A STUDY OF THE NORMAL AND COLLATERAL ANGIOARCHITECTURE OF THE PELVIC LIMB OF THE DOG USING RADIOPAQUE MEDIA AND GROSS DISSECTION TECHNIQUES

by

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INTRODUCTION

The normal angiology of the pelvic limb of the dog is easily understood to mean the normal arterial and venous arrangement within the limb. However, the collateral circulation of the limb may be interpreted in various ways by different persons. Collateral circulation may be defined as the subsidiary vascular channels which are present or which will develop when the primary vessels are occluded or destroyed. An adequate collateral circulation represents anastomoses of sufficient capacity to supply the vascular needs of the organ when the main vessels are injured. In this study, three types of collateral vessels were considered: those secondary vessels readily visible and well known to the anatomist; those vessels that are present, but, grossly speaking, invisible and functionally dormant; and newly-formed blood vessels.

Although considerable work has been done in the study of the collateral circulation of the pelvic limb, most of it has been in the field of human medicine. These studies were either with human subjects or, if performed upon dog or rabbit subjects, the emphasis and interest were quite naturally directed with the human problems in mind. In addition, observations of the collateral circulation and of the normal radiographic angioarchitecture of the pelvic limb of the dog were conflicting, confusing, and incomplete. In reviewing the literature available on the subject, only isolated reports of the sequelae incurred from ligation of the femoral artery alone, the femoral vein alone, and the femoral artery and vein simultaneously could be found. It seemed that no controlled research study had ever been made in this area. This is of great interest to the practicing veterinarian for the femoral vessels often are occluded or damaged and a concrete knowledge of what effect this would have on the life and function of the limb is needed. An investigation was deemed necessary to determine the normal and potential collateral circulation chanrels available when the femoral artery or vein was occluded or destroyed either separately or concomitantly. The question as to whether or not it is advisable or even preferable to ligate simultaneously the concomitant artery and vein when one or the other was occluded or destroyed needed to be answered. For the veterinary radiologist there is the need for knowledge of the normal radiological vascular patterns as well as the collateral circulation patterns of the pelvic limb of the dog since improved methods of diagnosis and therapy can be developed only when the normal angiology is known.

Information as to the amount of a radiopaque substance necessary to outline adequately the vessels of the pelvic limb of the dog, and the possible toxic sequelae resulting from such intra-arterial and intravenous injections was not readily available.

MATERIALS AND METHODS

Thirty-five dogs were used in the investigation. Fifteen animals were used to study femoral artery occlusion, ten to study femoral vein occlusion, and ten to study simultaneous occlusion of the femoral artery and vein. As well as could be ascertained by clinical examination, only healthy animals were used. The ages varied from five months to old adults with the majority of them ranging from one to three years of age. The sex of the animals was fairly well divided with 16 female and 19 male specimens studied.

All of the dogs were anesthetized with sodium pentobarbital, and surgery performed using aseptic technique.

The first series, consisting of 15 dogs, had the primary blood supply to the pelvic limb arrested by ligation of the femoral artery. The second series, consisting of 10 dogs, had the primary blood drainage from the pelvic limb arrested by ligation of the femoral vein. The third and final series, consisting of 10 dogs, had both the femoral artery and vein simultaneously ligated. In 15 animals the vessels were ligated only, while in 20 animals they were ligated and completely severed. All ligations were performed in the femoral triangle. Care was exercised to prevent trauma to the saphenous nerve and to the surrounding tissue with its lymphatics, muscle, and blood vessels.

In the first 10 dogs, immediately following the initial surgery, an arteriogram was made using a commercial radiopaque substance (Urokon Sodium 70%) for the injection.[1] This was done to show the normal angiological pattern of the limb. A series of radiographs was made at two-day intervals and later at four-day

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[1] Urokon Sodium 70%, brand of sodium acetrizoate. Mallinckrodt Chemical Works, St. Louis, Missouri.

intervals in order to show gradual collateral development. Such frequent intervals were found to cause excessive stress on the animals. The dogs were not able to maintain adequate food intake with the frequent anesthesia, and additional local tissue trauma was brought about by frequent manipulation of the injection site and accidental extravasation of the radiopaque material. In order to facilitate the injection of the contrast agent, polyethylene tubing was inserted into each segment of the ligated femoral artery and, after being sealed off, left in the vessel as a permanent cannula. Injections and radiographs were then repeated every seven days. This procedure was abandoned after ten dogs were injected since the radiographs disclosed very little of value. Difficulty occurred after two weeks with the polyethylene tubing becoming brittle and cracking and the blood vessels becoming so fibrotic and occluded that satisfactory injection of radiopaque material could not be made. Four (40%) of ten dogs exhibited a slight to severe anaphylactoid reaction when an intraarterial injection of radiopaque contrast material was given. Therefore, it was decided to make only one terminal radiograph immediately following euthanasia of the animal. The normal pelvic limb was used as the control to be compared with the opposite ligated limb. This technique proved to be very satisfactory. Additional dogs that were not injected with contrast medium were added to the artery ligation series to overcome the loss of accurate results incurred in using the contrast material on the live animals. Sufficient comparison was thus available.

Following surgery, the animal was given intramuscular injections of procaine penicillin and dihydrostreptymycin for a minimum of three days. This was administered with the idea that in a typical clinical case of occluded or damaged femoral vessels, antibiotics would be indicated to combat bacterial invasion into a limb in which the circulation was deficient. The animals were examined daily, and pathological changes in the ligated limb as well as the general condition of the animal were noted. The observations included taking the rectal temperature and noting the appetite, condition, bowel movements, general attitude, and limb appearance and function. At times, colored photographs were taken of the dogs to record the appearance and the function of the limbs.

Each dog was observed daily for an average period of four weeks, and at the end of that time was euthanized. Euthanasia was performed by anesthetizing the subject with sodium pentobarbital intravenously and then bleeding out by the common carotid artery. Immediately after euthanasia the pelvis and pelvic limbs were separated from the rest of the body by sawing through the lumbar vertebrae, leaving approximately two to three inches of the aorta intact cranial to its bifurcation. The aorta was then cannulated and the blood vessels flushed out with physiological saline or tap water, with both achieving equal results. Arteriograms were made within 20 to 30 minutes by injection of radiopaque medium into the aorta just cranial to its bifurcation. Eight to 12 cc. were injected into each leg. When venograms were made, the injection sites were the recurrent tarsal vein (saphenous parva) and the caudal vena cava. Six cc. were injected into the caudal vena cava and 12 cc. into the recurrent tarsal vein. This double injection was found to be necessary because of frequent interference and arresting of any injection into the caudal vena cava alone by the valves of the veins. In the limbs with both the femoral artery and vein ligated, the arteriogram was made first and the venogram last. Most of the arteries were obscured by the injected veins which are normally larger in diameter. The arteries that remained visible could be distinguished from the veins in most instances. This permitted the venograms to be read without excessive arterial interference. The arteriogram had already been made on another film. However, if the venogram was made first, and the arteriogram of the same animal last, the arterial patterns were obliterated by the injected larger veins and therefore useless.

Soon after taking the radiographs, the cadaver was embalmed by injection, using an embalming solution containing formalin (12%), glycerine (3.7%), acetic acid (0.5%), and water (83.8%). Immediately following the embalming, the arteries were injected with red latex and the veins with blue latex. The injection sites for both the embalming solution and the latex were the same as were used for the radiopaque medium injections. A small amount of weak ammonia solution (0.5%) was pre-injected to prevent premature "setting" of the latex. The amount of latex necessary varied with the size of the animal. The cadaver was stored for a day or more to allow the latex to "set" in the blood vessels before dissection was attempted.

Detailed dissection of both limbs was performed. Gross or macroscopic observations were made of the circulatory changes in the limbs. Special attention was given to those changes in the area of ligation. Photographs were taken of the dissected limbs. Measurements of the primary arteries and veins were made and duly recorded. The vessels were difficult to measure accurately for comparative study since the latex injection, which influenced the vessel diameter, varied greatly. In addition, the shape of the vessel, air-drying, and the embalming process caused size variations. The measurements were considered inaccurate and therefore of limited value. However, after measuring the primary arteries on 26 cadavers and the primary veins on 17 cadavers, some idea of the range in diameters of the normal arteries and veins was attained as well as an indication of hypertrophic and atrophic changes in the large vessels. The recorded measurements were, therefore, included in this thesis. Veins were measured with even less accuracy since they were extremely variable, depending greatly upon the amount of latex injected.

REVIEW OF LITERATURE

A substantial volume of literature, either directly or indirectly concerned with this study, was reviewed. Practically all of the previous investigations were made by men working in the field of human medicine. Much of the investigation had been performed upon human subjects, and the remainder on dogs and rabbits.

The standard veterinary text books, which include Bradley (4), Ellenberger and Baum (12), Miller (19), and Sisson and Grossman (29) necessarily concentrate upon giving detailed accounts of the major circulatory channels and not the secondary collateral channels. The pre-existing, but usually non-functioning collateral channels, as well as collateral circulation in general, are entirely or almost entirely neglected. Normal and collateral venous circulation is neglected even more than the arterial in that secondary normal vessels are discussed fleetingly. Miller mentioned that the femoral artery can be ligated in the femoral canal without great disturbance to the function of the limb and he quoted Dukes in saying only temporary lameness is caused. Miller stated that apparently the caudal gluteal artery insures adequate collateral circulation and that, judging from the quick recovery from lameness, arterial hypertrophy is rapid. Nothing more is said on this subject.

Allen (1) reported on 1,518 ligations and interruptions of the femoral vein in human clinical cases with no deaths and no loss of limb.

Allen (2) studied human cases of thrombo-angiitis obliterans and reported collateral circulation development.

Bickham (3), after describing the surgical procedure to ligate the various blood vessels of the human limb, listed the vessels that he considered to be the primary collateral channels that would function following each ligation.

Brooks and Martin (5) quoted several investigators who suggested that simultaneous ligation of the satellite vein along with the artery is or may be advantageous. They then reported their own results of an investigation on rabbits and dogs in which they performed simultaneous ligation of the common iliac and external iliac vessels. The femoral vessels were not included in this study and venous ligation alone was not done. A detailed study of the normal and collateral vessels was not performed.

Brooks, Johnson, and Kirtley (6) studied the effect that concomitant artery and vein ligation had on the incidence of gangrene in the human limb following arterial obstruction.

Deterling, Essex, and Waugh (7), using dogs and performing arteriovenous fistulas in the femoral artery and vein, noted that a lumbar sympathectomy greatly aided the development of the collateral circulation. They stated that the fistula itself, contrary to general belief, did little to develop arterial collateral circulation. It dilated the thigh veins, but these veins were relatively nonfunctioning as collateral circulation after the fistula was removed.

Dible (8) studied human cases of vessel thrombosis and reported on histological changes of the collateral vessels including the vasa vasorum and other vascular changes in the region of the thrombus. He differed with Eckstein, Gregg, and Pritchard and other investigators in stating that all collateral vessels are already formed vessels with no new vessels formed.

Doerr and Janes (9), in their study of the effect of arteriovenous fistula of the femoral artery and vein and the ligation of the proximal segment of the femoral vein on the growth of bone in pups, stated that arteriovenous fistula was the best stimulus to the development of collateral circulation. This statement disagrees with Deterling, Essex, and Waugh (7). Although much information concerning collateral circulation was reported including the condition of the limb following the arteriovenous fistula, there was no study made of the effect upon the limb in ligating the artery and vein alone or simultaneously and no detailed study was made of the development of collateral circulation.

Dotter (10), Pendergrass et al. (24), and Anonymous (33) reported on the unfavorable sequelae that may occur following the administration of intravascular contrast agents in the human.

The time rate of collateral development following ligation of the femoral artery and in some cases the femoral vein in the upper thigh region of nine dogs was studied by Eckstein, Gregg, and Pritchard (11). They theorized as to what type of collateral vessels were brought into use to cause the changes in blood flow and pressure. No detailed comparison of the effect of ligating the artery or vein alone or simultaneously was made, and no detailed anatomical study of collateral vessels was undertaken.

Halstead (13) ligated the subclavian and axillary arteries of a human patient in excising a subclavian aneurysm and noted an increased warmth and circulation to the hand four hours after surgery. He thought this was due to vasodilation from crushing the nerves in ligating the arteries and thus accidentally performing a periarterial sympathectomy. This, no doubt, was true but he also had ligated the cephalic vein and, although he felt at the time that this had nothing to do with any temperature rise, it may have aided future collateral development.

Holman and Edwards (14) worked with dogs and rabbits, ligating the satellite vein proximal to the site of ligation of the femoral and popliteal arteries. In femoral artery ligation, they recommended ligation of the femoral vein proximal to the deep femoral artery which was, in their estimation, the primary collateral artery. They did not make an experimental study of the benefit or lack of benefit in ligating the femoral artery alone, the femoral vein alone, or both vessels simultaneously. Also a detailed anatomical study of the development of the collateral vessels was not made.

Homans (15) felt that ligation of the common iliac vein was superior in treating venous thrombosis of the pelvic limb of the human to ligation of the common femoral vein for two reasons: there was less chance of pulmonary embolism occurring and better venous collateral circulation was available.

Kountz (16) used perfusion experiments on the recently dead and indicated the various drugs and methods that were of value in re-establishing circulation in peripheral disease.

Lewis and Reichert (17), working with human cadaver limbs of cases of thrombo-angiitis obliterans, showed by injection of a radiopaque medium a striking development of collateral circulation.

Makins (18), as a result of his wartime experiences with gunshot injuries to blood vessels, felt that it was preferable to ligate simultaneously the uninjured satellite vein when the main artery to a human limb was necessarily ligated. He thought that this joint ligation maintained the smaller amount of available blood within the leg for a longer time.

Mulvihill and Harvey (20), although doubtful as to the exact mechanism involved, worked with dogs ligating the femoral artery and observed that lumbar sympathectomy caused a more rapid development of collateral circulation and prevented gangrene in the limb. They felt that the sympathetic nerves controlled vasoconstriction and that when sympathectomy was performed, vasodilation occurred immediately rather than later on. No venous ligations were performed and thus no ligation comparison studies were made.

O'Neil (21) described collateral venous pathways when the caudal vena cava was ligated in the human.

Patten (22) described the embryological formation of blood vessels in the human.

Pearse (23) performed an excellent experimental study of arterial collateral circulation of the pelvic limb of the dog. His study included observations and reports of collateral artery changes, blood pressure changes, vasa vasorum changes, and the condition of the limb following various artery ligations. However, his work did not include a comparative study of the results of venous ligations alone, arterial ligations alone, and simultaneous artery and vein ligations. A detailed study of the hypertrophy of primary collateral blood vessels was not made and normal angioarchitecture was not specifically studied.

Piiper and Schoedel (25) contributed reports of the normal arteriovenous anastomoses in their work on the pelvic limb of the dog. Their study did not cover collateral circulation or anything further concerning the normal vessel patterns. They did state that sympathectomy, accomplished by severing the sciatic and saphenous nerves, increased blood flow and that most, but not all, arteriovenous anastamoses were in the paw region.

Quiring (26) gave probably the most comprehensive and complete coverage of collateral circulation in the human, and included many quotations reporting the highlights of work done in the field of collateral circulation, in general, by workers using experimental animals. He also discussed in considerable detail, the normal angioarchitecture of the human. However, since much of his report consists of quotes of the observations and experiments of many other investigators in many areas of the human and animal bodies and with numerous goals and approaches, the overall picture is confusing to the reader who is seeking more definite and concise information. The results of the various investigators often conflict and this adds to the confusion.

Redisch, Tangco, and Saunders (27) wrote an excellent treatise on human peripheral circulation, in general, with some mention of the development of collateral circulation. Most of the latter information consisted of quotes of work done by other investigators.

Reichert (28) also performed an excellent experimental study on the collateral circulation of the dog, ligating several vessels including the femoral artery and vein. However, ligation results were not clearly stated and there was no controlled study of the relative benefits of simultaneous artery and vein ligation as compared to ligation of the artery and vein alone.

Spalteholz (30) gave a thorough discussion of the various factors he believed were responsible for the establishment of collateral circulation and the success or failure of the collateral circulation.

Theis (31) reported on the favorable effect of lumbar sympathectomy in the treatment of occlusive vascular disease in the human.

Thorpe and Burch (32) studied 12 human clinical cases of caudal vena cava ligation for thrombophlebitis, noting superficial venous changes in the limbs and abdomen as well as the general appearance and function of the limb.

VanLoo and Heringman (34) studied and reported on the blood flow and pressure changes, both local and systemic, produced by an artificial arteriovenous fistula between the femoral artery and vein of the dog. No study was made of anatomical vessel changes or of normal vessel patterns.

Wisham, Abramson, and Abel (35) studied the value of active and passive exercise in increasing blood flow in the limbs of human patients suffering from peripheral arterial disease.

OBSERVATIONS

Contrast Medium Reactions

Four of ten dogs (40 percent) exhibited a slight to severe anaphylactoid reaction when an injection of a radiopaque contrast medium was made into the femoral artery. This reaction included tachycardia, crying as if in pain, retching, tonic leg movements, dyspnea, and in one case, a bilateral posterior paralysis. Except in the case of posterior paralysis, which appeared permanent, the reactions lasted one to three minutes. The contrast medium, as well as the repeated surgery, seemed to increase leg edema and pain (Table 4).* These were most severe when the medium was known to extravasate into the surrounding tissues, and resulted in greater local swelling, increased pain, and fibrosis. This reaction interfered with the accuracy of experimental results since the function and condition of the limb and the animal, in general, could not be accurately determined. An additional possibility existed, that the repeated injections of the contrast material caused vasospasms and other vascular irritations that altered, either unfavorably or favorably, the development of the collateral vessels. It was of interest to note that in four dogs no reaction of any type occurred when the contrast medium was injected into the cephalic and recurrent tarsal veins. However, these same dogs exhibited moderate reactions, indicating pain as

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* All Tables and Plates are in the Appendix.

in arteriospasm when the femoral artery was injected. Due to the unfavorable reactions, the live animal injection of contrast material was discontinued after injecting ten dogs of the artery series.

Normal Angioarchitecture

The normal angioarchitecture was observed by two methods: a detailed gross dissection of the normal limb following injection of colored latex into the arteries and veins, and a study of radiographs of the normal limb following injection of the vessels with radiopaque material.

The normal pattern of the arteries exhibited no variances from the established pattern in the veterinary anatomy text books.

The normal venous pattern also exhibited no variances, except in detail, from that already established in the veterinary anatomy texts. Several medium-sized muscle branches entered the recurrent tarsal vein (saphenous parva) that were not shown or mentioned in the standard veterinary anatomy books. The normal arterial and venous circulations, as observed in this study, are depicted in Plates I, II, III, IV, and V. The normal circulation in the thigh region may be seen radiographically in Plates XVIII and XX.

The minimum and maximum diameters, as well as the average diameters, of the normal primary arteries and veins of 26 and 17 cadavers, respectively, were carefully measured and recorded (Tables 2 and 3). These measurements indicate the approximate diameter of the primary vessels of the pelvic limb of most dogs.

Collateral Circulation

Series I, Femoral Artery Ligation. Detailed dissection of the dog cadaver limbs revealed the vessel changes in the primary collateral channels as well as in the secondary and tertiary channels. The vessels that were found to be the primary collateral channels were listed (Table 2). Of these vessels, the most important arteries were the pubo-femoral, deep femoral, cranial femoral, caudal gluteal, and distal caudal femoral. This was determined by the degree of hypertrophy and the consistent number of times that they were hypertrophied. The minimum, maximum, and average diameters of the primary collateral arteries in all three ligation series were recorded (Table 2). These measurements indicated the average increase in size (hypertrophy) of the arteries as well as the minimum and maximum range in the various sizes and breeds of dogs. When the primary collateral vessels of the artery ligation series were averaged, all but three: the descending genicular, saphenous, and middle caudal femoral, showed an increase in size. However, this was true only of the average of the vessels. When each individual blood vessel was examined in all 14 cadavers (one dog was euthanized early because of posterior paralysis), it was found to be hypertrophied in most, atrophied in some, and the same diameter as in the normal limb in many. These artery changes were computed in percentage designation, and recorded (Table 2). Many small, innominate arteries, both subcutaneous and muscular branches, were hypertrophied to a large degree. They were usually quite tortuous and anastomotic. Most of these vessels paralleled the area of ligation and arose from the cranial femoral, deep femoral, proximal caudal femoral, and the proximal and distal segments of the femoral artery in an attempt to traverse the ligated area.

Interesting hypertrophic changes were observed in addition to those already mentioned in the gross dissection study, and included the appearance of otherwise non-visible arteries. Arteries that were not visible to the naked eye in the normal limb were hypertrophied or newly-formed in the ligated limb. These vessels in the normal limb were recorded as 0 diameter, and since they were initially so small, the measurements that were made of them show a very great increase in diameter (Table 2). The vasa vasorum, or at least what appeared to be the vasa vasorum of the femoral artery, in most animals was greatly hypertrophied. Four or five, to as many as a dozen, arteriole-sized vessels canalized the fibrotic artery ligation area to unite the two severed ends. This development was most pronounced if the artery was merely ligated and not severed, but it also occurred in the severed arteries if the gap between the ends was not too great. Photographs of the dissected cadaver limbs, and direct tracings of the arteries of the photographs were made to illustrate the above vessel changes (Plates VI and VII).

Arteriograms of the ligated limbs showed much collateral development (Plates VIII and IX). Arteries that were normally present were hypertrophied, more tortuous, varied in diameter in different parts of their lengths, and exhibited a greater number of anastomoses. Many arteries that were not visible in the arteriogram of the normal limb were present in the arteriogram of the ligated limb. These vessels crisscrossed each other and also were tortuous and anastomotic. The rapid appearance of these arteries left little doubt that dormant reserve channels had become functional and hypertrophied when the need for them arose. No proof was derived, but some or many of the latter-type arteries were possibly newly-formed. This was indicated in that early arteriograms exhibited a lesser number of these collateral arteries than later arteriograms in the same live animals. Anastomoses were plainly visible in regions surrounding the femur within the muscle structures. Well-developed anastomotic arteries usually were present between the cranial femoral and cranial branches of the distal caudal femoral arteries. These anastomoses passed through the quadriceps femoris muscle in connecting the two arteries just named, and formed an efficient collateral channel paralleling and bypassing the ligated area. Well-developed anastomoses were formed connecting the caudal gluteal, deep femoral, saphenous, proximal, middle, and distal caudal femoral arteries. These arteries formed an extensive network of collateral channels within the large caudal thigh muscles and thus bypassed the area of ligation and supplied the nutritional needs of the thigh muscles and lower limb.

The primary collateral arteries with their primary anastomoses were therefore observed to be:

1. Cranial femoral artery - formed anastomosis with the deep femoral artery by means of the lateral circumflex femoral and medial circumflex femoral branches.

2. Deep femoral artery - formed anastomoses with caudal gluteal, proximal, middle, and distal caudal femoral, and cranial femoral artery.

3. Caudal gluteal artery - formed anastomoses with the deep femoral, proximal, middle, and distal caudal femoral arteries.

4. Distal caudal femoral artery - formed anastomoses with the cranial femoral, deep femoral, and caudal gluteal arteries.

5. Pubo-femoral artery - formed origin of the deep femoral and external pudic artery.

Additional named arteries that contributed considerably to the collateral circulation were:

1. Proximal caudal femoral artery - formed anastomoses with the caudal gluteal, deep femoral, middle, and distal caudal femoral arteries.

2. Middle caudal femoral artery - formed anastomoses with the caudal gluteal, deep femoral, proximal, and distal caudal femoral arteries.

3. Saphenous artery - sometimes formed anastomoses with vessels in the thigh region. This vessel is quite variable, remaining normal for the greater percentage of the time.

4. Descending genicular artery - about the same as the saphenous artery.

5. Superficial circumflex iliac artery - hypertrophied most of the time but is also quite variable.

6. Caudal superficial abdominal artery - also was quite variable but remained normal most of the time.

The ligated part of the femoral artery usually became a completely fibrous cord within two weeks. Fibrosis, for the most part, extended one to two inches along the artery and usually terminated where a major arterial branch originated (Plate VI). Since the artery was ligated distal to the cranial and deep femoral arteries and proximal to the proximal caudal femoral, the area between these vessels usually was fibrotic. In one instance, fibrosis extended as far distally as the popliteal artery and, in a few animals, the proximal caudal femoral artery became fibrotic. Fibrosis tended to cause adhesions of the femoral artery and vein to the surrounding tissue. The adhesions did not seem to interfere with the flow of blood through the femoral vein.

The satellite veins of the primary arteries exhibited little or no hypertrophy. Two of 15 dogs (13.3 percent) showed visible hypertrophy of the satellite veins. A few veins showed slight atrophy and the rest appeared normal. Small veins in the areas of secondary and tertiary collateral development also appeared to be slightly to moderately hypertrophied.

The muscles of the ligated limb usually appeared as normal in size and strength as those of the normal limb. The dogs walked and ran in an apparently normal manner. Slight atrophy occurred in one dog apparently from disuse of the limb because of severe lameness. Considerable hypertrophy of the muscles of the ligated limb occurred in one dog. A summary of the effect of ligation upon limb function and edema was made (Table 4). This showed that lameness and edema were slight to absent when contrast medium was not used and repeated surgery was not performed. No limb gangrene or deaths occurred as a result of the ligation.

Series II, Femoral Vein Ligation. Detailed dissection of the dog cadaver limbs revealed the venous changes in the primary, secondary, and tertiary collateral channels. The vessels that were found to be the primary collateral channels were listed (Table 3). Of these vessels, the most important were the caudal superficial abdominal, distal caudal femoral, cranial femoral, deep femoral, and caudal gluteal. This was determined, as it was with the arteries, by the amount of hypertrophy and the consistent number of times that they were hypertrophied. However, it was found that all of the veins that were satellites to the primary collateral arteries hypertrophied to a greater relative diameter and with a greater consistency. The minimum, maximum, and average diameters of the primary collateral veins in all three ligation series were recorded (Table 3). These measurements indicated the average increase in size of the veins, as well as the minimum and maximum range in the various sizes and breeds of dogs. The primary collateral veins, when averaged, all showed an increase in size. However, this was, as with the arteries, true only of the average of the vessels. When each individual vein was examined in ten cadavers, it was found that most of them hypertrophied, a very few atrophied, and the rest remained the same diameter. These venous changes were computed in percentage and recorded (Table 3).

Many small innominate veins were hypertrophied to a large degree; even more so than had the innominate arteries of the artery ligation series. The subcutaneous innominate veins had increased in size to the extent that they were visible beneath the skin of several of the live dogs, resembling somewhat human varicose veins. These veins were very tortuous and anastomotic; again, more than the arteries had been in the artery ligation series. Most of these subcutaneous innominate veins formed anastomoses between the caudal superficial abdominal vein and the saphenous magna, distal caudal femoral, and the distal segment of the femoral vein. In this manner, a wide collateral channel was formed which bypassed the ligated femoral vein. Many other hypertrophied innominate veins took part in the collateral circulation with several paralleling the area of ligation and anastomosing the proximal and distal segments of the femoral vein directly and indirectly. Indirectly they bypassed the ligated vessel by linking the distal segment with the cranial femoral and by veins passing from the ligation area proximally to the cranial femoral and deep femoral veins and distally to the proximal caudal femoral, saphenous magna, and descending genicular veins. Newly-visible innominate veins were rather numerous (Table 3). Innominate branches also were prevalent, anastomosing the recurrent tarsal vein with the caudal gluteal and all three caudal femoral veins.

What appeared to be the vasa vasorum of the femoral vein was hypertrophied in most dogs, and varying numbers of venule-sized vessels canalized the fibrotic area to unite the two severed ends. This was most pronounced if the vein was merely ligated and not severed, but it also occurred in severed veins if the gap between the ends was not too great. Photographs of the dissected limbs and direct tracings of the veins were made to illustrate the vessel changes (Plates X and XI).

Venograms of the ligated limbs showed much collateral development (Plate XII). Veins that were normally present, like the arteries of the previous series, were hypertrophied, more tortuous, varied in diameter in different parts of their lengths, and exhibited a greater number of anastomoses. Many veins that were not visible in the venogram of the normal limb were present in the venogram of the ligated limb. These veins crisscrossed and also were tortuous and very anastomotic. They probably were dormant reserve channels that had become functional and hypertrophied when the need for them arose. Some possibly were newly-formed veins. Many anastomoses were plainly seen in the muscles surrounding the femur. Well-developed anastomoses were present between the cranial femoral and cranial branches of the distal caudal femoral vein, thus bypassing the ligated vein. A magnificent network of anastomoses was present in the caudal thigh muscles uniting the caudal gluteal, deep femoral, saphenous magna, recurrent tarsal, and all three caudal femoral veins.

The primary collateral veins with their primary anastomoses therefore, were observed to be:

1. Caudal superficial abdominal vein - formed anastomoses with the saphenous magna; proximal, middle, and distal femoral; and distal femoral segment.

2. Cranial femoral vein - formed anastomoses with the cranial branches of distal caudal femoral and with the deep femoral and distal femoral segment.

3. Deep femoral vein - formed anastomoses with the caudal gluteal; proximal, middle, and distal caudal femoral; cranial femoral, distal femoral segment, and recurrent tarsal veins.

4. Caudal gluteal vein - formed anastomoses with the recurrent tarsal; deep femoral; proximal, middle, and distal caudal femoral veins.

5. Distal caudal femoral vein - formed anastomoses with the recurrent tarsal, caudal gluteal, deep femoral, cranial femoral, and proximal and middle caudal femoral veins.

Additional named veins that contributed considerably to collateral circulation were:

1. Proximal caudal femoral vein - formed anastomoses with the caudal gluteal, deep femoral, middle and distal caudal femoral veins, and sometimes the caudal superficial abdominal vein.

2. Middle caudal femoral vein - formed anastomoses with the same vessels as did the proximal caudal femoral vein.

3. Saphenous magna vein - formed anastomoses with the caudal superficial abdominal vein and indirectly with the caudal gluteal, deep femoral, and all three caudal femoral veins.

4. Descending genicular vein - often formed an anastomoses with the cranial femoral and superficial circumflex iliac veins as well as with veins in the region of the vastus medialis muscle.

5. Superficial circumflex iliac vein - often anastomosed with the descending genicular vein.

The ligated part of the femoral vein usually became a completely fibrous cord within two weeks. Fibrosis usually extended a distance of one to two inches along the vein and terminated where the cranial femoral and proximal caudal femoral veins entered the femoral vein. Fibrosis caused adhesions of the vein and satellite artery to the surrounding tissues, but no interference with arterial blood flow was apparent.

Most of the satellite arteries of the primary collateral veins exhibited considerable hypertrophy along with the veins. This was in contrast to the negligible hypertrophy of the satellite veins in the artery ligation series. This probably was due to retrograde pressure exerted when the femoral vein was ligated. Several arteries atrophied and many remained the same diameter as normal.

The muscles of the ligated limb appeared normal in size and strength. The dogs walked and ran in an apparently normal manner. A summary of the effect of the ligation upon limb function and edema was made (Table 5). This showed that edema and lameness was slight to absent in the majority of the dogs. However, when compared with the dogs in the artery ligation series that had not received intravascular injections of irritating contrast material and had not undergone repeated surgery, there was a slightly higher incidence of lameness and edema in the femoral vein ligation. No limb gangrene or deaths occurred as a result of the ligation.

Series III, Femoral Artery and Vein Ligation. Detailed dissection of the dog cadaver limbs was performed and the changes in the primary, secondary, and tertiary artery and vein channels were studied. The vessels that were found to be the primary collateral channels were recorded (Tables 2 and 3). The vessels that appeared to be the most important, determined by the degree and consistency of hypertrophy, were the same as those already mentioned in the artery ligation series and in the vein ligation series. The arteries were the pubo-femoral, deep femoral, cranial femoral, caudal gluteal, and distal caudal femoral. The veins were the caudal superficial abdominal, distal caudal femoral, cranial femoral, deep femoral, and caudal gluteal. The minimum, maximum, and average diameters of the primary collateral arteries and veins in all three ligation series were recorded (Tables 2 and 3). These measurements, as was the case in the former two ligation series, indicated the average increase in size and the minimum and maximum range of the arteries and veins in the various sizes and breeds of dogs. All of the primary collateral veins and all but two arteries, the descending genicular and proximal caudal femoral, when averaged, had increased in size in the artery and vein simultaneous ligation series. The hypertrophy of the arteries was slightly less than that of the arteries in the artery ligation series and slightly more than that of the arteries in the vein ligation series. Hypertrophy of the veins was considerably greater than that of the veins in the vein ligation series and appeared to be greater than that of the veins in the artery ligation series, although measurements of the veins were not made in the latter-mentioned series. Again, this was true only of the average of the vessels since some atrophied and some remained essentially normal in diameter when ten cadavers were examined. The arterial and venous changes were computed in percentage and recorded (Tables 2 and 3).

Small innominate veins, some newly-visible, were more numerous and more hypertrophied than in the venous series. The subcutaneous veins could be seen beneath the skin of the thigh in several of the dogs. These veins were very tortuous and had many anastomoses, particularly between the caudal superficial abdominal vein and the saphenous magna, distal caudal femoral, and the distal segment of the femoral vein. As had occurred in the previous series, many hypertrophied innominate arteries and veins paralleled the ligation area and anastomosed the proximal and distal segments of the femoral artery and vein. These vessels originated and terminated, for the most part, in the cranial femoral, deep femoral, saphenous magna, proximal caudal femoral, and the femoral segments themselves. Thus, various bypassing collateral channels were established. The recurrent tarsal, caudal gluteal, and distal caudal femoral arteries and veins also were united by hypertrophied innominate vessels.

In the immediate ligation area, arteriole and venule size vessels canalized the fibrotic area which extended usually one to two inches. Again, these vessels were more numerous and obvious when the vessels were only ligated and not severed. Photographs were taken of the dissected limbs, and direct tracings of the arteries and veins were made to show the vessel changes (Plates XIII, XIV, and XV).

Arteriograms and venograms of the normal and ligated limbs showed much collateral development, both arterial and venous (Plates XVI, XVII, XVIII, XIX, and XX). The veins were more extensively developed than in the previous ligation series whereas the arteries were approximately the same, perhaps slightly less than in the artery ligation series. The same patterns of development were present with the vessels hypertrophied, crisscrossed, tortuous, variable in diameter, and highly anastomotic. Newly-visible vessels were again present. The same anastomoses as were present in the previous two series again were present in the muscles surrounding the femur. These included the anastomoses between the caudal gluteal, all three caudal femorals, and deep femoral arteries in the caudal thigh muscles and between the cranial femoral and cranial branches of the distal caudal femoral arteries in the cranial thigh muscles. The same veins, plus the recurrent tarsal vein, were anastomotic.

The primary collateral arteries and veins were the same as those of the artery ligation series and vein ligation series, respectively.

Fibrosis of the ligated vessels usually occurred in approximately two weeks and ended where the cranial femoral and proximal caudal femoral arteries and veins originated or terminated. Adhesions occurred between the fibrotic vessels and the surrounding tissues.

The muscles of the ligated limb appeared normal in size and strength. A summary of the effect of the ligation upon limb function and edema was made (Table 6). This showed that edema and lameness were negligible to absent. When compared to the results in the vein ligation series, there was less lameness and edema by the simultaneous ligation. When compared with the dogs in the artery ligation series that did not receive contrast material or undergo repeated surgery, the lameness and edema were approximately the same. No limb gangrene or deaths occurred as a result of the ligation.

DISCUSSION

Contrast Medium Sequelae

The unfavorable sequelae that were encountered from the intravascular injection of the radiopaque contrast agent agreed with many of the reactions reported occurring in the human by Dotter (10), Pendergrass et al. (24), Anonymous (33), and Theis (31). The contrast material seemed to cause generalized anaphylactoid reactions and local pain in four of the dogs. The local pain probably was due to vasospasm and apparently was more intense with the intra-arterial injections than it was with the intravenous injections. This agreed with the report made by Theis (31). No study was made of the effects of the contrast material on the arteries and veins other than in the immediate ligation area. Fibrosis was stimulated at the area of ligation by the irritating medium. No thrombosis was detected in the arteries or veins when the radiographs were examined and the cadavers dissected. Dotter (10) reported that all available contrast media were irritating, and chemical thrombosis of injected veins was common in the human.

The case of posterior paralysis that occurred immediately after the injection of the contrast material, was assumed to have been caused by contrast medium damage to the spinal cord. This would agree with previous reports of such damage having occurred with an animal in the supine position. Radiographic examination and hand palpation revealed no apparent intervertebral disc damage or exostosis.

Normal Angioarchitecture

The standard veterinary anatomy text books did not depict or mention the veins that originated from the caudal thigh region and entered the recurrent tarsal vein in the normal limb. These veins hypertrophied and were important collateral channels when the femoral vein was ligated.

Collateral Angioarchitecture

The arterial and venous collateral channels, if intact and healthy, were adequate to supply the nutritional needs of the limb following sudden and complete occlusion of the main artery and vein of the limb. This was true if the artery and vein were ligated alone or simultaneously. Ligation of the femoral artery alone, or the femoral artery and vein concomitantly, apparently achieved approximately the same results. The collateral arteries developed very well with both ligations. There was only slight edema and lameness in both instances, provided no contrast material or repeated surgical trauma was administered. These results indicated that simultaneous ligation of the artery and vein, when the artery was occluded, was unnecessary. The suggestions made by other investigators, Brooks and Martin (5); Brooks, Johnson, and Kirtley (6); Holman and Edwards (14); Makins (18); and Reichert (28), that simultaneous ligation of the satellite vein when the main artery to the limb was occluded was advantageous was not supported. Choice of the vein ligated and species difference evidently influence the need for a simultaneous ligation. Simultaneous ligation was superior to ligation of the femoral vein alone. Ligation of the vein alone resulted in slightly more edema and lameness. The increased edema was caused by venous stasis which was greater since the venous drainage was impaired and the arterial blood flow was unchecked. Simultaneous ligation of the femoral artery along with the femoral vein, impaired the inflow of blood to the limb and achieved a more normal pressure differential between the arterial and venous circulations. This decreased the amount of venous stasis, and, with it, the chance of gangrene occurring. However, without simultaneous ligation, the collateral venous channels were adequate enough to prevent edema in most of the dogs and allow only a slight temporary edema in the rest of the animals. The results showed that simultaneous femoral artery and vein ligation, if necessary, could be performed in the dog with negligible threat of gangrene or loss of normal limb function.

The arteries that were found to be the main collateral channels were the caudal gluteal, pubo-femoral, deep femoral, cranial femoral, and distal caudal femoral. Miller (19) mentioned the caudal gluteal artery, and Holman and Edwards (14) the deep femoral artery as being the primary collateral artery. They were not complete in their list since each of the above arteries was of prime importance as a collateral channel. The caudal gluteal artery offered a bypass by means of the internal iliac route. The caudal gluteal and deep femoral arteries were of prime importance in furnishing nutrition to the caudal thigh muscles and as a bypass to the lower limb by anastomosing with all of the caudal femoral arteries. The pubo-femoral was a consistently hypertrophied short trunk that gave origin to the deep femoral and external pudic arteries with their respective thigh and abdominal branches. The cranial femoral artery was of great importance in supplying the cranial thigh muscles and in bypassing the ligated area to reach the lower leg. It anastomosed with the deep femoral artery in the proximal thigh region and with the descending genicular, distal caudal femoral, and the distal femoral segment in the distal thigh region. Another collateral route that was noted but not emphasized, occurred between the deep circumflex iliac, saphenous, and superficial medial genicular arteries.

Vessel changes that consisted of hypertrophy and meandering (varicose veins), occurred in the subcutaneous innominate veins in the medial thigh region and in the caudal superficial abdominal vein. Varicosities did not occur in the other superficial named veins of the limb. The varicosities encountered in the caudal superficial abdominal and subcutaneous innominate veins did not seem to cause chronic pain or any loss of limb function. These results agreed with those of Thorpe and Burch (32) who ligated the caudal vena cava in 12 human clinical cases of thromboangiitis obliterans and reported the large leg veins did not become varicose although the superficial abdominal and small skin veins did. No loss of limb function occurred.

The veins that were found to be the main collateral channels were the caudal superficial abdominal, deep femoral, caudal gluteal, cranial femoral, saphenous magna, and distal caudal femoral. The recurrent tarsal was of considerable importance. The caudal superficial abdominal vein helped form an efficient bypass from the external pudic vein to the saphenous magna, distal caudal femoral, middle and proximal caudal femorals, and the distal part of the femoral vein itself. The caudal gluteal, deep femoral, and cranial femoral veins formed collateral channels as did the arteries of the same names. The recurrent tarsal vein formed a drainage route by means of several branches extending from it to the branches of the caudal gluteal and the deep and caudal femoral veins. No muscle fibrosis was caused through venous ligation. Brooks and Martin (5) had questioned such a ligation because of the possibility of muscle fibrosis and chronic venous stasis.

Many of the vessel changes reported by Allen (2) to occur in collateral vessels were observed in this study. The collateral arteries and veins were observed to be tortuous, anastomose freely, crisscross, and vary in size. Branching and anastomosing of the two segments of the femoral vessels also was prevalent.

The area of ligation was canalized by arteriole- and venule-sized vessels that appeared to be hypertrophied extensions of the vasa vasorum. This is a controversial issue with the various investigators: Dible (8), Pearse (23), and Reichert (28). Whether the vessels were the hypertrophied vasa vasorum or newly-formed vessels entering the area of inflammation does not seem to be known.

Doerr and Janes (9), in their study of arterio-venous fistula of the femoral artery and vein of pups, reported that the arterial collateral response was most rapid, but limited, and the venous response was slower, but much greater. These results agreed with the collateral response observed in this study. The arterial collateral development was slightly more rapid than the venous, but the venous hypertrophy was greater. Only one dog appeared to have an increase in muscle volume which differed from the results of Doerr and Janes who reported an increase in muscle volume in all of their pups. This difference in results may have been due to the young age of the dogs used by them and to the arterio-venous fistula used in their study.

The information attained in this study appeared to support the theory of Eckstein, Gregg, and Pritchard (11) and Redisch, Tangco, and Saunders (27) that collateral vessels include functioning and grossly visible channels that bypass the primary route even prior to occlusion of the main channel; pre-existing dormant potential channels not normally grossly visible; and newly-formed channels. Some investigators, including Dible (8) and Allen (2) considered all collateral vessels to be pre-existing with no new vessels being formed. The presence of newly-formed vessels was indicated by the increase in the number of vessels seen in the later radiographs than were seen in the early radiographs. However, no proof that these were newly-formed vessels was obtained. The vessels could have been pre-existing potential channels that had gradually increased in size to where they could be seen when injected with contrast material. Redisch, Tangco, and Saunders (27) postulated that the new channels were formed by mesenchymal cells reverting to angioblastic activity. The newly-formed capillaries, in turn, fused and further differentiated to form larger vessels.

Mulvihill and Harvey (20), in ligating the femoral artery of dogs and in performing lumbar sympathectomies, stated that lumbar sympathectomy caused a more rapid development of collateral circulation and prevented limb gangrene. Lumbar sympathectomy allowed vasodilatation to occur and therefore, was of benefit to the development of collateral circulation. This was true of the beneficial effects of lumbar sympathectomy, but the results of this study indicated that if the collateral vessels were healthy and intact, lumbar sympathectomy was unnecessary to prevent gangrene in occlusion of the femoral vessels.

An interesting histological study of the changes in the walls of the collateral vessels of humans was made by Dible (8). He reported that collaterals dilate into thin-walled vessels rather than into thick-walled vessels as occurs in hypertension. The cells in the wall increase in number and length and therefore, become thinner.

Spalteholz (30) gave a detailed report of the factors that he considered influenced the development of collateral circulation. The following is a summary of these factors as given in Quiring (26).

1. Interrelations of the circulatory channels
    a) Extent of the vascular bed
    b) Length of the vascular channels
    c) Arrangement of the vascular network
    d) Condition of the vessel walls
2. Condition of the heart
3. Condition of the blood
    a) Blood volume
    b) Blood pressure
    c) Blood composition
4. The organ or body part in which the collateral changes occur
5. General body condition
6. Time sequence of occlusion (acute or chronic)
7. Species of animal involved

Wisham, Abramson, and Abel (35) reported from their work on humans that active exercise was of definite benefit to the development of collateral circulation, and that passive exercise was of negligible value. Forced exercise of the dogs in this study seemed to aid collateral development, and reduced edema.

SUMMARY

The normal and collateral circulation of the pelvic limb of 35 dogs was studied, using a commercial radiopaque contrast agent (Urokon Sodium 70%) and gross dissection techniques. The femoral artery was ligated in 15 dogs, the femoral vein in 10 dogs, and the femoral artery and vein simultaneously in 10 dogs.

With the exception of several medium-sized veins entering the recurrent tarsal vein that were not shown or mentioned previously, the normal patterns of the arteries and veins were the same as those in the standard veterinary anatomy text books.

It was determined that the arterial and venous collateral channels, if intact and healthy, were adequate to furnish the nutritional needs of the limb following sudden and complete occlusion of the primary artery and vein of the limb. This was true if the artery and vein were ligated separately or simultaneously. Ligation of the femoral artery alone, or the femoral artery and vein simultaneously, achieved approximately the same results with no gangrene and little or no edema and lameness occurring in both ligations. Simultaneous ligation seemed preferable to ligation of the femoral vein alone since slightly less edema and lameness occurred.

The primary collateral arteries were found to be the deep femoral, cranial femoral, caudal gluteal, pubo-femoral, and distal caudal femoral. These arteries formed important anastomoses and bypass routes to maintain the blood supply to the limb.

The primary collateral veins were found to be the caudal superficial abdominal, distal caudal femoral, caudal gluteal, deep femoral, and cranial femoral. These veins formed important anastomoses and bypass routes which served to maintain adequate blood drainage from the limb.

Many changes were observed in the collateral vessels. They became more tortuous, more anastomotic, crossed and recrossed profusely, and varied in diameter in various parts. Branches were present that paralleled the area of ligation. Collateral vessels that were not grossly visible in the normal limb hypertrophied and became visible in the ligated limb. Newly-visible vessels, when they appeared immediately following ligation of the main vessels, were believed to be pre-existing potential, but non-functioning channels. Newly-visible vessels that appeared later following the ligation of the main vessels were believed to be newly-formed vessels.

Vessels of arteriole and venule size were observed to canalize the fibrotic area of ligation to unite the two femoral vessel segments. These vessels were either hypertrophied vasa vasorum or newly-formed channels. No proof was established as to which type of vessel they were or whether they consisted of both types.

The muscles of the ligated limb, in all but two cases, appeared normal in size and strength as determined by their appearance and the ability of the animal to exercise (run and jump) in an apparently normal manner. However, no severe exercise stress tests were administered.

Unfavorable sequelae from the intravascular use of a contrast agent were observed.

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APPENDIX

Table 1. Description of the dogs used in this study.

Dog No.	Breed	Approx. age	Sex	Weight (lbs.)	Ligation
1	Fr. Poodle	3 yrs.	Female	40	Femoral artery
2	Pointer	5 yrs.	Male	45	Femoral artery
3	Collie	2 yrs.	Female	55	Femoral artery
4	Elkhound-X	1 yr.	Male	40	Femoral artery
5	Collie-X	6 yrs.	Male	50	Femoral artery
6	Spaniel-X	1 yr.	Male	25	Femoral artery
7	Terrier-X	7 yrs.	Male	40	Femoral artery
8	Boxer-X	1 yr.	Male	40	Femoral artery
9	Collie-X	3 yrs.	Male	44	Femoral artery
10	Collie-X	5 yrs.	Female	46	Femoral artery
11	Boxer-X	6 yrs.	Female	48	Femoral vein
12	Collie-X	4 yrs.	Male	40	Femoral vein
13	Pug-X	1 yr.	Male	15	Femoral art. & vein
14	Terrier-X	4 yrs.	Male	27	Femoral vein
15	Spaniel-X	5 yrs.	Male	45	Femoral vein
16	Boxer-X	5 yrs.	Male	47	Femoral art. & vein
17	Setter-X	3 yrs.	Male	36	Femoral art. & vein
18	Hound-X	6 mos.	Female	16	Femoral art. & vein
19	Hound-X	1 yr.	Female	28	Femoral art. & vein
20	Spitz-X	6 mos.	Male	21	Femoral vein
21	Setter-X	1 yr.	Female	30	Femoral art. & vein
22	Collie-X	7 mos.	Male	28	Femoral art. & vein
23	Collie-X	8 mos.	Female	22	Femoral vein
24	Spaniel-X	2 yrs.	Male	30	Femoral vein
25	Cocker-X	2 yrs.	Female	20	Femoral vein
26	Terrier-X	1 yr.	Female	15	Femoral art. & vein
27	Spaniel-X	8 yrs.	Female	40	Femoral vein
28	Terrier-X	3 yrs.	Female	45	Femoral art. & vein
29	Cocker-Span.	7 yrs.	Female	30	Femoral art. & vein
30	Shepard-X	8 mos.	Male	40	Femoral vein
31	Cocker Span.	1 yr.	Female	29	Femoral artery
32	Hound-X	3 yrs.	Female	52	Femoral artery
33	Terrier-X	1 yr.	Male	28	Femoral artery
34	Spaniel-X	3 yrs.	Male	32	Femoral artery
35	Hound-X	5 mos.	Female	16	Femoral artery

Table 2. Measurements in millimeters of primary collateral arteries.

Arteries	Normal limb			Abnormal limb			Percentage changes		
	Min.	Max.	Aver.	Min.	Max.	Aver.	N.[1]	A.[2]	H.[3]
Superficial circumflex iliac	0.19	1.98	0.70	0.40	2.38	0.89	42.2	3.8	53.8
Proximal caudal femoral	0.40	1.98	1.41	0.79	2.78	1.53	46.2	19.2	34.6
Middle caudal femoral	0.79	1.98	1.46	0.79	2.38	1.49	46.2	19.2	34.6
Distal caudal femoral	0.79	2.78	1.66	1.19	3.17	2.04	30.8	7.7	61.5
Cranial femoral	0.79	4.36	1.99	0.40	7.94	2.19	15.4	19.2	65.4
Deep femoral	0.79	3.57	2.61	1.59	4.00	2.88	19.2	15.4	65.4
Descending genicular	0.40	1.59	0.82	0.40	1.98	0.84	50.0	19.2	30.8
Saphenous	0.79	2.38	1.51	0.79	2.38	1.52	46.2	23.0	30.8
Caudal gluteal	1.59	2.78	2.17	1.19	3.17	2.44	46.2	3.8	50.0
Caudal superficial abdominal	0.79	1.98	1.32	0.79	2.38	1.45	69.2	--	30.8
Pubo-femoral	2.38	3.97	3.08	2.38	4.36	3.41	26.9	7.7	65.4
Innominate arteries[4]	0.00	1.98	0.67	0.40	2.38	1.17	--	--	--

[1] N- Designates the percentage of collateral arteries that remained the same diameter size.

[2] A- Designates the percentage of collateral arteries that atrophied in diameter size.

[3] H- Designates the percentage of collateral arteries that hypertrophied in diameter size.

[4] In most cases only the primary innominate arteries are listed. The designation 0.00 means the vessel, if already present, was not visible to the naked eye. No percentage changes were computed.

Table 3. Measurements in millimeters of primary collateral veins.

Veins	Normal limb			Abnormal limb			Percentage changes		
	Min.	Max.	Aver.	Min.	Max.	Aver.	N.[1]	A.[2]	H.[3]
Deep femoral	2.38	6.75	3.64	2.38	7.14	4.08	23.5	5.9	70.6
Cranial femoral	0.79	7.35	3.39	1.59	8.33	4.22	5.9	11.7	82.4
Proximal caudal femoral	0.79	5.56	2.20	0.79	5.95	2.71	29.5	11.7	58.8
Middle caudal femoral	0.79	3.97	1.87	1.19	4.76	2.44	35.3	--	64.7
Distal caudal femoral	1.19	4.76	2.54	1.59	5.16	3.06	29.4	--	70.6
Saphenous	1.19	3.57	2.33	1.59	3.57	2.65	29.4	5.9	64.7
Caudal gluteal	1.78	4.36	2.90	2.38	4.76	3.44	23.5	--	76.5
Descending genicular	0.40	1.59	1.07	0.79	1.98	1.38	35.3	5.9	58.8
Caudal superficial abdominal	1.59	5.16	3.20	1.98	6.35	4.13	5.9	5.9	88.2
Recurrent tarsal	2.38	3.57	2.87	2.38	4.36	3.20	23.5	11.8	64.7
Superficial circumflex iliac	0.40	1.98	0.77	0.40	2.78	1.18	18.7	--	81.3
Innominate veins[4]	0.00	1.98	0.13	0.40	3.17	1.13	--	--	--

[1] N- Designates the percentage of collateral veins that remained the same diameter size.

[2] A- Designates the percentage of collateral veins that atrophied in diameter size.

[3] H- Designates the percentage of collateral veins that hypertrophied in diameter size.

[4] In most cases only the primary innominate veins are listed. The designation 0.00 means the vessel, if already present, was not visible to the naked eye. No percentage changes were computed.

Table 4. Summary of the effect of femoral artery ligation upon limb function and edema.

Limb condition	Total dogs	Number of dogs given contrast medium	Number of dogs not given contrast medium	Duration of lameness (days)	Duration of edema (days)
No lameness or edema	5	1	4	-	-
No lameness	7	2	5	-	-
No edema	7	3	4	-	-
Severe lameness	3	3	0	4-32	-
Severe edema	2	2	0	-	4-36
Severe edema and lameness	2	2	0	4-32	4-36
Slight to moderate lameness	4	3	1	1- 8	-
Slight to moderate edema	6	5	1	-	1- 9
Complete posterior paralysis	1	1	0	Permanent	

Table 5. Summary of effect of femoral vein ligation upon limb function and edema.*

Limb condition	Total dogs	Duration of: lameness (days)	Duration of edema (days)
No lameness or edema	3	-	-
No lameness	4	-	-
No edema	8	-	-
Severe lameness	1	6	-
Severe edema**	1	-	7
Severe edema and lameness	0	-	-
Slight to moderate lameness	5	1-4	-
Slight to moderate edema	1	-	1

* No contrast media injected.

** Injected with contrast medium.

Table 6. Summary of the effect of femoral artery and vein ligation upon limb function and edema.*

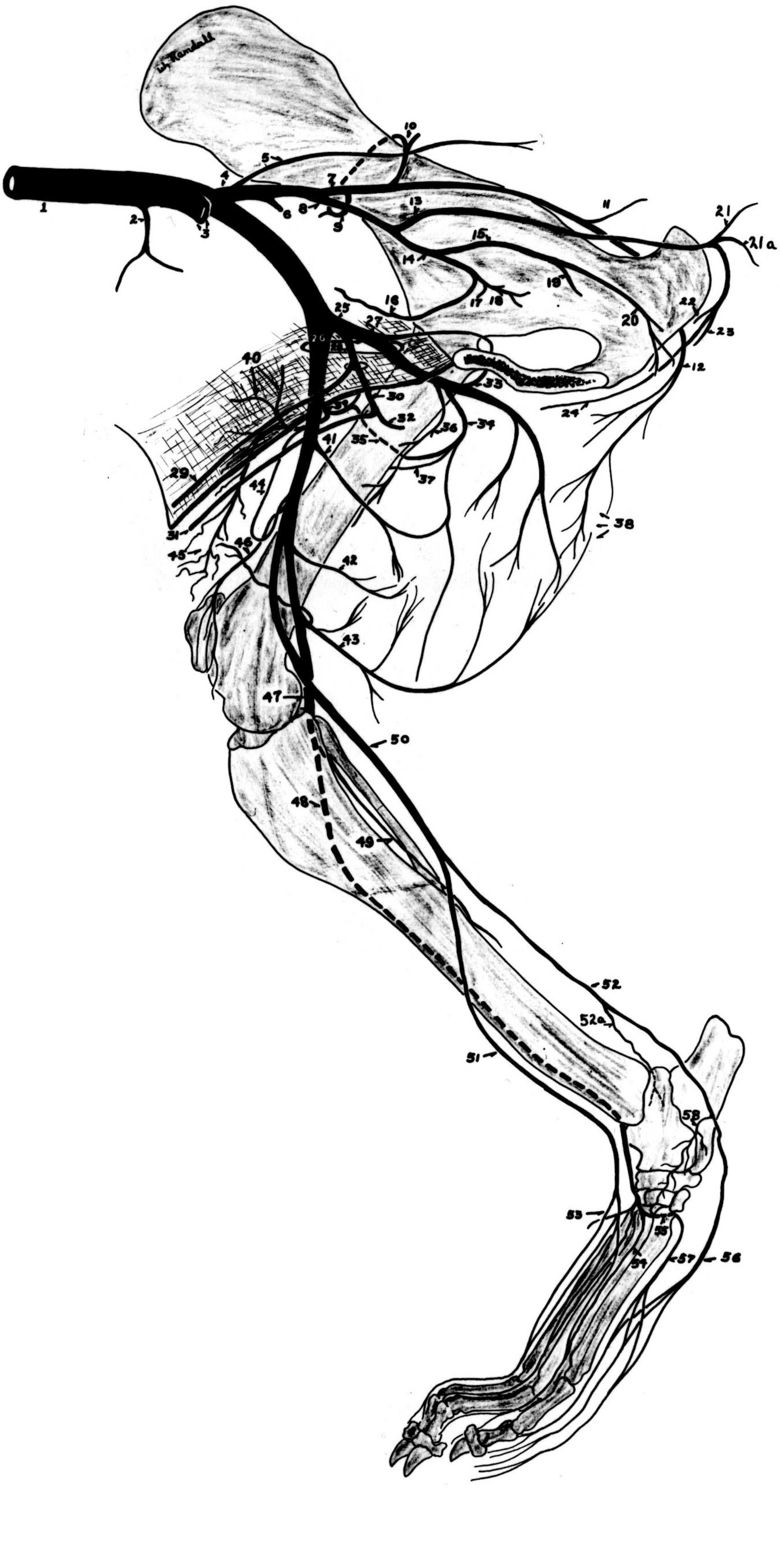
Limb condition	Total dogs	Duration of: lameness (days)	Duration of edema (days)
No lameness or edema	6	-	-
No lameness	7	-	-
No edema	8	-	-
Severe lameness	0	-	-
Severe edema	0	-	-
Severe edema and lameness	0	-	-
Slight to moderate lameness	3	1-3	-
Slight to moderate edema	2	-	2-4

* No contrast media injected.

EXPLANATION OF PLATE I

Medial view of the normal arterial circulation to the pelvic limb of the dog. 1, Aorta; 2, deep circumflex iliac; 3, external iliac; 4, internal iliac (hypogastric); 5, middle sacral; 6, umbilical; 7, parietal branch of internal iliac (hypogastric); 8, visceral branch of internal iliac (hypogastric); 9, ilio-lumbar; 10, cranial gluteal; 11, perineal branch; 12, caudal gluteal; 13, internal pudic; 14, urogenital (middle hemorrhoidal); 15, vaginal or prostatic; 16, caudal uterine or deferential; 17, caudal ureteral; 18, caudal vesicular; 19, urethral; 20, vestibular; 21, caudal hemorrhoidal; 21a, perineal (vestibular and labial branches); 22, artery of the clitoris or artery of the bulb; 23, deep artery of penis or vestibular and labial branches; 24, dorsal artery of penis or internal pudic to mammary gland; 25, pubofemoral; 26, femoral; 27, deep femoral; 28, prepubic (pudendo-epigastric trunk); 29, caudal deep abdominal (epigastric); 30, external pudic; 31, caudal superficial abdominal (epigastric); 32, branch of external pudic to scrotum, prepuce or inquinal mammary glands; 33, obturator; 34, medial circumflex femoral; 35, lateral circumflex femoral; 36, internal circumflex femoral; 37, nutrient artery of femur; 38, muscle branches; 39, cranial femoral; 40, superficial circumflex iliac; 41, proximal caudal femoral; 42, middle caudal femoral; 43, distal caudal femoral; 44, anastomotic branch; 45, muscle branches; 46, descending genicular; 47, popliteal; 48, cranial tibial; 50, saphenous; 51, dorsal branch of saphenous; 52, plantar branch of saphenous; 52a, lateral tarsal (fibular or peroneal); 53, superficial dorsal metatarsal; 54, deep dorsal metatarsal; 55, perforating metatarsal; 56, superficial plantar metatarsal; 57, deep plantar metatarsal; 58, medial plantar.

PLATE I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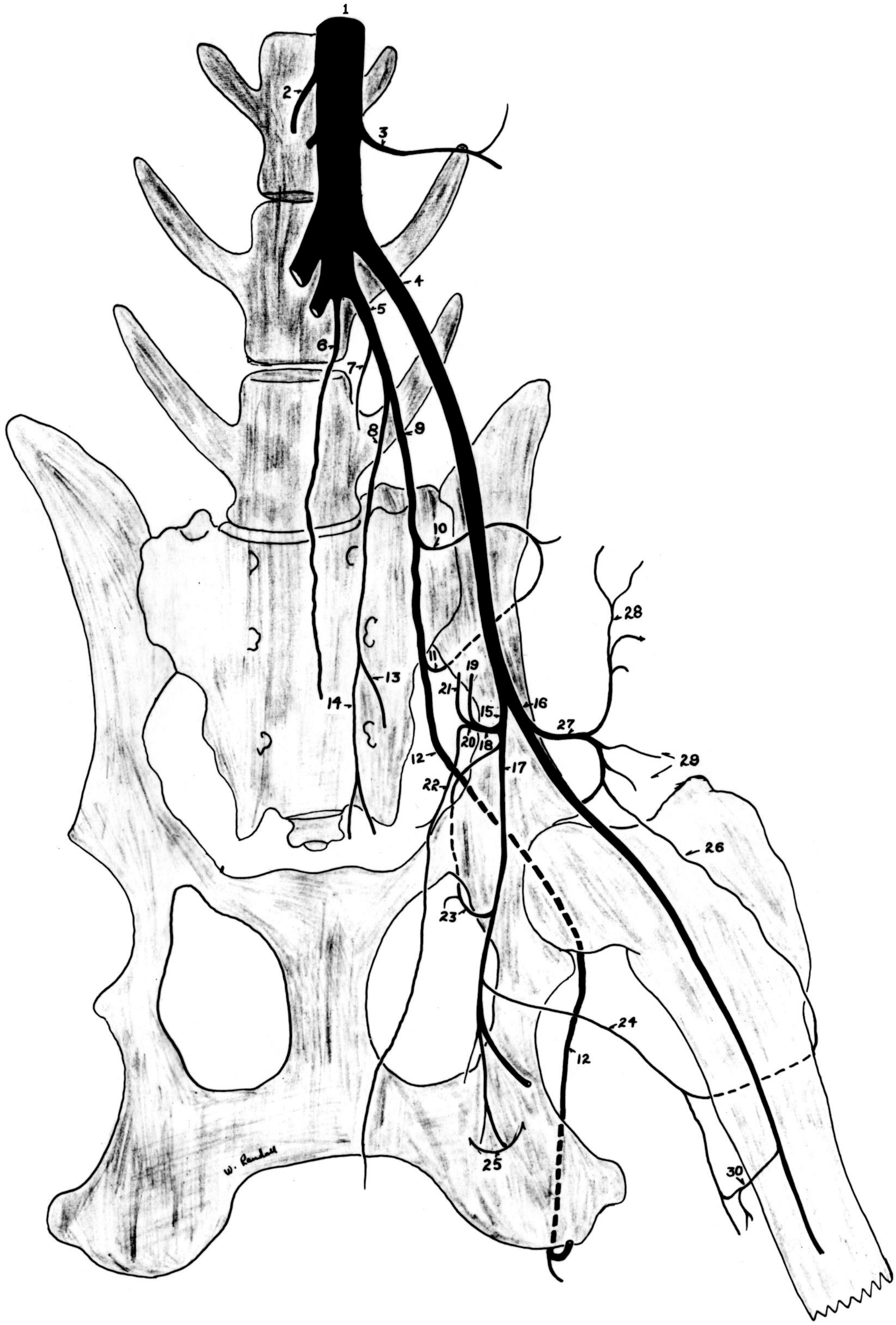
EXPLANATION OF PLATE II

Ventral view of the normal arterial circulation to the pelvis and coxo-femoral regions of the dog. Dog is in dorsal recumbency. 1, Aorta; 2, lumbar artery; 3, deep circumflex iliac; 4, external iliac; 5, internal iliac (hypogastric); 6, middle sacral; 7, umbilical; 8, visceral branch of internal iliac (hypogastric); 9, parietal branch of internal iliac (hypogastric); 10, ilio-lumbar; 11, cranial gluteal; 12, caudal gluteal; 13, internal pudic; 14, urogenital (middle hemorrhoidal); 15, pubo-femoral; 16, femoral; 17, deep femoral; 18, prepubic (pudendo-epigastric trunk); 19, caudal deep abdominal (epigastric); 20, external pudic; 21, caudal superficial abdominal (epigastric); 22, branch of external pudic artery to scrotum or to inquinal mammary glands; 23, obturator; 24, medial circumflex femoral; 25, muscular branches of deep femoral; 26, lateral circumflex femoral; 27, cranial femoral; 28, superficial circumflex iliac; 29, muscular branches; 30, proximal caudal femoral.

PLATE II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EXPLANATION OF PLATE III

Medial view of the normal venous circulation to the pelvic limb of the dog. 1, Caudal vena cava; 2, deep circumflex iliac; 3, middle sacral; 4, common iliac; 5, internal iliac (hypogastric); 6, ilio-lumbar; 7, cranial vesicular; 8, caudal vesicular; 9, cranial gluteal; 10, lateral coccygeal; 11, caudal gluteal; 12, internal pudic; 13, caudal hemorrhoidal; 14, perineal; 15, branches from external genitalia; 16, external iliac; 17, deep femoral; 18, pubo-abdominal; 19, external pudic; 20, caudal deep abdominal (epigastric); 21, caudal superficial abdominal (epigastric); 22, cranial femoral; 23, superficial circumflex iliac; 24, proximal caudal femoral; 25, middle caudal femoral; 26, femoral; 27, descending genicular; 28, saphenous magna; 29, distal caudal femoral; 30, saphenous parva (recurrent tarsal); 31, muscular branches; 32, popliteal; 33, cranial tibial; 34, caudal tibial; 35, dorsal branch of saphenous magna; 36, plantar branch of saphenous magna; 37, cutaneous branches of saphenous magna; 38, dorsal branch of saphenous parva; 39, plantar branch of saphenous parva; 40, cutaneous branch from tuber calcis area; 41, superficial dorsal metatarsal; 42, deep dorsal metatarsal; 43, anastomosis between dorsal and plantar branches of saphenous magna and cranial tibial; 44, superficial plantar metatarsal; 45, deep plantar metatarsal.

PLATE III


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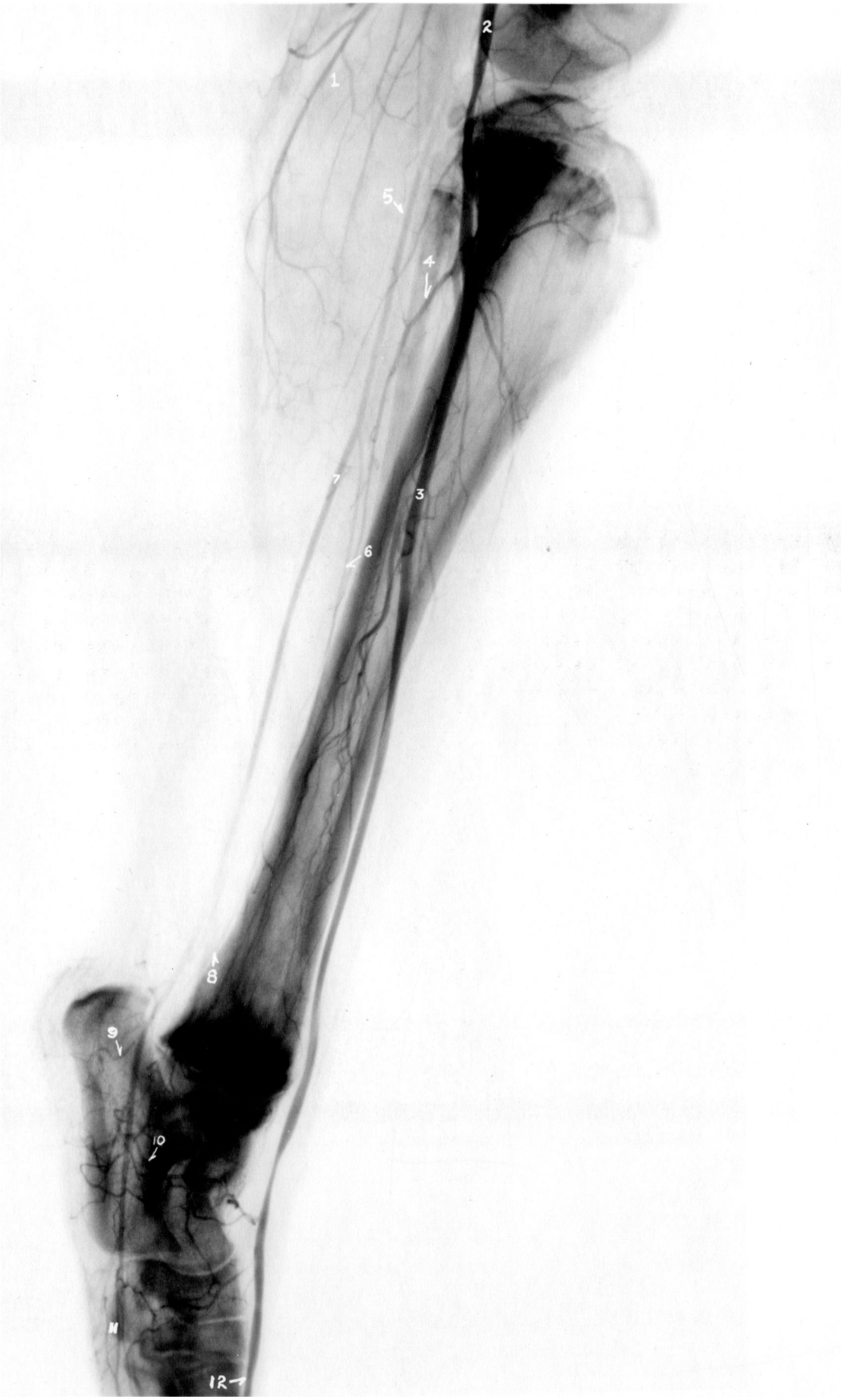
EXPLANATION OF PLATE IV

Normal arteriogram of the pelvic limb of the dog showing the normal arterial pattern in the tibia and tarsal regions. View is lateral. 1, Muscle branch of distal caudal femoral artery; 2, popliteal artery; 3, cranial tibial artery; 4, caudal tibial artery; 5, saphenous artery; 6, dorsal branch of saphenous artery; 7, plantar branch of saphenous artery; 8, lateral tarsal artery (fibular or peroneal artery); 9, lateral plantar artery; 10, medial plantar artery; 11, plantar artery (plantar metatarsal artery); 12, dorsal pedal artery (continues as deep dorsal metatarsal artery).

PLATE IV



EXPLANATION OF PLATE V

Normal arteriogram of the lower pelvic limb of the dog. Dorsal view. 1, Cranial tibial artery; 2, saphenous artery, plantar branch; 3, lateral tarsal (fibular) artery; 4, continuation of plantar branch of saphenous artery; 5, superficial branch of cranial tibial artery; 6, saphenous artery, dorsal branch; 7, dorsal pedal artery; 8, transverse metatarsal artery; 9, deep dorsal metatarsal arteries; 10, artery to dewclaw; 11, digital arteries.

PLATE V

EXPLANATION OF PLATE VI

Medial view of the pelvic and thigh regions of a male dog showing the arterial changes in the area of ligation of the left femoral artery. Most of the primary collateral arteries are visible. The right limb shows the normal arterial pattern. All veins have been dissected away. The arrows point to the fibrotic area of ligation. 1, Aorta; 2, external iliac; 3, pubo-femoral; 4, femoral; 5, superficial circumflex iliac; 6, cranial femoral (hypertrophied in ligated limb); 7, deep femoral; 8, caudal deep abdominal (epigastric); 9, external pudic; 10, caudal superficial abdominal (epigastric); 11, proximal caudal femoral; 12, middle caudal femoral; 13, descending genicular; 14, saphenous; 15, hypertrophied branches of deep femoral; 16, hypertrophied branches of deep femoral to gracilis, adductor, and semimembranosis muscles; 17, hypertrophied vasa vasorum in the fibrotic area of ligation; 18, hypertrophied ascending branches of proximal caudal femoral; 19, psoas major muscle; 20, stump of abdominal muscle; 21, rectum; 22, urethra (bladder removed); 23, sartorius muscle, cranial part; 24, stump of sartorius muscle, caudal part; 25, vastus medialis muscle; 26, adductorius muscle; 27, gracilis muscle; 28, semimembranosis muscle; 29, prepuce; 30, penis; 31, patella; 32, area of ligation.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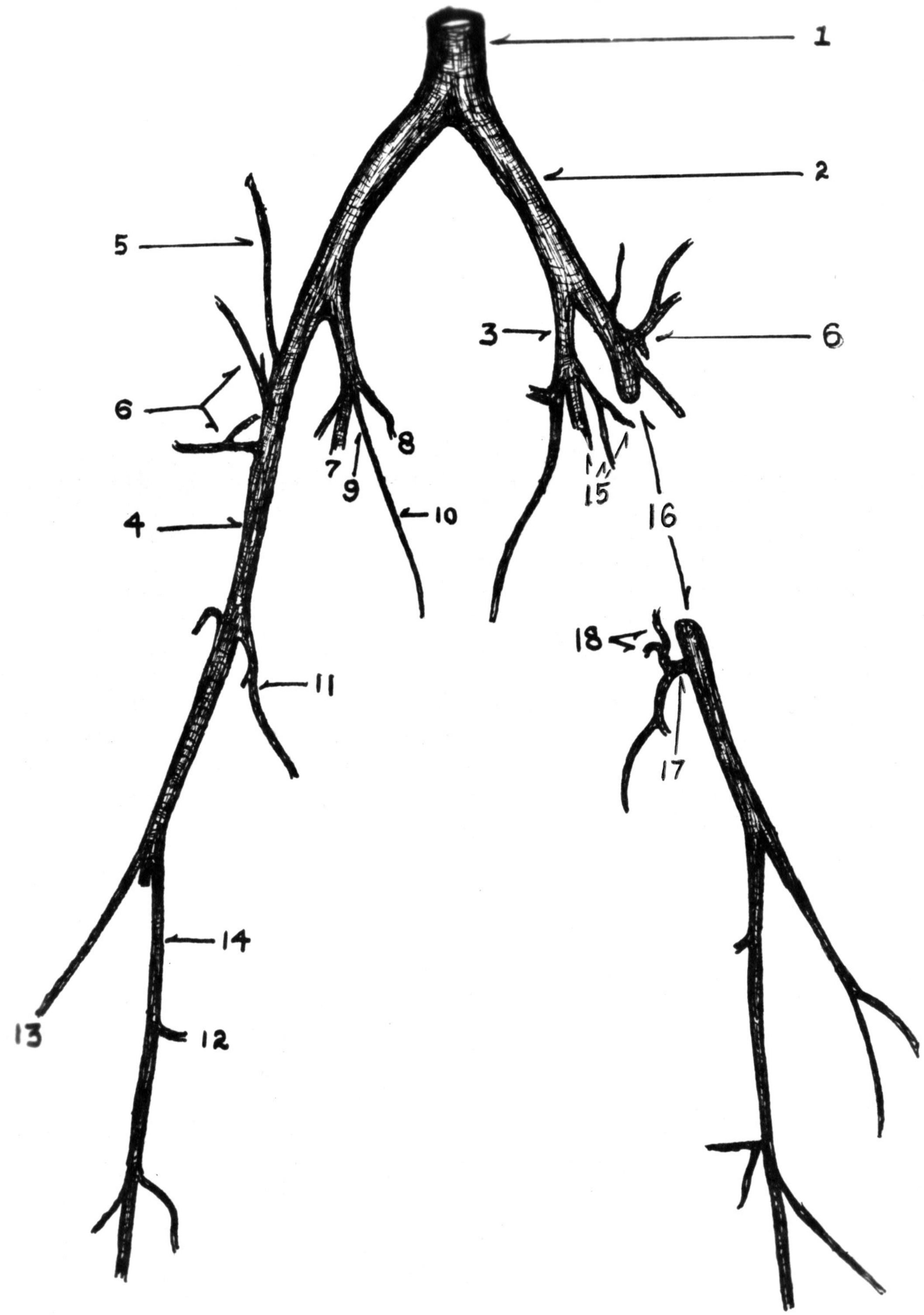
EXPLANATION OF PLATE VII

Tracing of arteries of preceding Plate VI to more clearly show the arterial pattern and the collateral changes in the area of ligation. 1, Aorta; 2, external iliac artery; 3, pubo-femoral artery; 4, femoral artery; 5, superficial circumflex iliac artery; 6, cranial femoral arteries (hypertrophied); 7, deep femoral artery; 8, caudal deep abdominal (epigastric) artery; 9, external pudic artery; 10, caudal superficial abdominal (epigastric) artery; 11, proximal caudal femoral artery; 12, middle caudal femoral artery; 13, descending genicular artery; 14, saphenous artery; 15, hypertrophied branches of deep femoral artery; 16, hypertrophied vasa vasorum in the fibrotic area of ligation; 17, proximal caudal femoral artery; 18, hypertrophied ascending branches of the proximal caudal femoral artery.

PLATE VII



EXPLANATION OF PLATE VIII

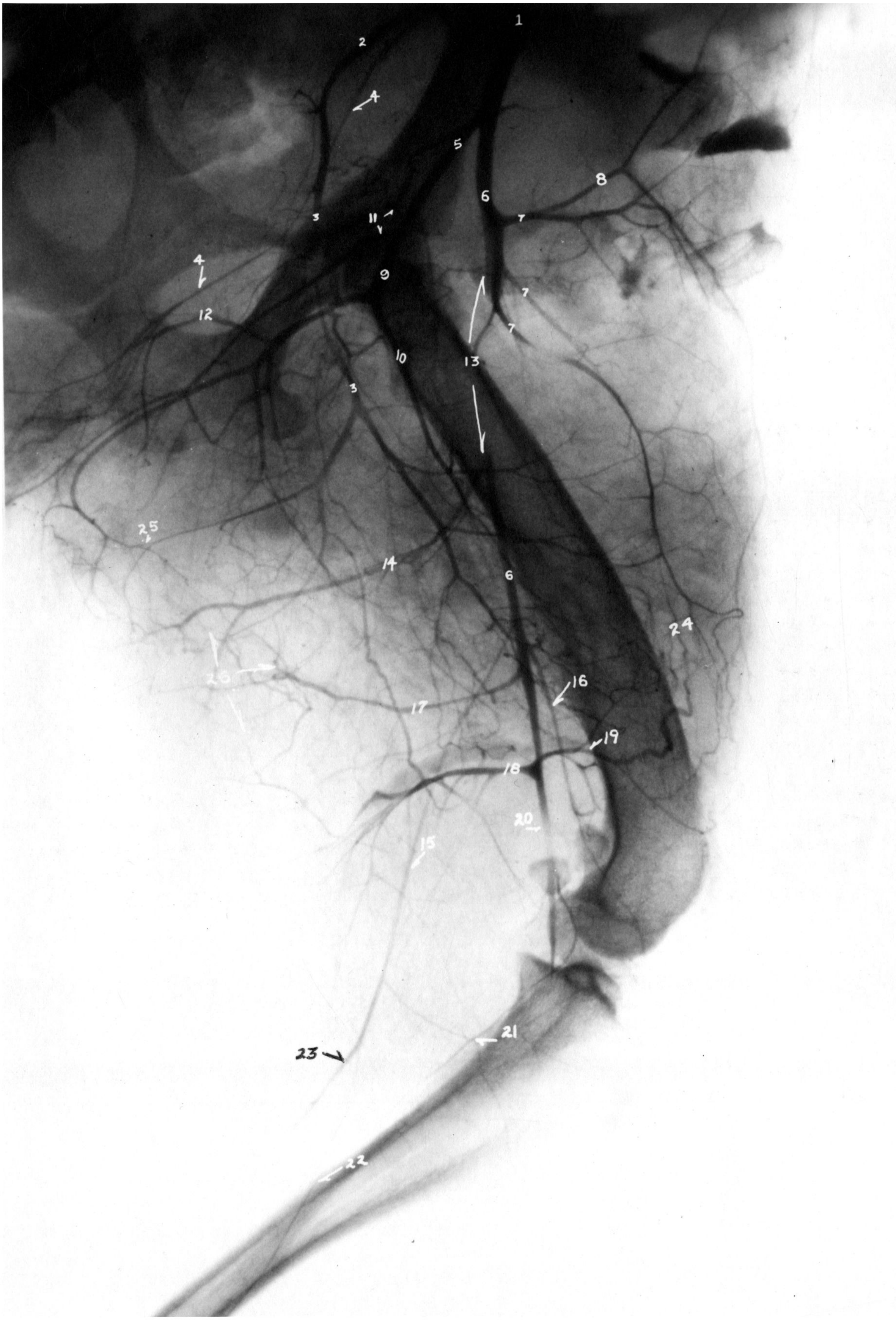
Dog #9, young adult, male. Arteriogram of the thigh region showing the development of the collateral circulation following ligation of the left femoral artery. The view is medial. 1, Muscle branch of superficial circumflex iliac artery; 2, muscle branch of cranial femoral artery; 3, muscle branches of deep femoral artery; 4, internal circumflex femoral artery; 5, caudal gluteal artery; 6, proximal caudal femoral artery; 7, femoral artery, distal segment; 8, saphenous artery; 9, middle caudal femoral artery; 10, distal caudal femoral artery, caudal branches; 11, distal caudal femoral artery, cranial branches; 12, popliteal artery; 13, cranial tibial artery; 14, caudal tibial artery.

PLATE VIII

EXPLANATION OF PLATE IX

Dog #10, adult, female. Arteriogram of the pelvic and thigh regions showing the development of the collateral circulation following ligation of the left femoral artery. The view is ventrodorsal with the dog in dorsal recumbency. 1, External iliac artery; 2, internal iliac artery, parietal branch; 3, caudal gluteal artery; 4, internal iliac artery, visceral branch; 5, pubo-femoral artery; 6, femoral artery; 7, cranial femoral artery; 8, superficial circumflex iliac artery; 9, deep femoral artery; 10, internal circumflex femoral artery; 11, external pudic artery; 12, obturator artery; 13, area of ligation; 14, proximal caudal femoral artery; 15, saphenous artery; 16, descending genicular artery; 17, middle caudal femoral artery; 18, distal caudal femoral artery, caudal branches; 19, distal caudal femoral artery, cranial branches; 20, popliteal artery; 21, caudal tibial artery; 22, dorsal branch of the saphenous artery; 23, plantar branch of the saphenous artery; 24, anastomosis between cranial femoral artery and cranial branches of the distal caudal femoral; 25, one of many anastomoses, this is between the caudal gluteal artery and the deep femoral artery; 26, anastomoses between all of the caudal femoral arteries.

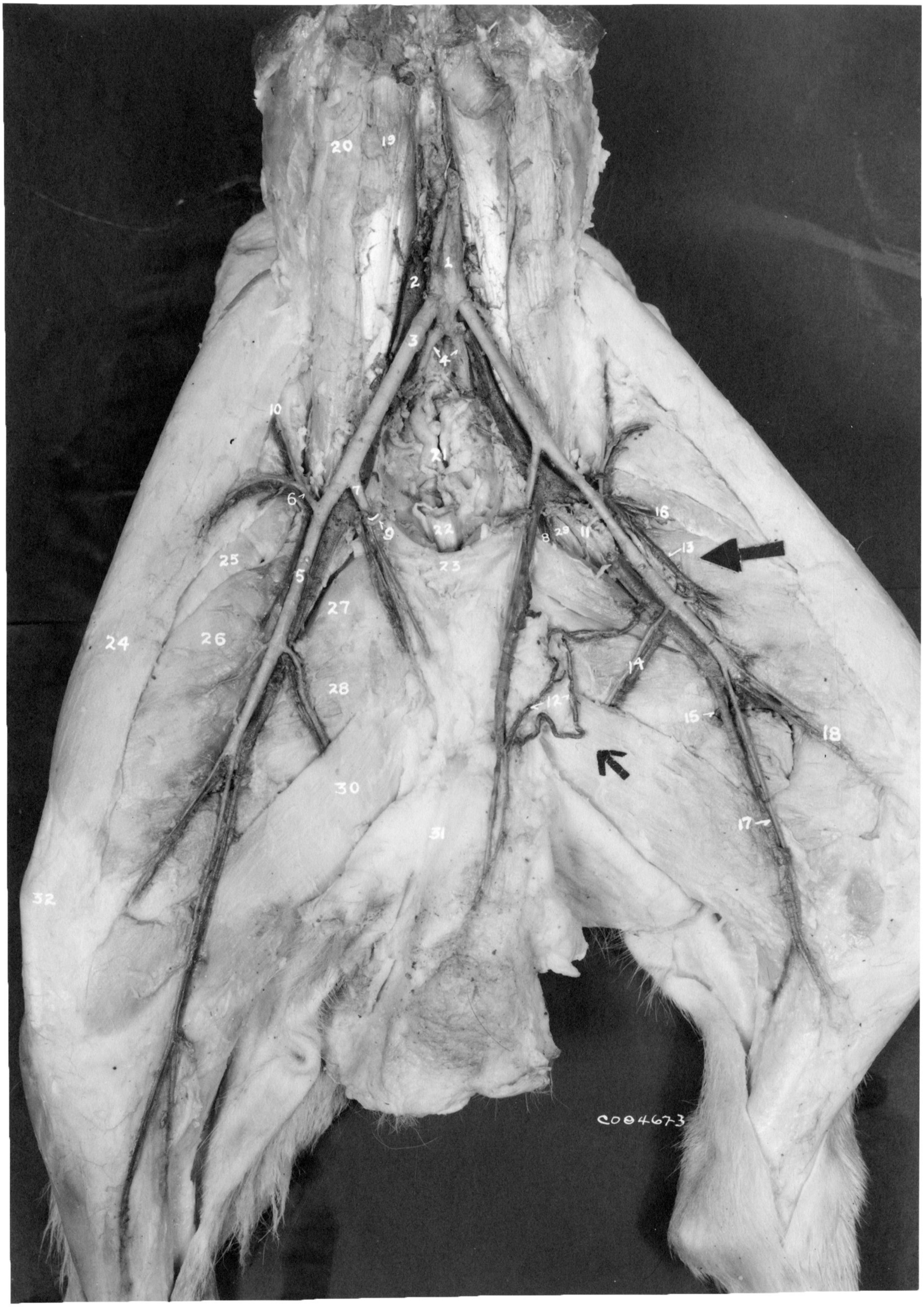
PLATE IX



EXPLANATION OF PLATE X

Medial view of the pelvic and thigh regions of a male dog showing the venous changes in the area of ligation of the left femoral vein. Most of the primary collateral veins are visible. The right limb shows the normal venous pattern. Arrows point to veins of outstanding hypertrophy. 1, Aorta; 2, caudal vena cava; 3, external iliac vessels; 4, internal iliac vessels; 5, femoral vessels; 6, cranial femoral vessels (vein hypertrophied in ligated limb); 7, pubo-femoral artery; 8, deep femoral vessels; 9, caudal deep abdominal (epigastric) vessels (hypertrophied); 10, superficial circumflex iliac vessels; 10a, caudal superficial abdominal (epigastric) vessels (hypertrophied); 11, area of ligation; 12, hypertrophied veins anastomosing femoral vein with caudal superficial abdominal vein; 13, hypertrophied branch of cranial femoral vein; 14, proximal caudal femoral vessels (vein hypertrophied); 15, middle caudal femoral vessels (vein hypertrophied); 16, muscle branches from vastus medialis (hypertrophied); 17, saphenous vessels (vein hypertrophied); 18, descending genicular vessels (vein hypertrophied); 19, psoas minor muscle; 20, psoas major muscle; 21, rectum; 22, urethra, bladder removed; 23, prepubic tendon; 24, sartorius muscle, cranial part; 25, rectus femoris muscle; 26, vastus medialis muscle; 27, pectineus muscle; 28, adductorius muscle; 29, vastus medialis muscle; 30, gracilis muscle; 31, penis; 32, patella.

PLATE X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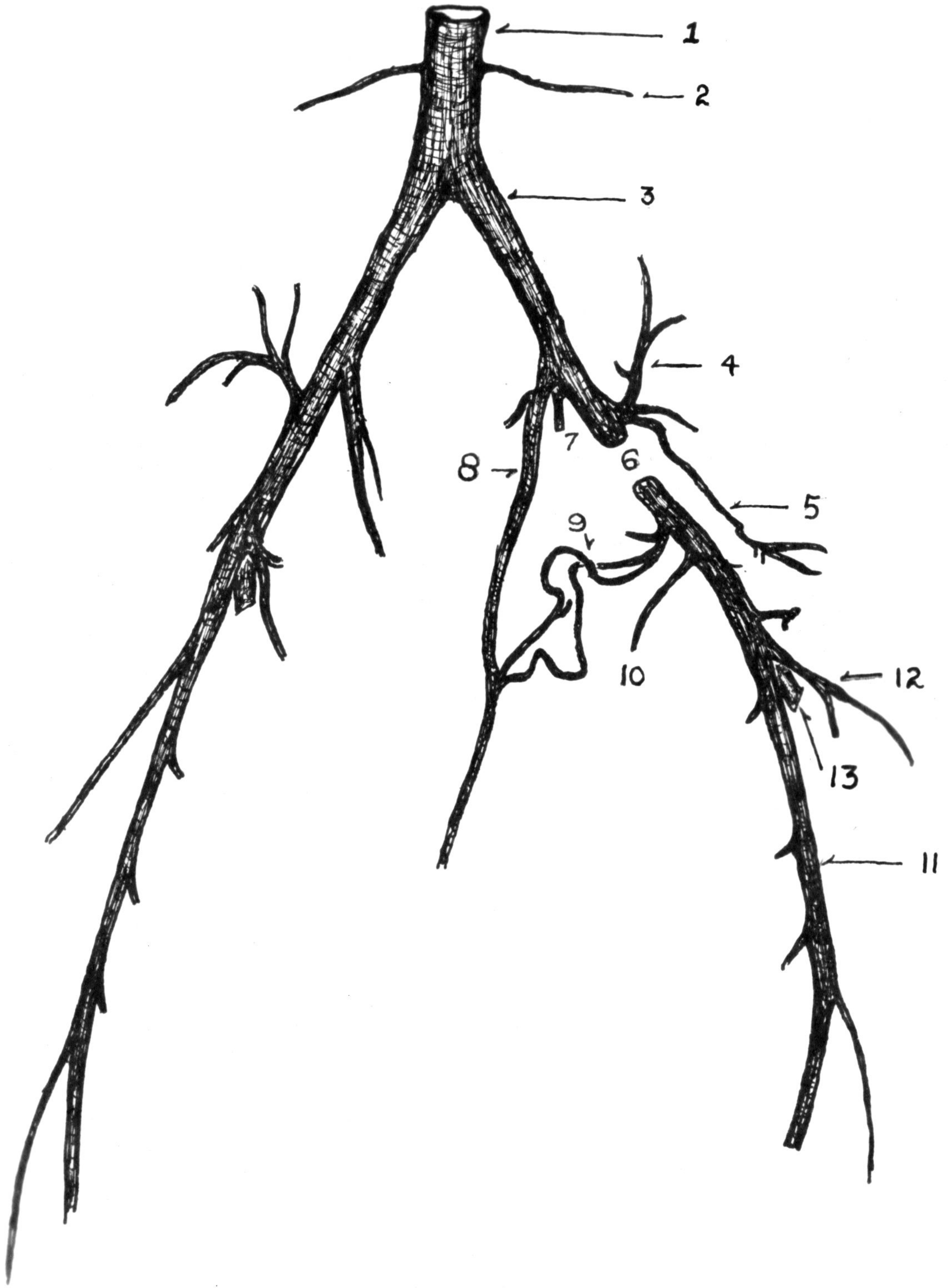
EXPLANATION OF PLATE XI

Tracing of veins of preceding Plate X to more clearly show the venous pattern and the collateral changes in the area of ligation. 1, Caudal vena cava; 2, deep circumflex iliac vein; 3, external iliac vein; 4, cranial femoral vein (hypertrophied); 5, cranial femoral vein (hypertrophied); 6, area of ligation; 7, deep femoral vein; 8, caudal superficial abdominal vein (hypertrophied); 9, hypertrophied veins anastomosing the femoral vein with the caudal superficial abdominal vein; 10, proximal caudal femoral vein (hypertrophied); 11, saphenous vein (hypertrophied); 12, descending genicular vein (hypertrophied); 13, popliteal vein.

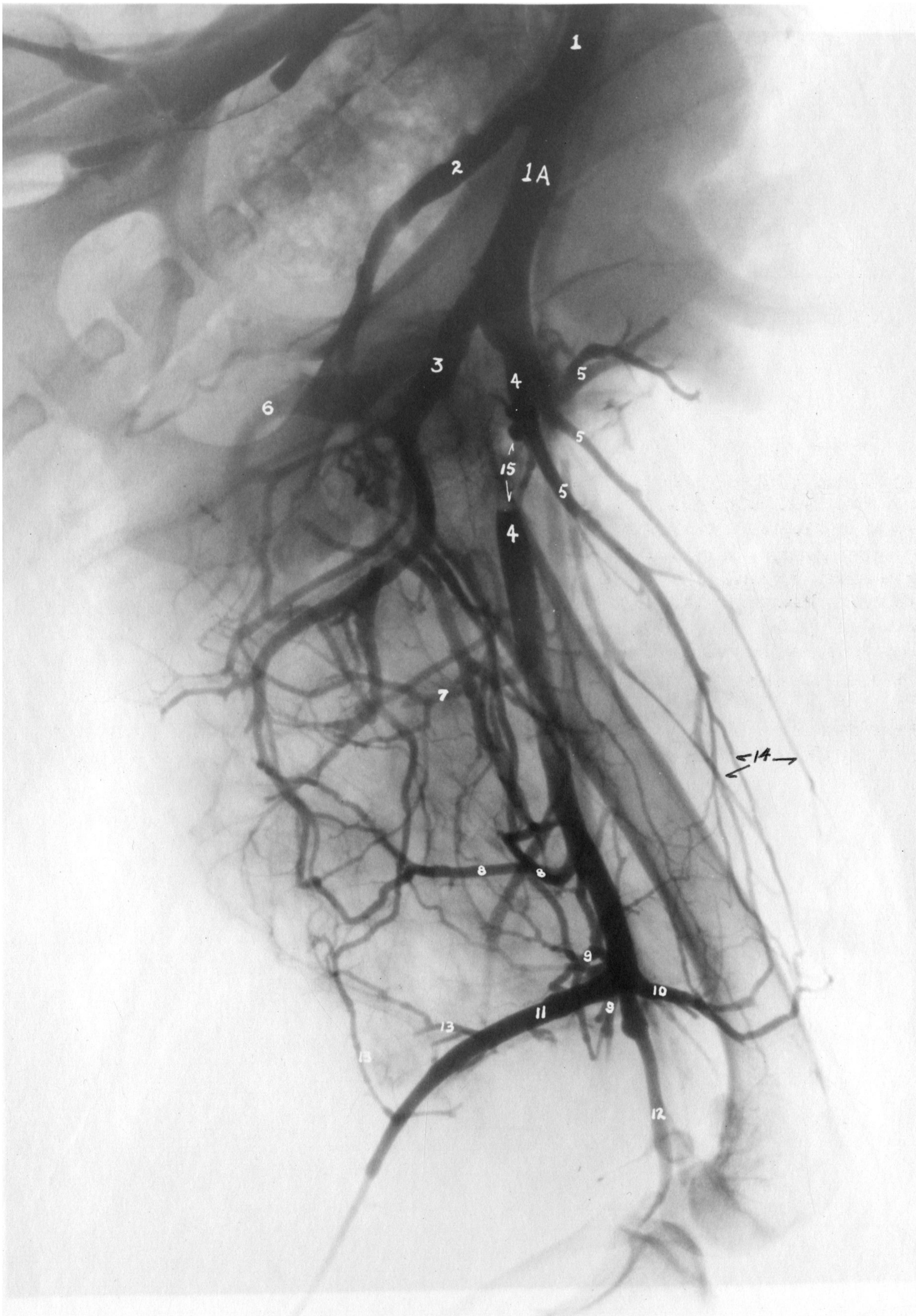
PLATE XI



EXPLANATION OF PLATE XII

Dog #15, adult, male. Venogram of the pelvic and thigh regions showing the collateral circulation following ligation of the left femoral vein. The view is ventro-dorsal with the dog in dorsal recumbency. 1, Common iliac vein; 1a, external iliac vein; 2, internal iliac vein; 3, deep femoral vein; 4, femoral vein; 5, cranial femoral veins; 6, caudal gluteal vein; 7, proximal caudal femoral vein; 8, middle caudal femoral vein; 9, distal caudal femoral vein, caudal branch; 10, distal caudal femoral vein, cranial branch; 11, saphenous parva (recurrent tarsal vein); 12, popliteal vein; 13, anastomosis of the recurrent tarsal with the deep caudal thigh veins; 14, anastomosis of the distal caudal femoral with cranial femoral veins; 15, area of ligation.

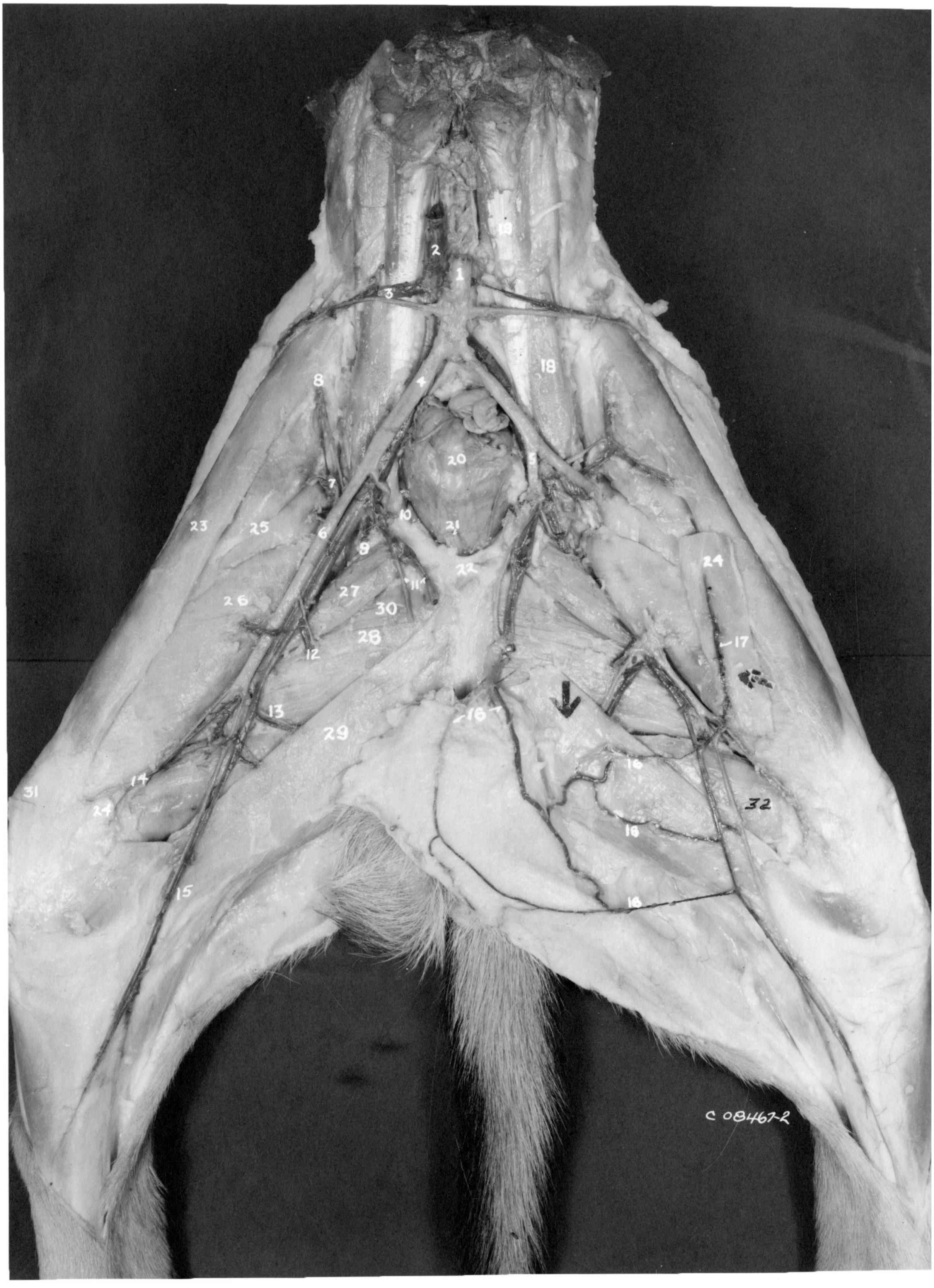
PLATE XII



EXPLANATION OF PLATE XIII

Medial view of the pelvic and thigh regions of a dog showing the arterial and venous changes in the area of ligation of the left femoral artery and vein. Most of the primary collateral arteries and veins are visible. The right limb shows the normal arterial and venous patterns. Arrows point to veins that have undergone considerable hypertrophy. 1, Aorta; 2, caudal vena cava; 3, deep circumflex iliac vessels; 4, external iliac vessels; 5, pubo-femoral artery; 6, femoral vessels (ligation area of left limb); 7, cranial femoral vessels; 8, superficial circumflex iliac vessels; 9, deep femoral vessels; 10, caudal deep abdominal (epigastric) vessels; 11, caudal superficial abdominal (epigastric) vessels; 12, proximal caudal femoral vessels; 13, middle caudal femoral vessels; 14, descending genicular vessels; 15, saphenous vessels; 16, hypertrophied innominate superficial veins anastomosing the caudal superficial abdominal vein with the saphenous and femoral veins; 17, hypertrophied artery and vein serving the caudal part of the sartorius muscle and anastomosing the femoral and descending genicular vessels with the cranial femoral vessels; 18, psoas major muscle (iliopsoas m.); 19, psoas minor muscle; 20, rectum; 21, urethra stump; 22, prepubic tendon; 23, sartorius muscle, cranial part; 24, sartorius muscle, caudal part; 25, rectus femoris muscle; 26, vastus medialis muscle; 27, pectineus muscle; 28, adductorius muscle; 29, gracilis muscle; 30, adductorius muscle, 31, patella; 32, semimembranosus muscle.

PLATE XIII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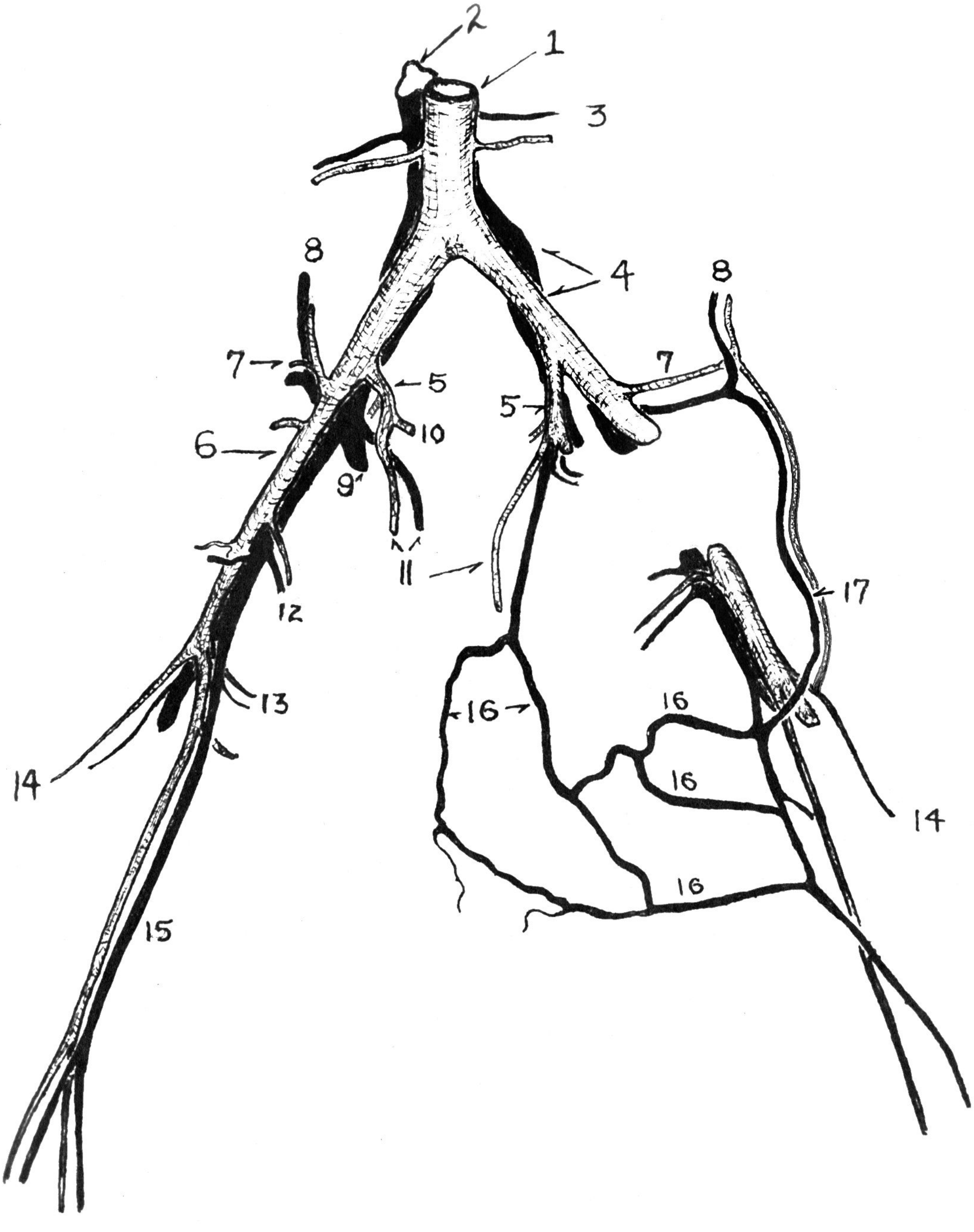
EXPLANATION OF PLATE XIV

Tracing of the arteries and veins of the preceding Plate XIII to more clearly show the arterial and venous patterns and the collateral changes in the area of ligation. 1, Aorta; 2, caudal vena cava; 3, deep circumflex iliac artery and vein; 4, external iliac artery and vein; 5, pubo-femoral artery; 6, femoral artery and vein; 7, cranial femoral artery and vein; 8, superficial circumflex iliac artery and vein; 9, deep femoral vein; 10, caudal deep abdominal artery (epigastric); 11, caudal superficial abdominal artery and vein (epigastrics); 12, proximal caudal femoral artery and vein; 13, middle caudal femoral artery and vein; 14, descending genicular artery and vein; 15, saphenous artery and vein; 16, hypertrophied innominate superficial veins anastomosing the caudal superficial abdominal vein with the saphenous and femoral veins; 17, hypertrophied artery and vein serving the caudal part of the sartorius muscle and anastomosing the femoral and descending genicular vessels with the cranial femoral vessels.

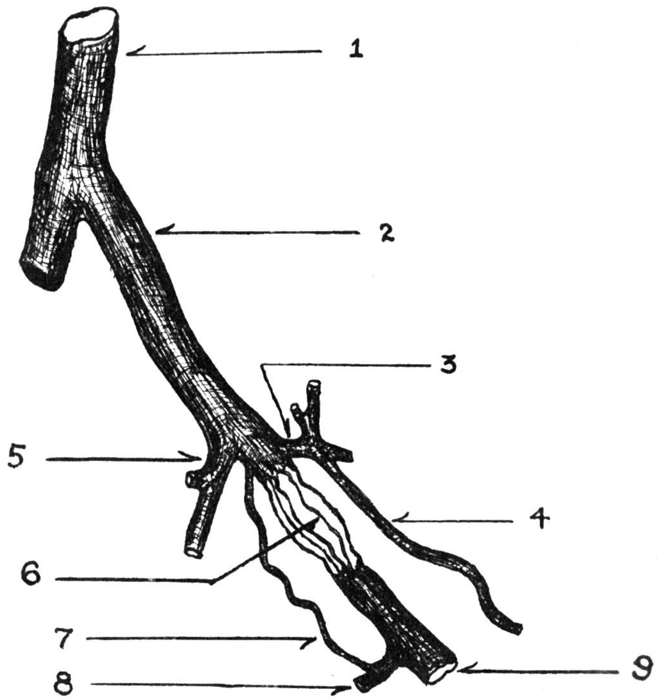
PLATE XIV



EXPLANATION OF PLATE XV

Detailed tracing of a photograph of the collateral circulation changes in the area of ligation of the femoral artery and vein of Dog #28. Only the veins have been traced and are pictured here although the arteries also followed a similar pattern. 1, Caudal vena cava; 2, external iliac vein; 3, cranial femoral vein; 4, hypertrophied branch of the cranial femoral vein; 5, deep femoral vein; 6, newly visible venules passing through the fibrotic ligation area in an attempt to continue the circulation, (newly visible arterioles were also present here); 7, newly visible collateral vein running parallel to the area of ligation; 8, proximal caudal femoral vein (hypertrophied); 9, distal segment of the femoral vein.

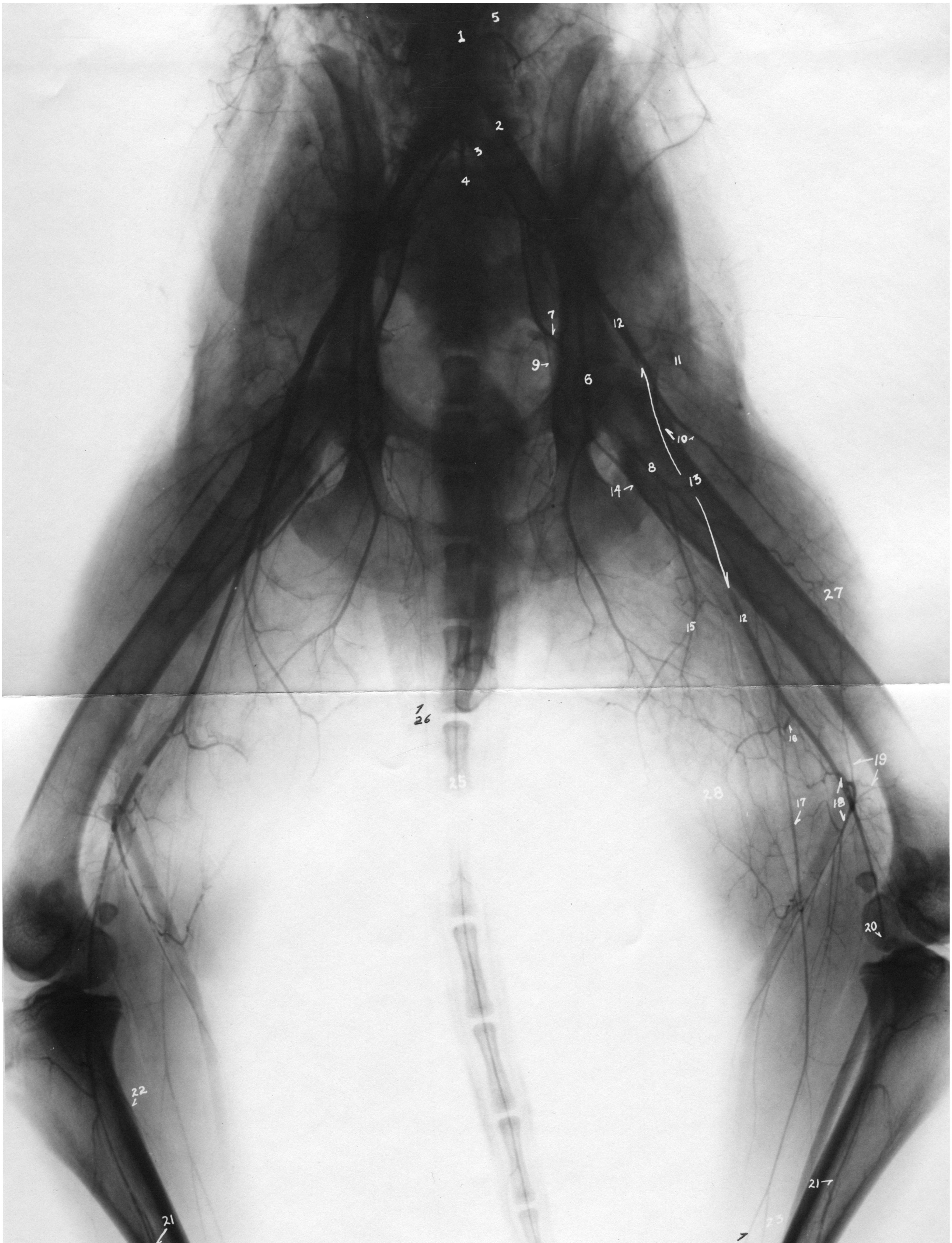
PLATE XV



EXPLANATION OF PLATE XVI

Dog #22, 8 months old, male. Arteriogram of the pelvic, thigh, and leg regions showing the development of collateral circulation following ligation of the left femoral artery and vein. The view is ventro-dorsal with the dog in dorsal recumbency. 1, Aorta; 2, external iliac artery; 3, internal iliac artery; 4, middle sacral artery; 5, deep circumflex iliac artery; 6, deep femoral artery; 7, internal iliac artery, parietal branch; 8, caudal gluteal artery; 9, internal iliac artery, visceral branch; 10, cranial femoral artery; 11, superficial circumflex iliac artery; 12, femoral artery; 13, ligation area; 14, internal circumflex femoral artery; 15, proximal caudal femoral artery; 16, middle caudal femoral artery; 17, saphenous artery; 18, distal caudal femoral artery, caudal branches; 19, distal caudal femoral artery, cranial branches; 20, popliteal artery; 21, cranial tibial artery; 22, caudal tibial artery; 23, dorsal branch of saphenous artery; 24, plantar branch of saphenous artery; 25, middle coccygeal artery; 26, lateral coccygeal artery; 27, anastomosis of cranial femoral artery and cranial branches of distal caudal femoral artery; 28, anastomoses of deep caudal femoral arteries of the thigh.

PLATE XVI



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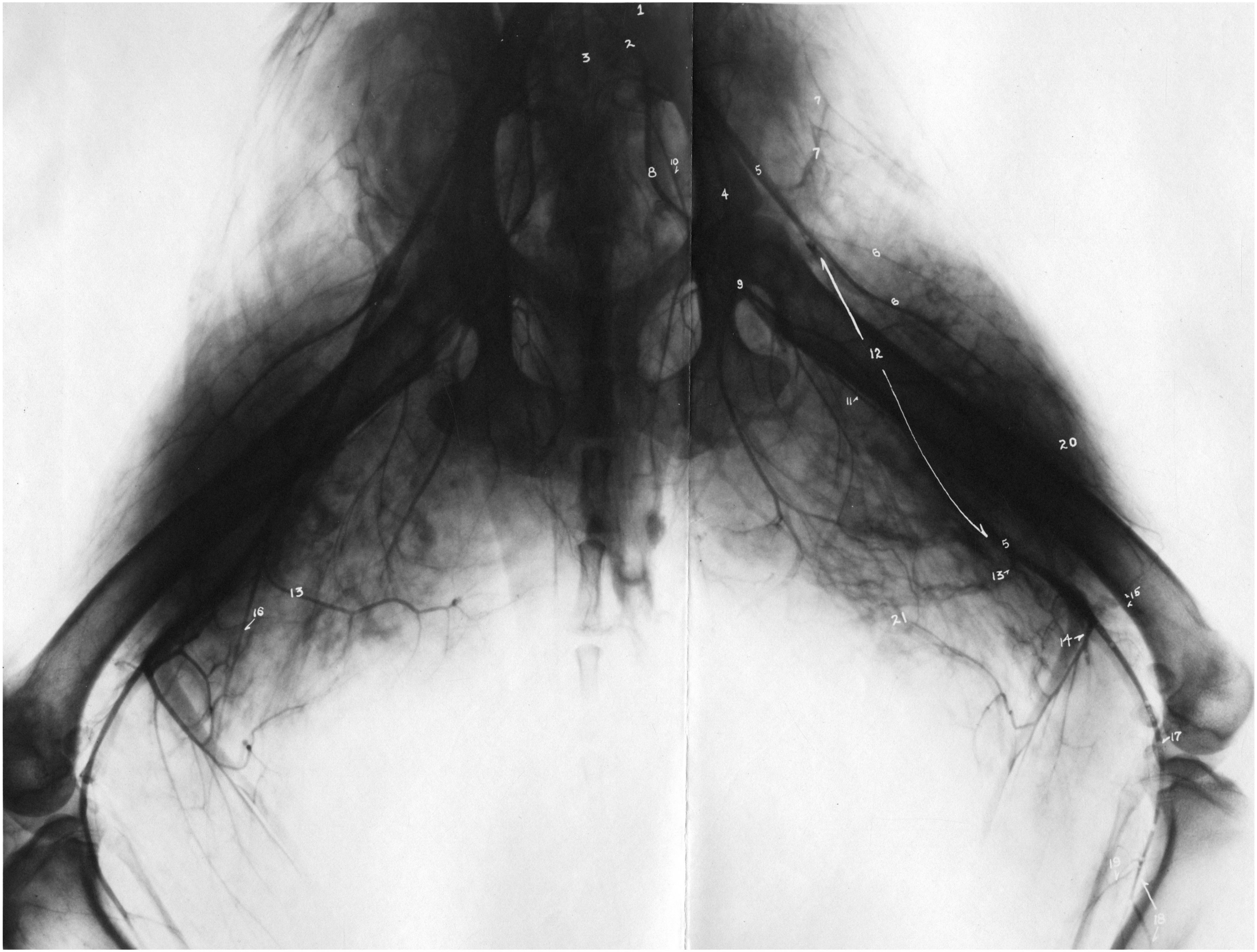
EXPLANATION OF PLATE XVII

Dog #21, 1 year old, female. Arteriogram of the pelvic, thigh, and upper leg regions showing the development of collateral circulation following ligation of the left femoral artery and vein. The view is ventro-dorsal with the dog in dorsal recumbency. 1, External iliac artery; 2, internal iliac artery; 3, middle sacral artery; 4, deep femoral artery; 5, femoral artery; 6, cranial femoral artery; 7, superficial circumflex iliac artery; 8, internal iliac artery, parietal branch; 9, caudal gluteal artery; 10, internal iliac artery, visceral branch; 11, internal circumflex femoral artery; 12, area of ligation; 13, middle caudal femoral artery; 14, distal caudal femoral artery, caudal branches; 15, distal caudal femoral artery, cranial branches; 16, saphenous artery; 17, popliteal artery; 18, cranial tibial artery; 19, caudal tibial artery; 20, anastomosis between the cranial femoral artery and the cranial branches of the distal caudal femoral artery; 21, anastomosis of deep caudal thigh arteries.

PLATE XVII



EXPLANATION OF PLATE XVIII

Dog #19, 1 year old, female. Arteriogram of the pelvic, thigh, and upper leg regions showing the development of collateral circulation following ligation of the left femoral artery and vein. The view is ventro-dorsal with the dog in dorsal recumbency. 1, External iliac artery; 2, internal iliac artery; 3, middle sacral artery; 4, femoral artery; 5, cranial femoral artery; 6, superficial circumflex iliac artery; 7, deep femoral artery; 8, internal iliac artery, parietal branch; 9, internal iliac artery, visceral branch; 10, internal circumflex femoral artery; 11, caudal gluteal artery; 12, middle caudal femoral artery; 13, saphenous artery; 14, distal caudal femoral artery, caudal branches; 15, distal caudal femoral artery, cranial branches; 16, popliteal artery; 17, cranial tibial artery; 18, caudal tibial artery; 19, dorsal branch of saphenous artery; 20, plantar branch of saphenous artery; 21, area of ligation; 22, anastomosis of cranial femoral and distal caudal femoral arteries; 23, anastomoses of deep caudal thigh arteries.

PLATE XVIII

EXPLANATION OF PLATE XIX

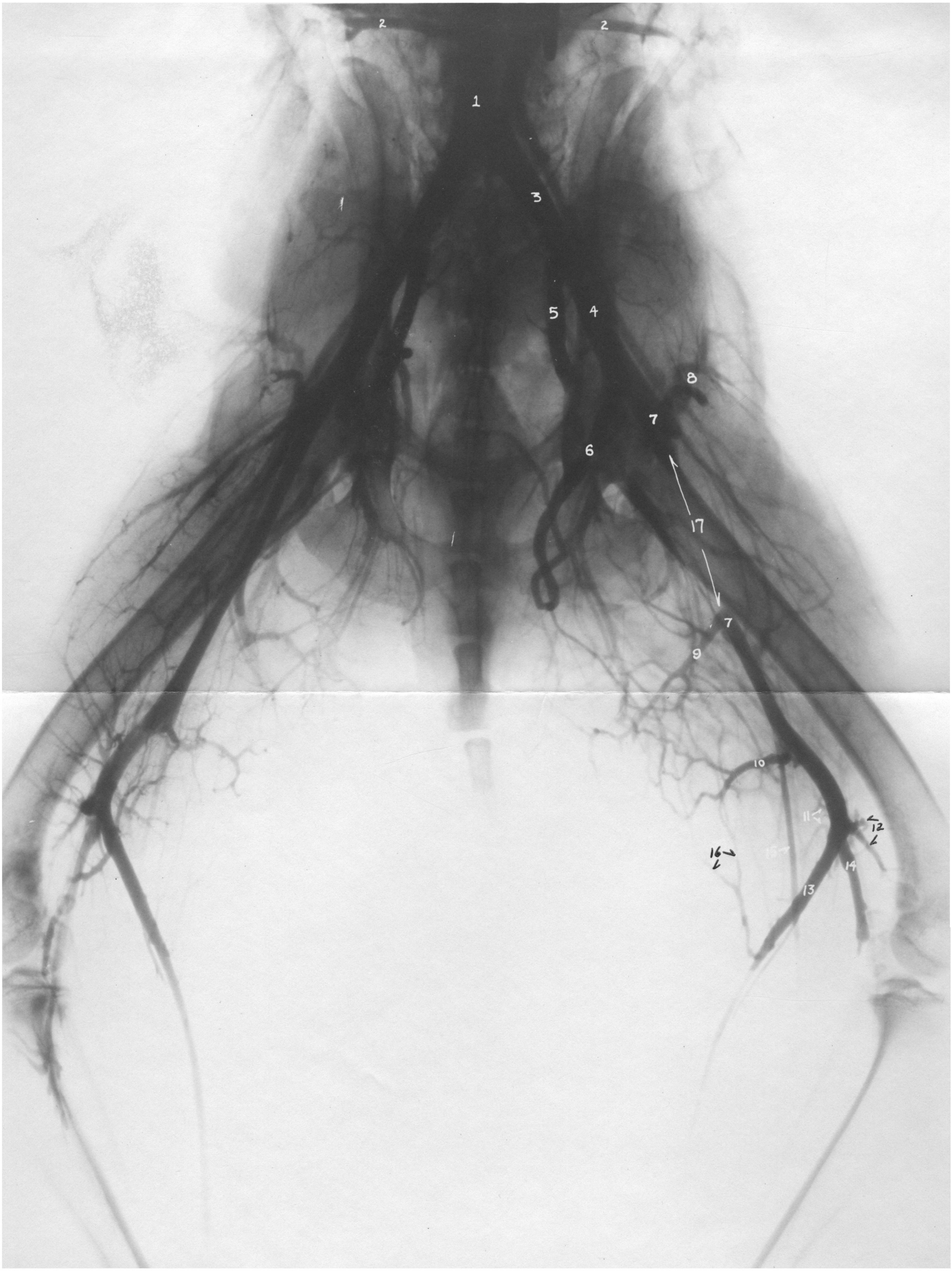
Dog #19, 1 year old, female. Venogram of the pelvic and thigh regions showing the development of the collateral circulation following ligation of the left femoral artery and vein. The view is ventro-dorsal with the dog in dorsal recumbency. 1, Common iliac vein; 1a, external iliac vein; 2, internal iliac vein; 3, deep femoral vein; 4, femoral vein; 5, cranial femoral vein; 6, proximal caudal femoral vein; 7, middle caudal femoral vein; 8, distal caudal femoral vein, caudal branches; 9, distal caudal femoral vein, cranial branches; 10, saphenous parva (recurrent tarsal vein); 11, popliteal vein; 12, anastomotic veins between recurrent tarsal vein and deep veins of caudal thigh muscles; 13, area of ligation; 14, anastomoses between the distal caudal femoral and cranial femoral veins.

PLATE XIX

EXPLANATION OF PLATE XX

Dog #22, 8 months old, male. Venogram of the pelvic and thigh regions showing the collateral circulation following ligation of the left femoral artery and vein. The view is ventro-dorsal with the dog in dorsal recumbency. 1, Caudal vena cava; 2, deep circumflex iliac vein; 3, common iliac vein; 4, external iliac vein; 5, internal iliac vein; 6, deep femoral vein; 7, femoral vein; 8, cranial femoral vein; 9, proximal caudal femoral vein; 10, middle caudal femoral vein; 11, distal caudal femoral vein, caudal branches; 12, distal caudal femoral vein, cranial branches; 13, saphenous parva (recurrent tarsal vein); 14, popliteal vein; 15, saphenous magna; 16, anastomotic branches from recurrent tarsal vein to caudal deep thigh veins; 17, area of ligation.

PLATE XX



A STUDY OF THE NORMAL AND COLLATERAL ANGIOARCHITECTURE OF THE PELVIC LIMB OF THE DOG USING RADIOPAQUE MEDIA AND GROSS DISSECTION TECHNIQUES

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Previous observations by other investigators of the collateral circulation and the normal angioarchitecture of the pelvic limb of the dog were conflicting, confusing, and incomplete. Only incomplete and often conflicting reports of the sequelae incurred from acute ligations of the femoral artery and vein separately or simultaneously were available. This study was undertaken to clarify and complete the previous available information.

The normal and collateral circulation of the pelvic limb of 35 dogs was studied using a commercial radiopaque contrast medium (Urokon Sodium 70%), and gross dissection techniques. Fifteen dogs were used to study femoral artery occlusion, ten to study femoral vein occlusion, and ten to study simultaneous occlusion of the femoral artery and vein.

With the exception of several veins entering the recurrent tarsal vein that were previously not depicted or mentioned, the normal patterns of the arteries and veins were the same as those in the standard veterinary anatomy text books.

This investigation determined that the arterial and venous collateral channels, if intact and healthy, were adequate to furnish the nutritional needs of the limb following sudden and complete occlusion of the primary artery and vein of the limb. This was true if the artery and vein were ligated separately or concurrently. Ligation of the femoral artery alone, or the femoral artery and vein simultaneously, achieved approximately the same results with no gangrene and little or no edema and lameness occurring in both instances. The primary collateral arteries were found to be the deep femoral, cranial femoral, caudal gluteal, pubo-femoral, and distal caudal femoral. The primary collateral veins were found to be the caudal superficial abdominal, distal caudal femoral, caudal gluteal, deep femoral, and cranial femoral. The recurrent tarsal vein was also of considerable importance. These arteries and veins formed important anastomoses and bypass routes to maintain an adequate blood supply to the limb.

Collateral vessels were observed to be more tortuous, more anastomotic, more variable in diameter in different parts of their length, and more profusely crossed and recrossed. Branches were present that paralleled the area of ligation. Many collateral vessels that were not grossly visible in the normal limb hypertrophied and became visible in the ligated limb. Vessels of arteriole and venule size were observed to canalize the fibrotic ligation area.

The muscles of the ligated limb, in all but two cases, appeared normal in size and strength as determined by their appearance and the ability of the animal to exercise in an apparently normal manner.

Unfavorable sequelae from the intravascular use of a contrast medium were observed.