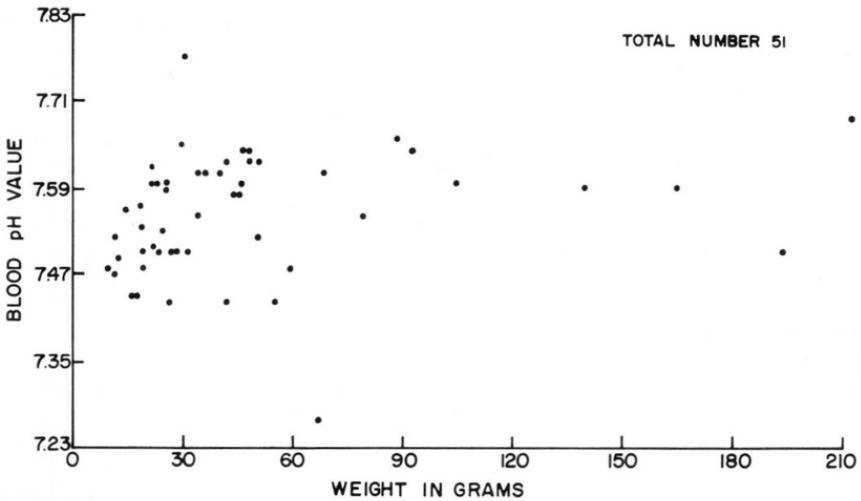


Figure 1. Blood pH values at various weights for channel catfish sampled in the laboratory.

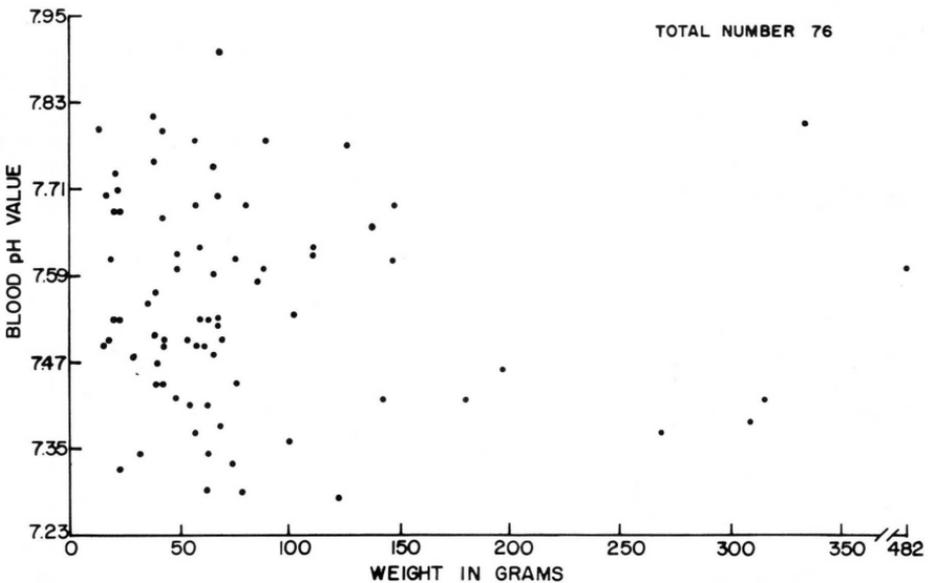


Figure 2. Blood pH values at various weights for channel catfish sampled at the Des Moines River.

EFFECT OF EXERCISE UPON BLOOD pH

Fish to be exercised were put into a 12" x 12" x 8" wooden screen-bottom box floated in the holding tank. Fish were continually harassed to keep activity as high as possible. Activity decreased during the first 5 minutes, and by 10 minutes the fish were so exhausted that they reacted very little. The blood pH dropped significantly by 5 minutes and further at 10 minutes, but began to rise after the fish were too fatigued to resist (Table 2).

Table 2. Blood pH values for unexercised, 5, 10, and 15 minute exercised channel catfish from the Des Moines River.

pH values	Unexercised	5 minutes	Exercised 10 minutes	15 minutes
7.90-7.94	1			
7.85-7.89				
7.80-7.84	2			
7.75-7.79	7			
7.70-7.74	5			
7.65-7.69	10			
7.60-7.64	26			
7.55-7.59	13	1		
7.50-7.54	23			1
7.45-7.49	13	2		1
7.40-7.44	14			
7.35-7.39	5	1		1
7.30-7.34	4		1	
7.25-7.29	4	1	1	1
7.20-7.24		2	2	6
7.15-7.19		2	2	2
7.10-7.14		1	2	1
7.05-7.09			3	
7.00-7.04		1	2	
6.95-6.99				
6.90-6.94			2	
6.85-6.89				
6.80-6.84			1	
Number	127	11	16	13
Mean	7.55	7.28	7.09	7.26

Black (1958), in exercising yearling kamloops trout, found that the pH would decline rapidly for the first 3 minutes and then rise slightly for the next 3 minutes. From the 6-minute point to 15 minutes of exercise, there was a slow but steady decline in the pH value. The drop in kamloops trout was only from 7.31 to 7.16, much less than in the channel catfish.

Caillouet (1968) reported blood pH values of 7.1-7.2 for channel catfish kept out of water for 15 minutes. Five catfish that had lost equilibrium after stress of transportation had pH values of 6.7-6.9, about the same as the most exhausted fish in my experiments.

CONCLUSION

The changes in blood pH when the catfish were put under stress probably indicate the buildup of blood lactic acid as reported by Caillouet (1967) and others. The pH test is simpler than lactic acid determinations and immediately indicates the condition of the fish whereas several hours must elapse before the lactic acid determinations are available.

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