ANATOMICAL STUDIES OF THE JOINT CAPSULE AND SYNOVIAL MEMBRANES OF THE COXOFEMORAL AND STIFLE JOINTS OF THE ADULT DOG

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

William S. Adam

1960

ANATOMICAL STUDIES OF THE JOINT CAPSULE AND SYNOVIAL MEMBRANES OF THE COXOFEMORAL AND STIFLE JOINTS OF THE ADULT DOG

By

WILLIAM S. ADAM

A THESIS

Submitted to the College of Veterinary Medicine
of Michigan State University in partial
fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Anatomy

1960

ACKNOWLEDGEMENTS

The author is deeply indebted to Dr. J. Thomas Bell, Jr., Associate Professor of the Department of Anatomy, for his inspirational guidance and interest during this investigation and for his constant help in the preparation of this manuscript.

It is with the utmost appreciation that the author extends his gratitude to Dr. M. Lois Calhoun, Professor and Head of the Department of Anatomy and to Dr. Esther M. Smith, Assistant Professor, Department of Anatomy, for their time and knowledge which was so generously given.

The writer wishes to thank Mr. James Tucker for his assistance in the preparation of the photomicrographs.

Many thanks are extended to Dr. Wade O. Brinker, Professor and Head of the Department of Surgery and Medicine, and to Dr. William D. Collings, Professor, Department of Physiology and Pharmacology, for their assistance in the procurement of the specimens.

The writer also wishes to express his most sincere gratitude to Dr. Madan M. Bharadwaj and to Mrs. Esther M. Babb Colby of the Department of Anatomy and also to Miss Margaret A. Kalder, senior medical technologist, for their invaluable assistance and unfailing enthusiasm in both the research and the researcher. It has been both a pleasure and a most memorable experience to have been associated with people of this caliber.

TABLE OF CONTENTS

LIST OF PLATES

INTRODUCTION

It has been noted that comparative description of the synovial membranes of the domestic animals has received little attention in the past. In most texts of histology and gross anatomy the synovial membranes are generally given only slight attention or classed with the peritoneum, pericardium, and pleura. This is unfortunate since it leads most people to believe that the joints and bursae are lined by endothelium or mesothelium. Actually the synovial membranes differ from the body cavities both structurally and embryologically.

The recent use of the intra-articular injection of steroids in the treatment of the various forms of arthritis and synovitis in man and domestic animals points up the need for a greater understanding of this area of histology. Since there appears to be a close relationship between the synovial membrane cells and the synovial fluid (which is used as an index in determining the effects of the different steroids) a better knowledge of the histology and histochemistry of this membrane is basic to a more complete understanding of the physiology of this area.

Therefore, the purpose of this work is to observe and record the variations, both histological and histochemical, which occur in the different areas of these joints of the dog and to try to recognize some correlation between them.

REVIEW OF LITERATURE

According to Kling (1938), Havers in 1691 described the intra-articular fat pads as mucilagenous (Haversian) glands which secrete the synovial fluid. Henle (1838) described the inner lining of the synovial membrane as epithelial and Soubbotine (1880) described goblet cells in this "epithelial" lining. The work of His (1868) on the primary germ layers caused the epithelial theory to be generally disregarded. Hunter (1743) stated that the synovial membrance formed a closed sac even over the cartilage. Velpeau (1837) disagreed with Hunter's findings. Cruveilhier (1843) showed that when the surface of the joint cavity was wiped dry synovial fluid reappeared over the soft lining and not over the cartilage, thus establishing the true area of the secretion.

Davies (1946) described the synovial membrane as a relatively smooth, glistening, yellowish or grey lining covering all intra-articular structures except the cartilage-covered weight-bearing ends. Miller (1952) stated that nearly all diarthroses or true joints possess the following features: (1) synovial capsules, (2) definite collagenous ligaments, (3) full mobility in one or more planes, and (4) adjacent bones covered with cartilage at the joints. He further stated that a synarthrosis or slightly movable joint becomes a diarthrosis when the fibrous tissue uniting adjacent bones develops a cavity which becomes lined with a synovial membrane. A joint capsule is thus composed of two parts--an

inner modified connective tissue--(synovial membrane) and an outer fibrous layer. The fibrous component always possesses parts which are thicker than the remaining capsule. These thickenings are relatively inelastic and are located at those places where there is least movement (Miller, 1952).

The thickness of the fibrous layer is variable (Sisson and Grossman, 1953). Tendons which pass over a joint may partially take the place of the fibrous layer; in other places parts of the capsule may be thickened to form ligaments which are inseparable, except artificially, from the rest of the capsule. The synovial layer frequently forms folds (plicae synoviales) and villi (villi synoviales) which project into the cavity of the joint (Sisson and Grossman, 1953).

Maximow and Bloom (1957) stated that the articular cartilage is avascular, the nourishment of the surrounding tissues being furnished by osmosis. The articular cartilages are closely adherrent to a layer of compact bone lacking canaliculi but possessing large lacunae which provide maximum circulatory efficiency when the joint is subjected to stress (Maximow and Bloow, 1957). A small area of perichondrium is reflected onto the membrane of the joint capsule at the base of the articular cartilage.

Coxofemoral joint. The hip joint of the dog, classified as an enarthroidial type, is formed by the articualtion of the proximal end of the femur with the acetabulum. The articular surface on the head of

the femur forms an almost hemispherical acetabular surface and is also continued for a short distance on the upper surface of the neck of the femur (Sisson and Grossman, 1953). The articular surface is therefore more extensive than that which is found lining the acetabular socket.

Bradley (1935) described the joint capsule as a double-mouthed sac with one end attached to the margin of the acetabulum and the transverse ligament and the other fixed to the neck of the femur a short distance from the acetabular margin. The femoral attachment does not encompass the trochanteric fossa or extend to the inter-trochanteric crest (Miller, 1952). The strongest part of the capsule is lateral and anterior (Bradley, 1935).

The entire acetabulum is not articular. Its medial half contains a depressed non-articular fossa called the fossa acetabuli. The continuity of the cavity is broken by the incisura acetabuli which is opposite the fossa. Because of this posteromedially positioned notch, Sisson and Grossman (1953) described the acetabulum as a typical "cotyloid cavity." A ring of fibro-cartilage, the labrum glenoidale, surrounds the acetabular margin and is continued across the incisura acetabuli by a ligamentous bridge, the transverse ligament (Bradley, 1935).

Miller (1952) stated that the ligamentum teres femoris (round ligament) extends from the non-articular acetabular fossa to the shallow, non-articular fovea capitis on the head of the femur.

Zeitzschmann (1928) claimed that in large dogs this ligament, when stretched, measures as much as five centimeters in length and one centimeter in width at its femoral end.

Stifle joint. The stifle joint is probably the most complicated joint in the dog due to the arrangement of its ligaments (Miller, 1952). Taken as a whole, the stifle may be considered as a ginglymus joint, although it is not a typical example of this group since it actually consists of two joints--the femoro-patellar and the femoro-tibial (Sisson and Grossman, 1953). Miller (1952) described four diverticula or chambers of the joint capsule which communicate with each other.

1. The main chamber lies beneath the patella, attaching around the margin of the trochlea proximally and on the sides of the epicondyles medially and laterally. Bradley (1935) stated that the patella itself may be regarded as a bony island in this part of the capsule. He also described a thickened capsule on both sides of the patella, the thickenings being connected with cartilagenous extensions of the bone.

2. The chamber around the long digital extensor at its origin in the extensor fossa of the femur is anterolateral and distal to the main chamber (Miller, 1952). Bradley (1935) pointed out that both the popliteus and long digital extensor muscles originate within the joint capsule.

3. There is also a chamber between the proximal articulation of the tibia and fibula (Miller, 1952). This arrangement is essentially

the same as in the pig (Sisson and Grossman, 1953). Both the main diverticulum and tibio-fibular diverticulum are adherent to the edges of the cartilagenous menisci interposed between the femur and tibia, and are continuous with the collateral ligaments of the joints (Bradley, 1935). The distal parts of the shaft of the tibia and fibula are often ankylosed (Sisson and Grossman, 1953).

4. A fourth chamber occurs between the articulation of the femur, proximal to both the medial and lateral femoral condyles, and the two fabellae (Miller, 1952). These sesamoid bones are embedded in the origin of the gastrocnemius muscle (Sisson and Grossman, 1953).

Innervation. Hilton (1863) observed that nerves which supply the joint muscles send branches to the skin over the insertion of these muscles and also supply branches to the interior of the joint. Hagen-Torn (1882) described nerve trunks piercing the fibrous capsule along with the larger vessels. These nerves branch and anastomose to form a network in the subsynovial tissues. Kling (1938) stated that the synovial lining is well supplied with medullated and non-medullated nerves which do not penetrate the surface of the membrane or enter the villi. They end in a variety of ways. Many form extensive terminal arborizations, others break into two or more terminal branches or terminate in bulbs or end plates. Using the Cajal method, Sigurdson (1930) was able to demonstrate in the connective tissue of the capsule a plexus which communicates with a very fine plexus immediately beneath the surface layer of the cells.

Rauber (1874) and Krause (1874) reported Pacinian corpuscles and end bulbs in the fibrous layer. Kling (1938) claimed the Pacinian corpuscle is present in all joints and varies greatly in form and size in the different species. However, Gardner (1948) and Davies (1946) claimed the Pacinian corpuscle is not a characteristic feature of the synovial membrane.

Blood supply. Blood vessels occur more predominately in the parts of the synovial membrane which contain numerous villi and are lined by loose subsynovial tissue. This was described by Hunter (1743) as the "circulosus vasculosus articuli," the vascular border of the joint. Hunter (1743) noted a division and anastomosis of the arteries around the neck of the bone in an arrangement similar to that found in the mesentery. The "circulosus vasculosus articuli" occurs at the zone of transition around the articular cartilage located at the ends of the bones. It is here that the vessels are abundant and loop to form short end-capillaries which project into the cartilagenous margin. The vessels in the area of the loose subsynovial connective tissue enter the fibrous capsule and course parallel to the surface to form an intricate network in the subsynovial areolar tissues (Kling, 1938). The smaller vessels often run so close to the surface of the cavity that they are covered by only a few strands of collagenous tissue. However, these strands are usually covered by one or more layers of synovial cells (Kling, 1938). Hueter (1866) and other workers of his

time assumed from silver nitrate preparations that the vessels lie bare on the surface of the cavity.

The areas of the synovial membrane not lined by loose subsynovial tissue are less vascular. The synovial membrane of the dense fibrous areas of the joint surfaces and that of the fat pads is sparsely supplied with small vessels (Kling, 1938). Davis (1946) claimed that the blood supply of the synovial membrane and capsule is closely associated with the periosteal and epiphyseal supply. The shaft of the bone forms one nutritional unit while the joint capsule and its corresponding epiphysis forms another, so there is an interdependence of the joint and epiphysis. Kling (1938) pointed out two reasons for such an elaborate and profuse blood supply in this area. First, it supplies the areas active in the production of mucin; secondly, it enables the rapid absorption of heat produced during strenuous activity.

According to Sigurdson (1930), the term "synovia" was first coined by Paracelsus (1943-1541), who recognized its mucilagenous and viscous character, while the term "synovial membrane" was introduced into the literature by Bonn (1763). Key (1928) pointed out that the term "membrane" is not appropriate when referring to the synovial surfaces since many areas of the surface are so similar to the underlying tissue that there is no definite demarcation into layers. He further pointed out that, while the general structural plan is the

same in all synovial membranes, the character of the surface varies considerably in the different parts of the same joint as well as in different joints of the same animal. Kling (1938) stated that the fibrous capsule is missing in some area so the synovial membrane rests upon fascia, periosteum or fat. The difference in the structure of neighboring areas was, to him, the most striking feature of the synovial membrane. Key (1928) attributed these variations to the mechanical conditions to which they are subjected. Vaubel (1933a and b), using tissue culture techniques, found a marked polymorphism of synovial cells in which such mechanical factors of joint movement were not present. He concluded that, although the synovial cells are of mesenchymal origin, they behave in tissue culture entirely different from cells of fixed connective tissue or serous membranes. Vaubel (1933a and b) also noticed that these cells were characterized by their ability to form either a closed arrangement, like endothelium, or an open arrangement, like connective tissue. The synovial membrane cells differ from fibroblasts in tissue culture by their ability to produce a noticeable mucin-like substance; therefore, Vaubel (1933a and b) suggested that these cells be termed "synovioblasts."

Hagen-Torn (1882), Hammer (1894) and Braun (1894) have meticulously described the synovial membrane in various areas of joints, pointing out that certain areas were "cell-rich" while others were "cell-poor." Franeschini (1930) divided the synovial surfaces

into a broader membrane type, corresponding to the "cell-poor" type, and reticulo-histiocyte type, corresponding to the "cell-rich" type, which he claimed should be part of the reticulo-endothelial system on the basis of their phagocytic power. However, Key (1928) disagreed with this theory on the grounds that material injected into a joint does not conglomerate in the synovial membrane cells.

Kling (1938) pointed out that these differences in structure have caused much confusion in the classification of the synovial membrane. He suggested that workers who regard the synovial lining as epithelial or endothelial should concentrate their attentions on the "cell-rich" areas. Other workers cited the "cell-poor" areas as proof that the synovial membrane is a modified connective tissue. Key (1928) believed that a classification based upon the underlying tissue would be more practical. Accordingly, he described three main types of synovial surfaces: areolar, dense, and adipose. He noted that the three main types are not clearly demarcated but gradually merge with each other.

Key (1928) stated that the areolar type of synovial membrane is generally found in those areas which are not subjected to pressure or strain. This may be regarded as the most typical area of the synovial membrane consisting of a well-defined surface layer supported by loose areolar tissue which separates it from the more dense areas of the joint capsule. Key (1928) and Sigurdson (1930) found that the

synovial membrane cells near the joint cavity do not lie on the surface; they may lie partly on the surface or entirely beneath the surface. Key (1928) also observed that the edges of the cells are not contiguous; therefore the surface of the synovial membrane may appear devoid of cells for distances of 50 microns or more.

Key (1928) stated that the fibrous type of synovial surface, which corresponds to the "cell-poor" type of Hagen-Torn (1882) and Hammer (1894), covers the intra-articular ligaments and lines those areas subjected to pressure or strain. The matrix of this type of synovial surface is composed almost entirely of coarse, wavy, collagenous fibers and a few cells. Those which are present appear to be encapsulated. Hammer (1894) described a broad, outer capsule and a thin, refractile, inner capsule around many of the cells in this "cell-poor" area. Key (1928) regarded these encapsulated cells as cartilage, or transitional, states between synovial membrane cells and chondrocytes.

Key (1928) described as adipose the synovial membrane which covers the fat pads and projects into the synovial cavity. He showed that the synovial membrane of the fat pads is similar to the areolar type except that the membrane rests directly upon adipose tissue due to the absence of a subsynovial areolar layer. However, Key (1928) observed a very thin collagenic layer which supports the synovial cells and envelops the fat pads. There may be three to four irregular layers of cells in this thin membrane, or it may contain

only a single layer of spindle-like cells which lie close to the surface of the cavity.

Lever and Ford (1958), with electron micrographs, have demonstrated an uneven, villous, plasma membrane of the cells with a featureless, semi-opaque material lining the tissue spaces of the superficial layer. They further showed the peripheral cytoplasm in surface synovial cells to be grossly fenestrated. It appears that this cytoplasmic vacuolization is an artifact caused by the lack of continuity of the irregular villous plasma membrane. In addition to these pseudo-vacuoles, numbers of small vesicles, sacs and other double membranous forms are scattered throughout the cytoplasm in the cells of the synovial surface layers (Lever and Ford, 1958). Luse and Reagan (1956) pointed out that the superficial synovial cells are discontinuous, have no basement membrane, and may lie either below or above the collagenous fibers. Luse (1960) distinguished the synovial membrane from mesothelium by: (1) lack of a basement membrane, (2) cellular contiguity, and (3) presence of true microvillous surface projections.

Synovial membrane cells. Key (1928) has divided the synovial membrane cells into three types based upon the different forms which a cell may take depending upon the situation of that cell as seen in cross section. Long, thin, spindle-like cells are usually found in the membrane over the fat pads and in the thin, areolar type

of joint surface. They are flattened and endothelial-like cells. The cell body may be irregularly shaped with many protoplasmic processes or it may be a round or oval disc-like structure. The nuclei usually stain deeply but show a coarse chromatin net. Short, spindle-like or comma-shaped cells are found in the more dense areas of the surface and especially on the villi. The cell body is usually flattened and parallel to the surface. There are often one or more protoplasmic processes of considerable length. The nuclei are quite large, stain deeply, and contain a coarse chromatin network. Ovoid or spherical cells occur most commonly in those areas of the synovial membrane which contain two or more layers of closely lying cells. They are usually mingled with the short spindle or comma-shaped cells and the two types are not clearly defined.

Key (1928) stated that the synovial membrane cells are connective tissue cells which have become fixed near the synovial surface. Because of their position, they are slightly modified in form and possibly in function. Using the rabbit as an experimental animal, Key (1925) traced the origin of the synovial membrane cells after synovectomy. He stated that the synovial membrane reforms by metaplasia of the underlying connective tissue. A leukocytic exudate forms first and is replaced by a clot of fibrin and cells. As the fibroblasts approach the free surface of the clot, they arrange themselves along the surface to become the synovial cells of the new membrane.

Lever and Ford (1958) demonstrated a strong PAS positive reaction by the cytoplasm of the cells of the synovial membrane and also by the intercellular material between them. They stated that the PAS reaction is unaffected by incubation for 24 hours with hyaluronidase, the deeper layers of the synovial membrane stain only slightly, and the mast cells are not clearly differentiated. Davies (1943) found that an area corresponding to this deeper layer stains with Southgate's mucicarmine (Carleton and Leach, 1947) but is also unaffected by hyaluronidase. Davies (1943) stated that the most striking feature in this procedure is the great intensity of the staining of the synovial cells immediately adjacent to the joint cavity. He further stated that the nuclei of the synovial membrane cells do not stain with mucicarmine but take the color of the basic dye, hematoxylin. Lever and Ford (1958) showed by staining with 1/1000 thionin that an occasional cell below the synovial surface exhibits metachromatic granules. However, they were not able to demonstrate metachromasia when toluidine blue was employed. Lever and Ford believed that these cells were probably those identified by Davies (1943) and Asboe-Hansen (1950) as mast cells. It was concluded from these histochemical tests that the lining cells of the synovial membrane contain a concentrated PAS positive material which is probably synovial mucin.

Lever and Ford (1958) stated that even with the use of the electron microscope it is impossible to distinguish clearly between

fibroblasts in the synovial stroma and the cells lining the surface of the membrane. Asboe-Hansen (1950) referred to these surface cells as connective tissue elements. Jackson (1955) reported granules within fibroblasts and osteoblasts and Rogers (1955) described a comparable internal structure in the mast cells around the hair follicles in young mice. He stated that in both types of cells the granules are metachromatic and react positively with the PAS reagents. Lever and Ford (1958) have pointed out that it is significant that the granules described by them within the cells on and below the synovial surface are directly comparable in electron appearance to those reported by Jackson (1955) in osteoblasts and fibroblasts. Jackson (1955) regarded these granules as precursors of collagen and ground substance, thus tending to the theory that mucin production is associated with granular cells at certain sites on the synovial surface (Kling, 1938).

Synovial folds and villi. Key (1928) pointed out that the folds and villi which project from the inner surface of the synovial membrane may vary in size from microscopic projections to structures as large as the fat pads of the stifle. Kling (1938) stated that these villous projections give the synovial wall its distinct character and are of the greatest importance for the normal and pathological physiology of the synovial membrane. He also stated that the number, size, and structure of the villi vary according to joint and area. They are scanty and small in the fibrous part and numerous over the areolar subsynovial

tissue and fat pads. Key (1928) stated that the folds may be of a transitory nature or may be permanent structures, either in the form of membranes spanning portions of the joint or as definite projections on the surface. He further stated that the structure of the villi generally corresponds to that of the joint surface to which they are attached, with size and number varying directly with the size of the joint. In the larger joints of man and in large domestic animals some of these villi may be over 2 cm. long and 0.5 cm. thick. They may be either pedunculated or sessile in type.

Davies (1945) stated that each villus is supplied by one or more arterioles. However, no lymphatics can be traced into the structures. Key (1928) stated that the villi are not innervated.

Synovial fluid. According to Sigurdson (1930), synovial fluid was so-named by Paracelsus because of its resemblance to the white of an egg. Sundblad (1951) stated that, biochemically, the synovial fluid is a blood dialysate with varying quantities of protein and a specific component--hyaluronic acid. This theory is supported by Asboe Hansen's finding that the marked vascularity of the synovial membrane provides for a certain permeability of the capillaries to albumen and globulin. Dukes (1955) and Bauer, et al. (1940) have theorized that synovial fluid is a protein-containing dialysate of blood plasma to which mucin secreted by the synovial cells is added as the plasma water diffuses through the synovial tissues into the joint cavity.

Because of its high viscosity, hyaluronic acid is able to form a lubricating fluid around the articular ends of bones (Sundblad, 1951). Asboe-Hansen (1950) stated that the viscosity of the synovial fluid is largely dependent upon the degree of polymerization.

Frerichs (1846) isolated a mucin from synovial fluid by precipating with acetic acid. This substance was first isolated from the vitreous humour of the eye. Meyer, et al. (1939) termed this fluid "hyaluronic acid." It has since been shown that hyaluronic acid forms a long molecular chain similar to that of chondroitin sulfuric acid of cartilage except that it contains no sulfate radical (Sundblad, 1951). Since its original isolation, hyaluronic acid has been shown to be present in the testes, the ciliary body, and the spleen (Asboe-Hansen, 1950). Sundblad (1951) reported that hyaluronic acid has also been found in the umbilical cord, connective tissue of the skin, tumors of mesenchymal origin, and in the capsules of groups A and C hemolytic streptococci. He also stated that it is generally assumed that chondroitin sulfuric acid, hyaluronic acid, and other related polysaccharides are the basic components of all connective tissue and act as gelatinous cementing substances for the collagenous fibers.

Lever and Ford (1958) stated that the most probable sources of synovial mucin are: (1) the surface layers of the synovial membrane, where the mucin is produced either as a product of cell degeneration or as a secretion, (2) the whole body of the synovial cell, where the mucin

is produced as an intercellular ground substance, and (3) the mast cells. Asboe-Hansen (1950) suggested that in mesenchymal tissues the heparin contained by the mast cell granules is a precursor to hyaluronic acid. He claimed that this is the site of synovial mucin production since the mast cell is the most "characteristic" cell element of the synovial membrane occurring in all its layers. Davies (1943) and Lever and Ford (1958), on the other hand, claimed that the mast cells are not located on the synovial surface but always deeper in the tissues.

Davies (1946) summarized the functions of the synovial fluid as follows: (1) lubrication--the amount of fluid in most joints is in excess of that required for lubrication, (2) nutrition, particularly of the avascular cartilage, (3) maintenance of a constant fluid medium within the joint (the water-binding power and high osmotic properties of mucin are essential to this), (4) maintenance of a constant chemical reaction within the joint, and (5) protection--mucin in other organs has been shown to protect the tissues against enzyme action and toxins.

MATERIALS AND METHODS

Twelve coxofemoral and twelve stifle joints from healthy adult dogs were used for histological and gross study. The specimens were obtained from the Departments of Surgery and Medicine, and Physiology at the Michigan State University, College of Veterinary Medicine. The animals were euthanized by the intravenous injection of magnesium sulfate.

The hind limbs were removed from each specimen and fixed immediately. Of the twenty-four joints used in this study, half were fixed in 10% buffered formalin (Lillie, 1954) and half in Rossman's fixative (Rossman, 1940). At the time of fixation the coxofemoral joint cavity was injected with 2 cc. of the fixing solution and the stifle joint was injected with 3 cc. The heavy musculature was removed after 6 hours fixation and fixation was continued for an additional 72 hours. Each joint was then washed and stored in 70% ethyl alcohol. Half the specimens for histological study were processed through 56° - 58° C. Tissuemat[1] according to the method of Johnson et al. (1943). The joint capsules and synovial membranes of the remaining specimens were removed intact, attached by cotton thread to a stiff paper card, processed through dioxane, and infiltrated with Bioloid.[2]

---

[1] Fisher Scientific Company, Pittsburgh, Pennsylvania.

[2] Will Corporation, Rochester 3, New York.

The joint capsules and synovial membranes were cut into sections and embedded, carefully orienting the sections as to area and surface. Sections were cut at 8 microns.

Several staining techniques were employed: (1) Hematoxylin and Eosin. (2) Weigert's and Van Gieson's. (3) Half per cent toluidine blue for determining the presence of mast cells and metachromasia. (4) Alcian Blue Periodic Acid Schiff (AB-PAS) reaction (Gridley, 1957). (5) Crossman's modification of Mallory's Trichrome (Crossman, 1937). (6) Gomori's stain for reticular fibers (Mallory, 1938).

RESULTS

I. THE COXOFEMORAL JOINT

Capsule. The capsule of the coxofemoral joint extended from the lip of the acetabulum to the distal end of the neck of the femur. That portion of the capsule which encircles the lip of the acetabulum was composed of fibrocartilage. The general structural contour of the internal surface of the joint capsule in this area was such that the fibrocartilage formed circular thickenings in the same plane as the lip of the acetabulum. Fibrocartilage extended in width from the lip of the acetabulum to a point opposite the margin of the articular cartilage of the head of the femur (Plate I). The fibrocartilage in this area stained intensely with toluidine blue and exhibited a positive PAS reaction. These histochemical reactions were interpreted as an indication of the presence of chondroitin sulfuric acid. The apparent size of the fibrocartilage lacunae ranged from 25.5 to 10.2 μ. The larger lacunae of the fibrocartilage appeared near the margin of the acetabulum, while the smaller lacunae were generally found in the area of transition from fibrocartilage to dense white fibrous connective tissue. In the area of transition there were a few lacunae in the white fibrous connective tissue.

The transition of the joint capsule from fibrocartilage to white fibrous connective tissue was quite abrupt. The remainder of

the joint capsule, excluding the fibrocartilage of the acetabular border, was composed predominately of white fibrous connective tissue. Distally, the joint capsule becomes the periosteum of the femur and is connected to the muscles of the area.

No reticular fibers were observed and elastic fibers were seen only in association with blood vessels. Adipose tissue was present between the bundles of collagenous fibers only in the deeper layers of the joint capsule. In each instance the adipose tissue was penetrated by one or more blood vessels and in many instances by nerves and lymphatics as well. A few mast cells were scattered through this area.

Synovial membrane. The synovial membrane extended from the distal margin of the fibrocartilage to the articular margin of the head of the femur (Plate I). The teres ligament and that portion of the synovial membrane lying beneath the joint capsule were of the dense fibrous type while that portion of the synovial membrane encircling the neck of the femur was loose areolar in type (Plate III). The dense fibrous portions varied from one-to-four cell layers in thickness, with most of the synovial membrane being one cell layer. The cells of the more superficial portions of the synovial membrane were slightly elongated and spindle shaped and were arranged, for the most part, with the long axis of each cell in the same plane as the surface (Plate IV). The synovial membrane cells of the deeper areas were embedded in the white fibrous connective tissues (Plate III).

Villi, which did not arise from the surface except at the traditional zones, were thin, short and sessile in form.

The dense fibrous type of synovial membrane found covering the teres ligament was similar to that lining the dense fibrous connective tissue of the capsule (Plate V). At its ends of attachment the dense fibrous connective tissue became fibrocartilage. The transition from fibrocartilage to articular cartilage was quite gradual. In none of the specimens did the fibrocartilage extend beyond the periphery of the fovea capitis. In some specimens the articular cartilage extended a short distance into the ligament. The teres ligament did not contain reticular fibers, and elastic fibers were observed only in association with the blood vessels. The membrane reacted positively when the PAS reaction was employed but did not stain metachromatically with toluidine blue.

The membrane extending from the articular margin of the head of the femur to the distal end of the neck of the femur (where it merged with the dense fibrous connective tissue) was of the loose areolar type (Plate I). The point of reflection was well supplied at the surface with small blood vessels and lymphatics. In many instances these vessels approached the surface so closely that they appeared to be separated from it by only one cell layer. The surface of the loose areolar type synovial membrane was continually lined in most places by a membrane of one-to-three cell layers in thickness, although

distances as great as 40 μ were observed which were devoid of any superficial cells (Plate VI). The majority of the cells in this area were comma shaped, although all variations occurred. The long axis of the surface cells were in the same plane as the surface of the cavity, while the deeper synovial membrane cells in the area of the blood vessels and lymphatics were arranged so that their long axis was in the same plane as the lumen of the blood vessels (Plates IV and VI). The loose areolar subsynovial tissue was composed mainly of white fibrous connective tissue and adipose tissue (Plate III). The collagenous fibers of this region did not conform to any definite place or pattern but extended in all directions. The diameters of the bundles of white fibrous connective tissue in this area were much smaller than were those in the area of the dense fibrous subsynovial tissue (Plate III). Short, individual fibers were noted in the loose areolar connective tissue and in the walls of blood vessels. The membrane showed a positive PAS reaction but did not exhibit metachromasia when stained with toluidine blue.

The villi in the area of the loose areolar subsynovial connective tissue were either pedunculated or sessile in nature. The longer pedunculated villi had much more adipose tissue in their central portion and were the longer of the two types. The sessile villi were composed almost entirely of loose areolar tissue and contained more synovial membrane cells in a given area than the pedunculated type.

Those synovial membrane cells surrounding the wall of the vessels appeared in many cases to be concave and to conform to the curvature of the lumen of the vessels (Plate IV).

II. THE STIFLE JOINT

Capsule. The main chamber of the joint capsule extended proximally on the anterior surface of the femur, under the quadriceps femoris muscle, to a point 1.5 to 2 cm. beyond that, where the articular cartilage of the patellar surface of the femur terminates. At this proximal-most point, the capsule reflected and extended distally to form a cavity (Plate II). In all specimens, there were fatty folds (the prepatellar fat pads) arising from the area of the proximal point of reflection and extending distally. At the proximal articular margins of the patellar surface, these folds became detached and extended as two villous projections--one over each marginal eminence of the patellar surface of the femur.

From this proximal point of reflection the joint capsule extended distally following the articular cartilage around the femoral epicondyles. Medially, and laterally from its proximal point of reflection to a point corresponding to the distal end of the patella, the joint capsule was relatively thin and compact in comparison to the remaining portion of the capsule. The capsule of this area was composed mostly of white fibrous connective tissue which could be divided into a dense inner and a less-dense outer layer. The dense inner layer of transversely arranged fibers appeared to vary in thickness over the extent of the capsule studied (Plate VIII). The fibers of the less-dense outer layer followed a longitudinal course, finally merging with the muscles of the

thigh. The innervation and vascular supply were greater here as compared to those of the inner layer of dense white fibrous connective tissue (Plates VII and VIII).

The lateral and medial walls of the joint capsule were not equal in extent. The lateral wall extended along the articular margin from the proximal point of reflection, to the articular surface, to the lateral epicondyle (where the extensor digitorum longus muscle originates). The medial margin of the joint capsule extended from the proximal point of reflection along the articular margin to the medial epicondyle.

That portion of the joint capsule on the anterior-most surface, which is directly covered by the tendon of the quadriceps femoris muscle, was much more dense in its arrangement. This thickening extended in length from the proximal end of the patella to the point of reflection of the proximal end of the joint capsule. The width and semicircular shape of the tendinous thickening were governed by the width and depth of the patellar surface of the femur. The entire area was composed of an avascular fibrocartilage which was without apparent innervation (Plate IX). This area of fibrocartilage stained metachromatically with toluidine blue and showed a strong positive PAS reaction (Plate VII). The fibrocartilage extended laterally and medially to include that portion of the joint capsule which comes directly into contact with the medial and lateral sides of the patellar

surface of the femur (Plate II). The thickest area of fibrocartilage occurred just proximal to the patella as two kidney bean-shaped areas. These thickenings, the parapatellar fibrocartilages, were situated so their hili were opposed along the midline (Plates II and IX).

The parapatellar fat pad encircling the patella was located distal to the parapatellar fibrocartilages. This soft area was widest at the proximal and distal ends of the patella and narrowest along its medial and lateral margins. In no instance was it more than 1 cm. in width and 0. 5 cm. in thickness (Plates II and X).

From the distal end of the patella, the joint capsule extended distally and posteriorly to attach to the anterior surface of the tibial condyles. From the surface of this area, large fatty projections seemed to project into, and fill, the intercondyloid fossa. These projections were composed of tissue near the surface of the cavity. The distal end of the joint capsule terminated at the distal anterior lateral and medial margins of the articular surface of the tibial condyles. From this point the capsule extended posteriorly along the articular margins of the tibial condyles. The walls of the capsule were thickened by the dense, white fibrous tissue of the medial and lateral collateral ligaments. On its posterior surface the joint capsule extended from the area of the intercondyloid fossa and popliteal surface of the tibia to the proximal surface of the femoral condyles. The tissue of this area was predominately adipose with collagenous fibers which extended longitudinally. The joint capsule was well supplied with nerves and blood vessels.

The diverticulum around the tendon of origin of the long digital extensor muscle was so thin that grossly it was semitranslucent in the fresh state. This sheath communicated with the main chamber by an opening on its medial side, at the point of origin of the tendon, and extended distally to the junction of the tendinous and muscular portions of the extensor digitorum longus, where the capsule reflected and became continuous with the tendon (Plate XI).

The fabellae in the posterior area of the joint were about the size and shape of a pea. They were embedded in the heads of the gastrocnemius and popliteus muscles in such a manner that they articulated with the proximal and posterior surfaces of the femoral condyles. The posterior portion of the main chamber of the joint capsule was continuous with any chamber existing around the fabellae. Grossly, this area appeared to be fatty so that in the fresh state the whole area assumed a spongy appearance. The fatty tissue extended over or around the articular surface of the fabellae and reflected inward to attach at the articular margins (Plate XII). Microscopically, the fabellae were composed of bone surrounded by cartilage (Plate XII). This portion of the joint capsule was well supplied with blood vessels and lymphatics which approached the surface of the joint cavity.

Synovial membrane. The synovial membrane of the stifle joint covered the surfaces of the articular cavity not covered

by cartilage (Plate II). In no case was a basement membrane observed, and in many areas a division between joint capsule and synovial membrane was indistinguishable.

The dense fibrous type of synovial membrane covered the area proximal to the distal end of the patella. This whole region, with the exception of those areas composed of fibrocartilage and the prepatellar and parapatellar fat pads, had a membranous internal surface. The membrane varied from one cell layer in thickness in the areas of transition to three cell layers along the majority of the dense fibrous tissue. The synovial membrane cells of the surface were flattened, while those found in the deeper layers were, for the most part, short and spindle shaped and arranged so that their long axis parallelled the surface of the cavity. There was no abrupt change from synovial membrane cells to chondrocytes; rather, this transition was so gradual that it was difficult, and sometimes impossible, to tell exactly where the fibrocartilage began and the synovial membrane ended (Plate XIV).

Dense fibrous type of synovial membrane also lined the intra-articular ligaments and the tendon of the extensor digitorum longus muscle. In these areas the superficial cells formed a closely packed layer one cell layer in thickness.

The collagenous fibers which pursued a wavy course paralleling the surface were the main components of the dense fibrous type synovial membrane. The fibers of this area were smaller in

diameter than the deeper lying fibers of the capsule. Elastic and reticular fibers, nerves, blood vessels, and lymphatics were not observed near the surface, and no villi were seen to arise from the true dense fibrous type synovial membrane (Plate X). The synovial membrane of this area did not stain metachromatically with toluidine blue but showed a strong PAS positive reaction.

The areas showing the loose areolar type of synovial membrane were the anterolateral and medial surfaces of the femur proximal to the patellar surface, the sides of the semilunar cartilages, the sheath of the flexor digitorum longus muscle, and the posterior surface of the cavity in the region of the popliteal surface. The surface layers of these areas were composed of strands of white fibers in which synovial membrane cells were embedded. The cells per area were found to vary in number and concentration. In general, those surfaces which were smooth were covered by one cell layer, while those areas which formed folds of plicae were up to four irregular cell layers in thickness. The cells of this area were long and spindle or comma-shaped. Thickness of the loose areolar type synovial membrane varied widely at different areas of the same section; areas having many cell layers were as thick as 50 μ, while areas of only one cell layer were as thin as 5.8 μ (Plate XV).

The loose areolar type membrane was PAS positive but did not exhibit any signs of metachromasia when stained with toluidine

blue. Elastic fibers were observed both in association with blood vessels and as short individual fibers in the subsynovial connective tissue. No reticular fibers were noted. Vessels were quite numerous near the surface of the membrane and extended into the villi (Plate XVI).

The villi, which varied greatly in size and thickness, appeared to be more numerous and characteristic of this type of synovial membrane than of any other type. Some were so large that they could not be seen completely in one low-power microscopic field. Each villus had one or more blood vessels coursing through its entire length. The vessels appeared to be either thick-walled arterioles or thin-walled venules and lymphatics. The synovial membrane cells congregated around the vessels and, in many cases, assumed the same radius of curvature as that of the vessels themselves (Plate XVII).

The adipose type of synovial membrane was present in the prepatellar and parapatellar fat pads, anterior and to the sides of the intercondyloid fossa, and around the articular surface of the fabellae (Plates X and XVII). It was similar to the loose areolar type except that a subsynovial areolar layer was not observed in the adipose type. The synovial membrane rested directly upon the adipose tissue and was thicker than that of the loose areolar type. The thickness of the adipose type synovial membrane varied from 10 to 45 μ, and the cells were long and spindle shaped. The surface cells formed a continuous layer, while the cells of the more internal layers were separated by strands

of collagenous tissue. The adipose type synovial membrane gave a positive PAS reaction. A few elastic fibers were scattered throughout the tissue. Nerves and reticular fibers were not observed. Blood vessels and lymphatics were not as numerous here as in the loose areolar type synovial membrane (Plate XVIII). Villi were similar to, but shorter and less numerous than those of the loose areolar type synovial membrane.

DISCUSSION

The joint capsule and the synovial membrane differ both in extent and structure. The joint capsule is found over the synovial membrane only in those areas which must be reinforced (due to the actions in which the articulation may become involved). There appears to be a strong correlation between the thickness and composition of the capsule and its location.

Maximow and Bloom (1957) stated that the fibrocartilage is a transitional form between articular cartilage and connective tissue. The fibrocartilage around the rim of the acetabulum appears to be well suited for this transition. Gross observation revealed that it is in this area that the most stress appears to occur when the joint is articulated. It was also seen in gross observation that the antero-lateral aspect of the lip of the acetabulum is not well protected by overlying structures. The middle and deep gluteals form a rather broad, tendinous insertion thus affording good support to the area of the neck of the femur, but it appears to give no real support to that portion of the joint capsule overlying the surface of the cavity composed of fibrocartilage. It appears reasonable to assume that if the dense white fibrous connective tissue attaches directly to the lip of the acetabulum the support afforded by this arrangement would not be as great as the normal arrangement. This correlation can be substantiated further by the fact that the loose areolar and adipose types

of connective tissue are observed only in those areas where little or no stress would normally be placed.

Hammer (1894) and Braun (1894) described the different areas of the synovial membrane as being either "cell-rich" or "cell-poor." These areas are not confined to any region but cover all types of subsynovial tissue; however, these "cell-rich" areas occur most frequently where the surface of the synovial membrane folds or bends. Therefore, many of these "cell-rich" areas may be other than they appear to be. The topography of the membrane exists in three dimensions, while a microscopic section theoretically exists only in two dimensions. However, all "cell-rich" areas should not be interpreted as illusions since some areas are probably true strata of cells. The shapes cells in the false "cell-rich" areas do not appear compressed or elongated even in the deeper strata but are uniformly the same shape (Plate XIX). In those areas which appear to be truly "cell-rich," the deeper cells appear more flattened and elongated than the superficial ones. Over certain areas of loose areolar tissues the synovial membrane cells do not actually lie entirely on the surface as do those of epithelium. Instead, they are embedded in the fibrous matrix and seem to lie on the surface, or partly on the surface, or entirely beneath the surface. The edges of the synovial membrane cells do not touch one another but overlap, or fail to meet, so that in cross section some surface areas appear devoid of synovial

membrane cells (Plate VI). This author believes that the "cell-poor" concept of Hammer (1894) and Braun (1894) and this observation are actually one and the same concept.

The present work appears to support the theories of Vaubel (1933a and b) and Key (1928) in that although the general shape of a cell is not entirely determined by the type of subsynovial tissue which covers it, the shape of many of the deeper cells appears to be at least partially influenced by the subsynovial tissue. In the deeper layers the cells are packed close together with a resulting effect upon their shape. The areas on the lateral and medial sides of the parapatellar fibrocartilages of the stifle are devoid of synovial membrane and grossly a depression can be seen in the joint capsule which is in constant opposition with the femoral condyles. It seems reasonable to hypothesize that any delicate cells in this area could be easily damaged.

Key (1928) observed that the fibroblasts of the deeper layers moved toward the surface following synovectomy. Because of their position they have become modified in form and possibly in function. In this present research the cells along the surface of the cavity resemble immature fibroblasts. It seems reasonable that if one is able to accept the unitarian or dualist theory of the formation of blood this theory is also acceptable.

Kling (1938), Rauber (1874) and Krause (1874), reported that the Pacinian corpuscle is a characteristic feature of the synovial

membrane. However, this present research supports the claims of Gardner (1948a and b) and Davies (1946) that the Pacinian corpuscle is not present at this site.

Asboe-Hansen (1954) stated that mast cells are present in large numbers where the synovial fluid is formed, with the numbers present varying according to site. He claimed that the fixative used (in this case 4% lead subacetate) is the important factor. When this method of fixation is followed by toluidine-blue stain, mast cells are seen in all synovial strata but are most plentiful along the lining of the joint cavity. Davies (1943) claimed that mast cells never occur in the synovial lining among the surface cells, an observation which appears to be in agreement with the findings of this present research.

Lison (1936) claimed that metachromasia is a specific test for higher esters of sulfuric acid. Pearce (1953) more recently stated that evidence indicates that it is not a specific test although esters of sulfuric acid do produce the reaction. Lever and Ford (1958) stated that when they stained with the two thiazin dyes, thionin and toluidine blue, their results varied. With 1/1000 thionin they demonstrated metachromatic granules in the cells below the surface but could not produce this when toluidine blue was employed. In this present research the synovial membrane appears to remain blue (orthochromatic), while the areas of fibrocartilage and mast cells located well below the surface showed a change of color to violet

(beta metachromatic). It appears from these present observations that the cells lining the surface of the cavity do not contain the same chromotrope as those seen below the surface and identified as mast cells (Plate VI).

Lever and Ford (1958) demonstrated a strong PAS positive reaction of the cells of the synovial membrane. In this present research a strong positive reaction was seen in both the cytoplasm and the intercellular material along that surface of the joint capsule which is lined with a synovial membrane. This was interpreted as an indication of the presence of a sulfated mucopolysaccharide (Plates VII and XX).

SUMMARY AND CONCLUSIONS

Gross and histological studies of the joint capsules and synovial membranes were made on twelve coxofemoral and twelve stifle joints of healthy dogs. No appreciable sex differences were noted.

The capsule of the coxofemoral joint extends from the lip of the acetabulum to the distal end of the neck of the femur. The lip is surrounded by fibrocartilage which merges distally with the dense collagenous tissue. The joint capsule is thickest anterolaterally and thinnest in the area of the trochanteric fossa. The collagenous portion of the joint capsule is supported by the tendinous insertions of the gluteal muscles.

The dense fibrous type synovial membrane of the coxofemoral joint extends from the distal margin of the fibrocartilage to the distal end of the neck of the femur and also lines the teres ligament. Loose areolar type synovial membrane extends from the distal end of the neck to the articular margin of the head of the femur. There is no adipose type synovial membrane associated with this joint.

The main chamber of the stifle joint capsule extends from a point proximal to the articular margin of the patellar surface of the femur to the margins of the tibial condyles and around the femoral epicondyles to the popliteal surface of the femur. From the distal end of the patella to the most proximal end of the cavity, the more anterior

portion of the cap is composed of fibrocartilage which is thickened proximally to form the parapatellar fibrocartilages. Anterolaterally and medially, the joint capsule is divisible into a thick, outer, longitudinal layer and a thin, dense, inner layer. The parapatellar fat pad is situated around the patella while the prepatellar fat pads lie over the proximal portions of the lateral and medial margins of the patellar surface of the femur. Distal to the patella, the inner surface of the joint capsule becomes soft and fatty; the outermost portion is composed of fibrocartilage. A fatty internal surface is also found around the fabellae and over the popliteal surface of the femur.

All three types of synovial membrane are present in the stifle joint. (1) The dense fibrous type covers that part of the joint capsule proximal, medial, and lateral to the patella, and lines the intra-articular ligaments and the tendon of the extensor digitorum longus muscle. (2) The loose areolar type synovial membrane is found covering the anterior lateral and medial surfaces of the femur proximal to the patella, the sheath of the flexor digitorum longus muscle and the posterior surfaces of the cavity in the region of the popliteal surface. (3) The adipose type synovial membrane occurs as the prepatellar and parapatellar fat pads, anterior and to the sides of the intercondyloid fossa, and around the articular surface of the fabellae.

Villi, which are most characteristic of the loose areolar type synovial membrane, vary in size, thickness and general shape.

Two types are recognized: (1) the pedunculated villus containing much adipose tissue and having a narrow attachment, and (2) the sessile type which is usually shorter and similar in composition to the loose areolar type synovial membrane.

The synovial membrane does not show metachromasia with toluidine blue although fibrocartilage and mast cells show a reaction indicating that the same chromotrope is not present in the different areas. A strong PAS positive reaction is shown by both the fibrocartilage and the synovial membrane indicating the presence of one or more sulfated mucopolysaccharides.

BIBLIOGRAPHY

Asboe-Hansen, G. 1950. The origin of synovial mucin. Ann. Rheum. Dis., 9:149-158.

Asboe-Hansen, G. 1954. The mast cell. International Review of Cytology, 3:399-453.

Bradley, O. C. 1935. Topographical Anatomy of the Dog. Macmillan Co., New York.

Braun, H. 1894. Untersuchungen ueber den Bau der Synovial Membrane und Gelenkknorpel, sowie ueber die Resorption Fluessiger, und fester koerper aus den Gelenkkoihlen. Deutsche Ztschr. f. Chir., 39:35-43.

Carleton, H. M. and E. H. Leach. 1947. Histological Technique. Oxford Medical Publications, London.

Crossman, G. 1937. A modification of Mallory's connective tissue stain with a discussion of the principles involved. Anat. Rec., 69:33-38.

Cruveillier, A. 1843. Traite d'anatomie descriptive. Paris, Labe, 1:365-374.

Davies, D. V. 1943. The staining reaction of normal synovial membrane, with special reference to the origin of synovial mucin. Jour. of Anat., 77:160-169.

Davies, D. V. 1946. Synovial membrane and synovial fluid of joints. Lancet, 251:815-819.

Franeschini, P. 1930. La formazione reticuleistiocitaria della membrane sinoviale. Mon. Zool. Ital., 40:367-374.

Frerichs, F. T. 1846. Synovia. In Wagner's handwoerterbuch der Physiologie. Braunschweig, Vieweg, 3:463-471.

Gardner, E. 1948a. Innervation of the hip joint. Anat. Rec., 101:353-371.

Gardner, E. 1948b. Innervation of the knee joint. Anat. Rec., 101: 109-130.

Gridley, M. F. 1957. Manual of Histologic and Special Staining Techniques. Armed Forces Institute of Pathology. Washington, D. C.

Hagen-Torn, O. 1882. Entwicklung und Bau der Synovial membranen. Arch. Mikr. Anat., 21:591-603.

Hammer, J. A. 1894. Ueber den Feineren Bau der Gelenke. Arch. f. Mikr. Anat., 13:266-271.

Henle, F. 1838. Ueber die Arthritis deformans. Virch. Arch., 264:541-553.

Hilton, J. 1863. Rest and Pain. Cambridge Press, London.

His, W. 1868. Untersuchungen uber die erste Anlage des Wirbelihierleibes. Die erste Entwickelung des Huknchens in Ei. F. W. Vogel, Leipzig.

Hueter, W. 1866. Zur Histologie der Gelenkklacken und Gelenkkapselen. Virch. Arch., 36:25-32.

Hunter, W. 1743. On the structure and diseases of articular cartilage. Phila. Trans., 42:514-521.

Jackson, S. F. 1955. Cytoplasmic granules in fibrogenic cells. Nature, 175:39-40.

Johnson, E., F. N. Andrews and C. L. Shrewsbury. 1943. The preparation of muscular tissue for histological study. J. Anim. Sc., 2:244-250.

Key, J. A. 1925. The reformation of synovial membranes in the knees of rabbits after synovectomy, J. Bone and Joint Surgery, 7:793-814.

Key, J. A. 1928. Synovial membrane of joints and bursa. In Cowdry, E. V., Special Cytology; the Form and Function of the Cell in Health and Disease; a Textbook for Students of Biology and Medicine. 2:1053-1085. Paul B. Hoeber, Inc. New York.

Kling, D. H. 1938. The Synovial Membrane and the Synovial Fluid. Baillere, Tindall and Cox, London.

Krause, W. 1874. Histologishe Notizen. Central-bl. F. Med. Wissensch., 14:211-217.

Lever, J. D. and E. H. Ford. 1958. Histological, histochemical and electron microscopic observations on synovial membranes. Anat. Rec., 132:525-529.

Lillie, R. D. 1954. Histological Technique and Practical Histochemistry. McGraw-Hill Book Co., New York.

Lison, L. 1936. Histochemie Animale. Gauthier-Villars, Paris.

Luse, S. A. 1960. A synovial sarcoma studied by electron microscopy. Cancer, 13:312-322.

Luse, S. A. and J. W. Reagan. 1956. Histocytologic microscopic study of effusions associated with malignany disease. Ann. New York Acad. Sc., 63:1331-1347.

Mallory, F. B. 1938. Pathological Technique. W. B. Saunders Co., Philadelphia.

Maximow, A. A. and W. Bloom. 1957. A Textbook of Histology. W. B. Saunders Co., Philadelphia.

Meyer, K., E. M. Smyth and M. H. Dawson. 1939. The specific component of synovial fluid. J. Biol. Chem., 128: 319-334.

Miller, M. E. 1952. Guide to the Dissection of the Dog. Ithaca, New York.

Pearse, A. G. 1953. Histochemistry; Theoretical and Applied. Little, Brown and Co., Boston.

Rogers, G. E. 1956. Electron microscopy of mast cells in the skin of young mice. Exp. Cell Res., 11:393-402.

Rauber, A. 1874. Uber die Votersche Koerper der Gelenkkopsein. Central-bl. f. Med. Wissensch., 20:305-313.

Rossman, I. 1940. The decidua of the Rhesus monkey. Amer. J. Anat., 66:276-342.

Sigurdson, L. A. 1930. Structure and function of articular synovial membrane. J. Bone and Joint Surgery, 12:603-639.

Sisson, S. and J. D. Grossman. 1953. The Anatomy of Domestic Animals. W. B. Saunders Co., Philadelphia.

Soubbotine, P. 1890. Resherches histologiques sur la structure des membranes synoviales. Arch. Phys. Biol., 7:532-539.

Sundblad, L. 1950. The chemistry of synovial fluid with special regard to hyaluronic acid. Acta Orthop. Scand. (Kobenhavn), 20:105-113.

Vaubel, E. 1933a. The form and function of synovial cells in tissue cultures. J. Exp. Med., 58:63-84.

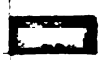
Vaubel, E. 1933b. The form and function of synovial cells in tissue cultures. J. Exp. Med., 58:85-95.

Velpeau, A. L. 1837. Traite Complet D'Anatomie Chirurgicale. Mequignon-Marvis, Paris, 1:178-182.

Zeitzschmann, O. 1928. Unter den Processes Vaginales der Hunden. Dtsch. Tierarztl. Woecheschr., 36:20-22.

PLATE I

Coxofemoral joint showing the area occupied by the joint capsule (within dotted line) and the extension of synovial membrane.

1.  Fibrocartilage.
2.  Dense fibrous type synovial membrane.
3.  Loose areolar type synovial membrane.

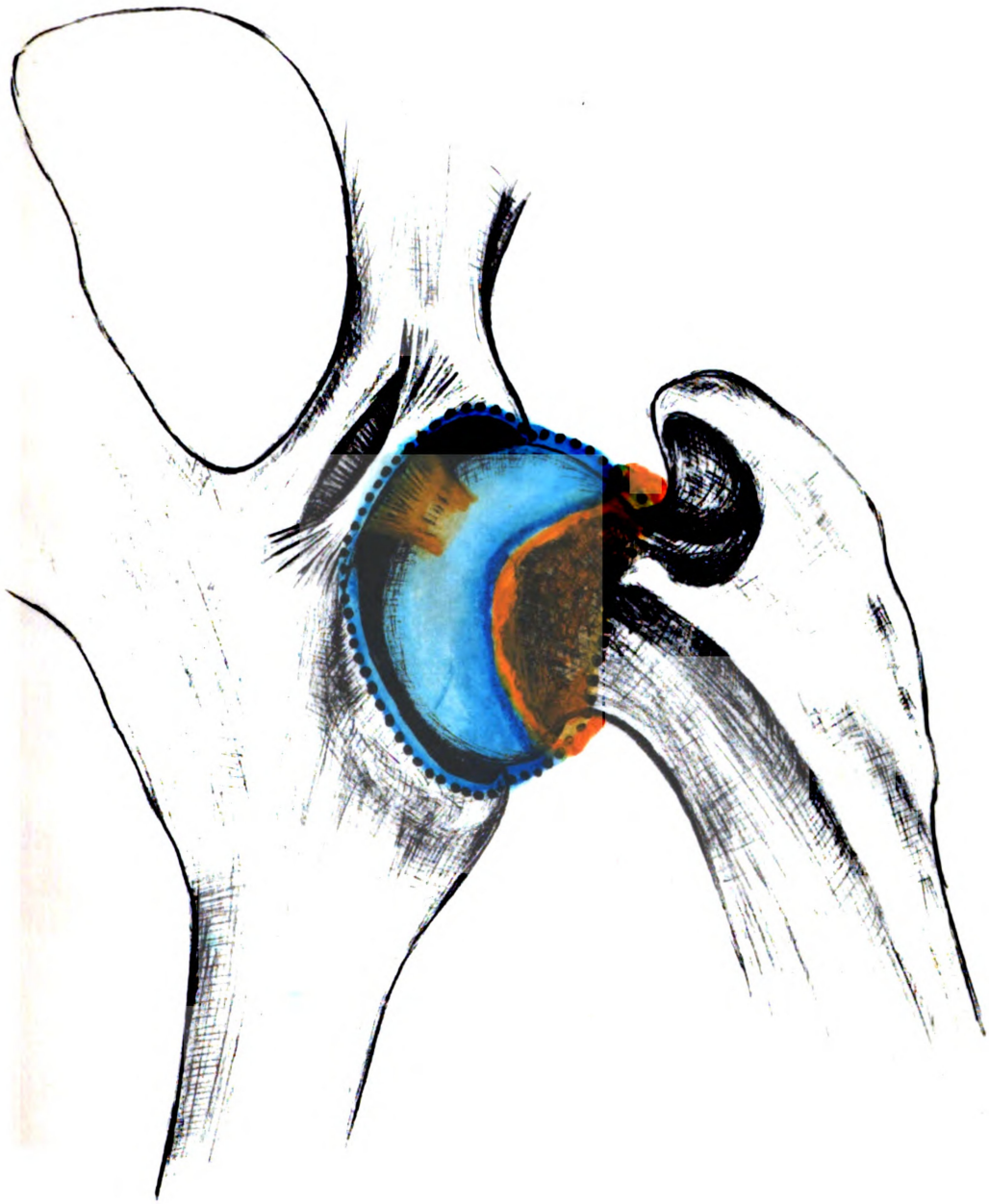
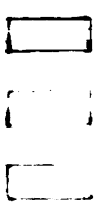


TABLE I

... area occupied by the

...) and the extension



... synovial membrane.

... synovial membrane.

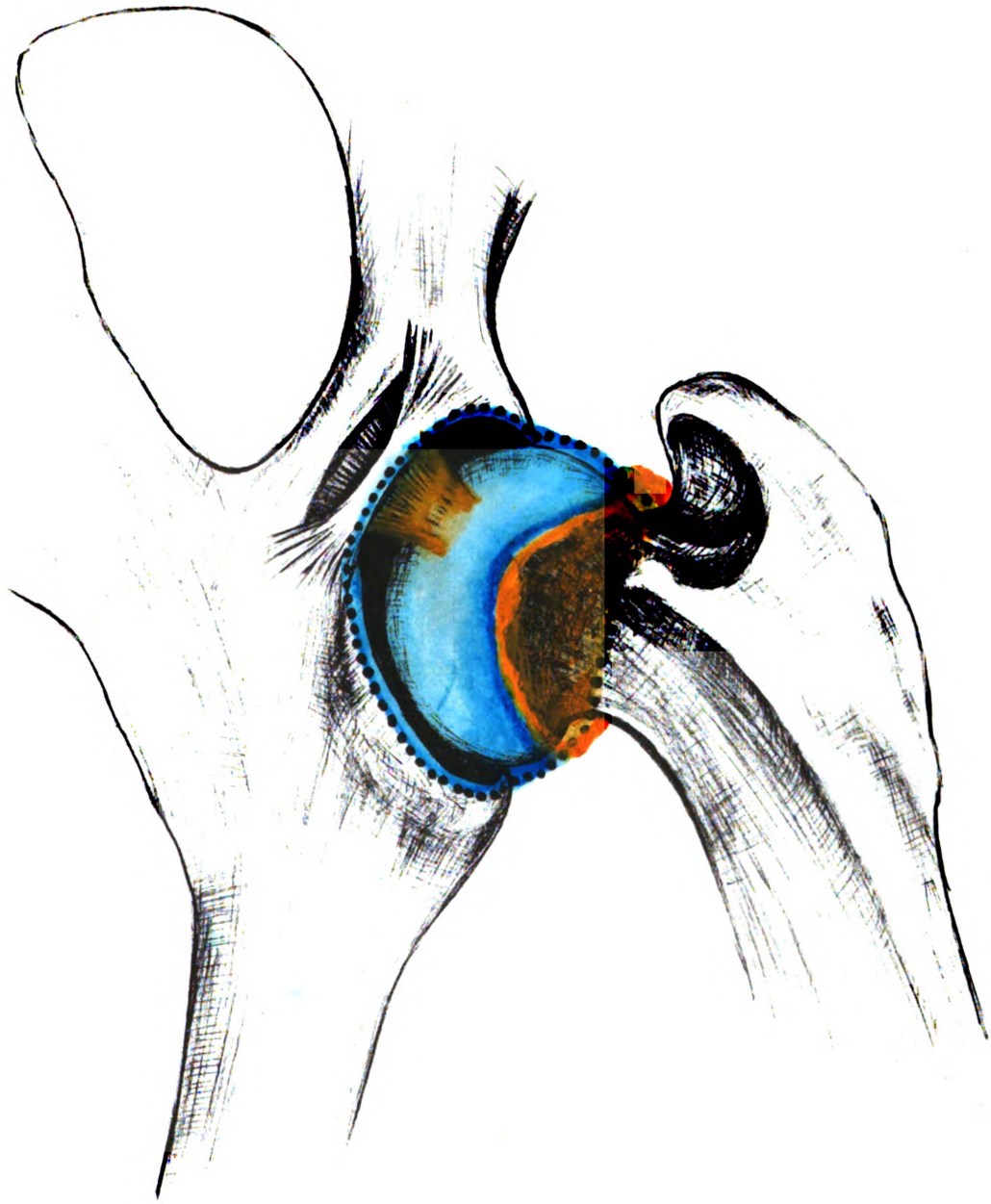
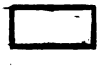


PLATE II

Stifle joint showing the area occupied by the joint capsule (dotted line) and the extent of the various types of synovial membranes.

1.  Dense fibrous type synovial membrane.
2.  Loose areolar type synovial membrane.
3.  Adipose type synovial membrane.

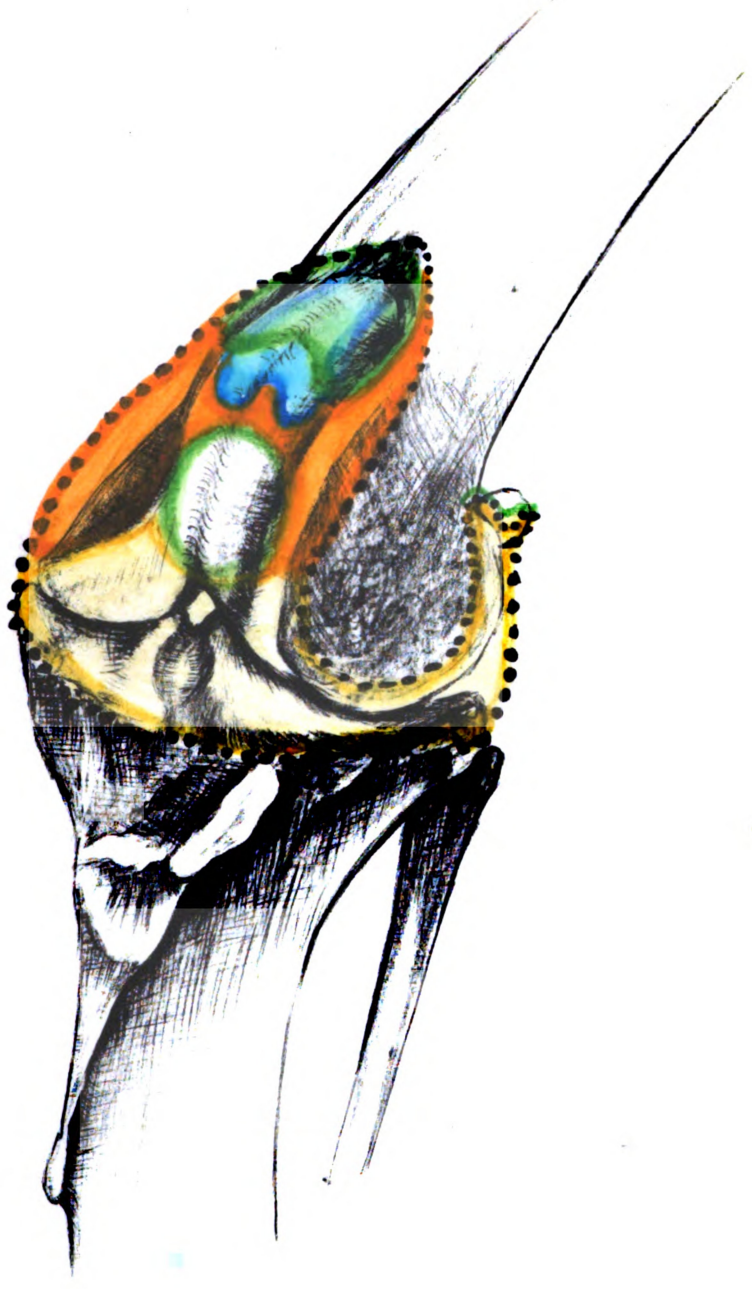


PLATE II

Stifle joint showing the area occupied by the joint cavity (solid line) and the extent of the various synovial membranes.

1.  [illegible] type synovial membrane.
2.  [illegible]ular type synovial membrane.
3.  [illegible]se type synovial membrane.

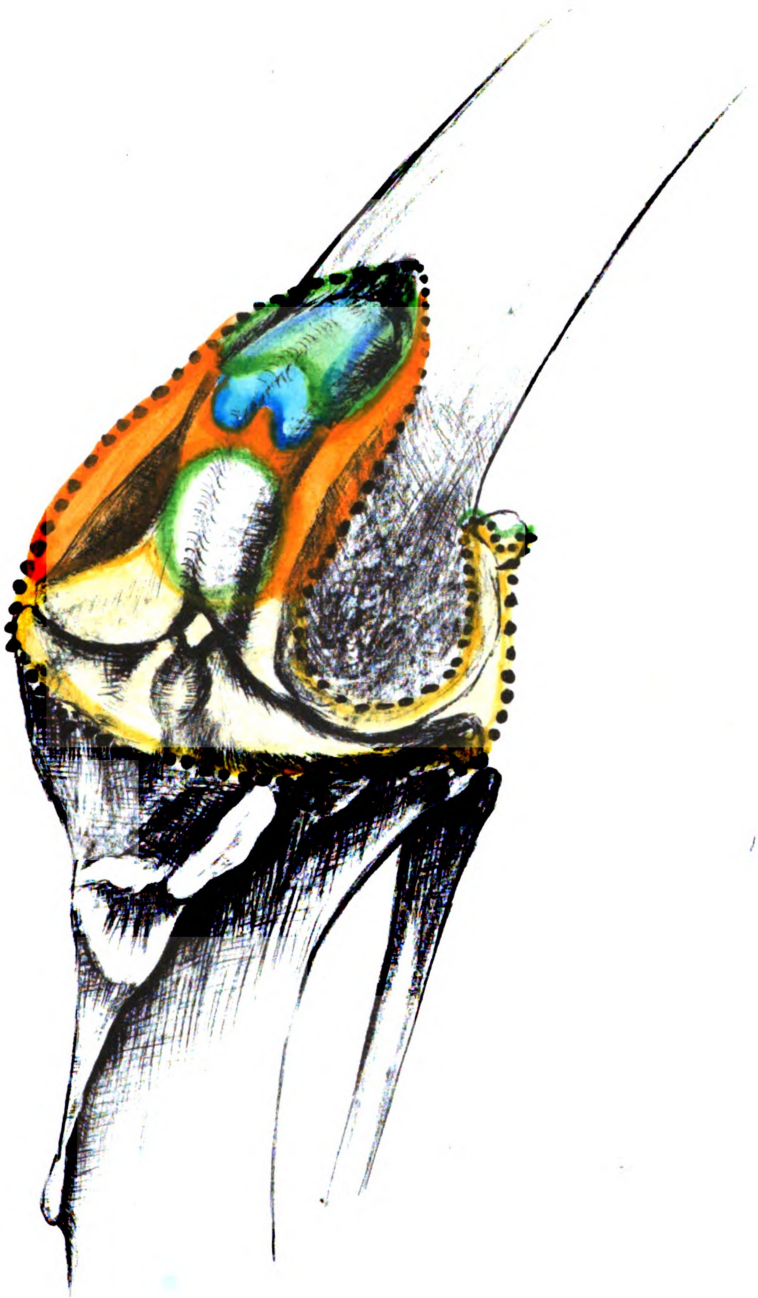


PLATE III

Section of the capsule and synovial membrane of the coxofemoral joint at the distal end of the neck of the femur. H and E; x 96.

1. Dense white fibrous connective tissue.
2. Loose areolar connective tissue.
3. Lymphatic vessels.

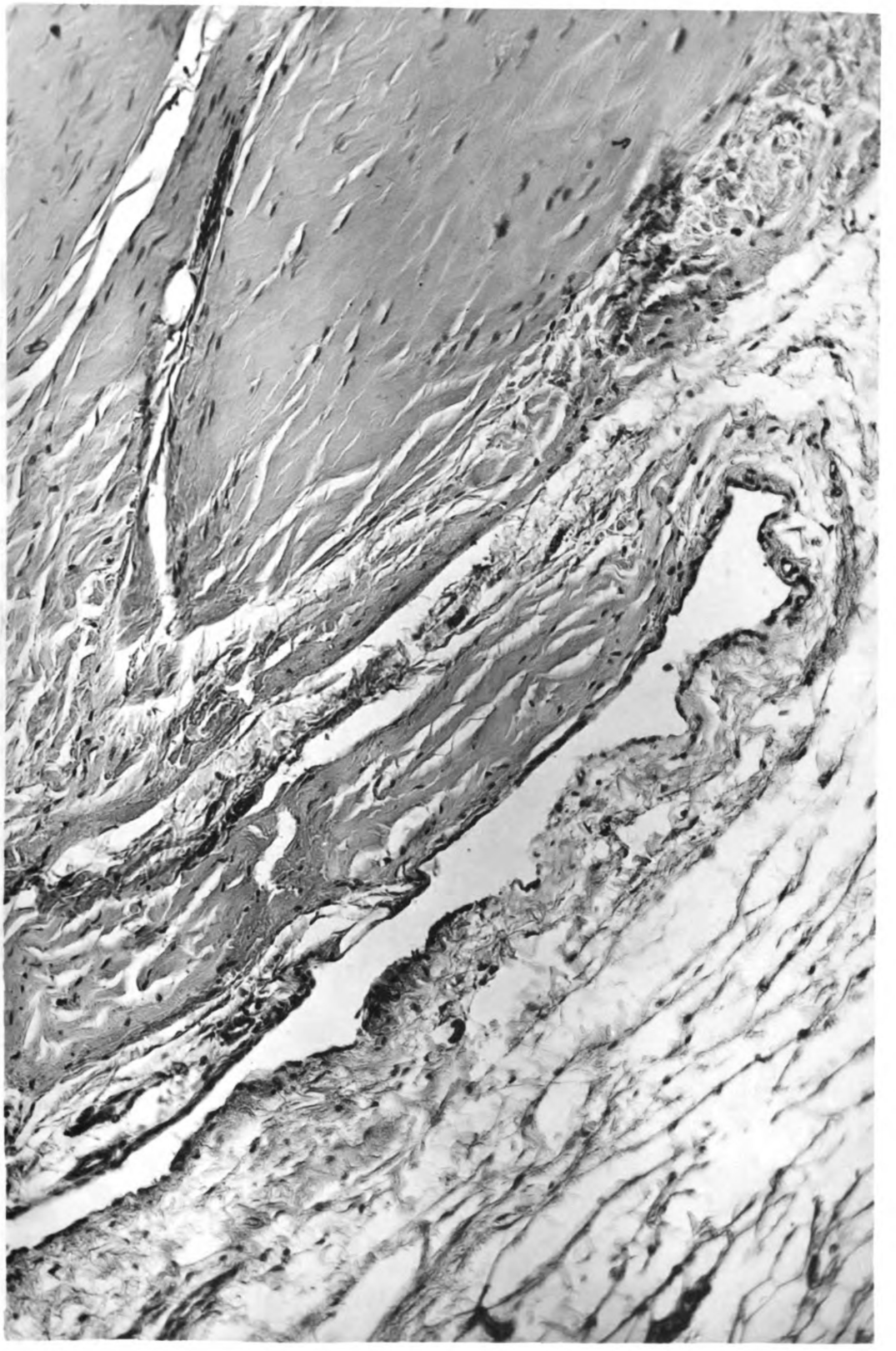


PLATE IV

Section of loose areolar subsynovial connective tissue and synovial membrane of coxofemoral joint. Toluidine blue; x 843.

1. Arteriole.
2. Lymphatic.
3. Endothelial nucleus.
4. Mast cell.
5. Fibroblast.
6. Synovial membrane cell.

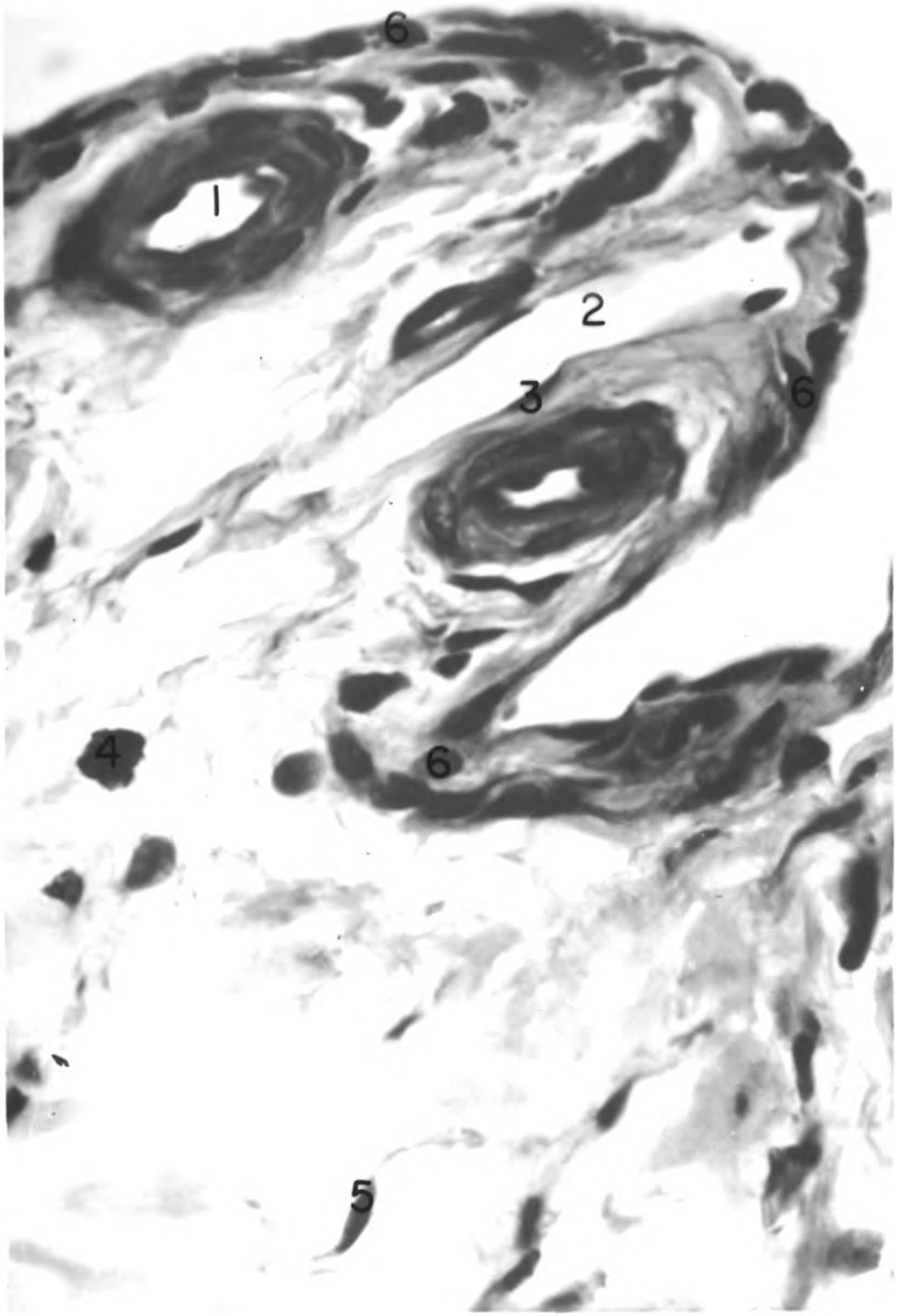

6
1
2
3
6
4
6
5

PLATE V

Transverse section of dense fibrous connective tissue and synovial membrane of the teres ligament. H and E; x 170.

1. Synovial membrane
2. Plicae synoviale.
3. Arterioles.
4. Joint cavity.

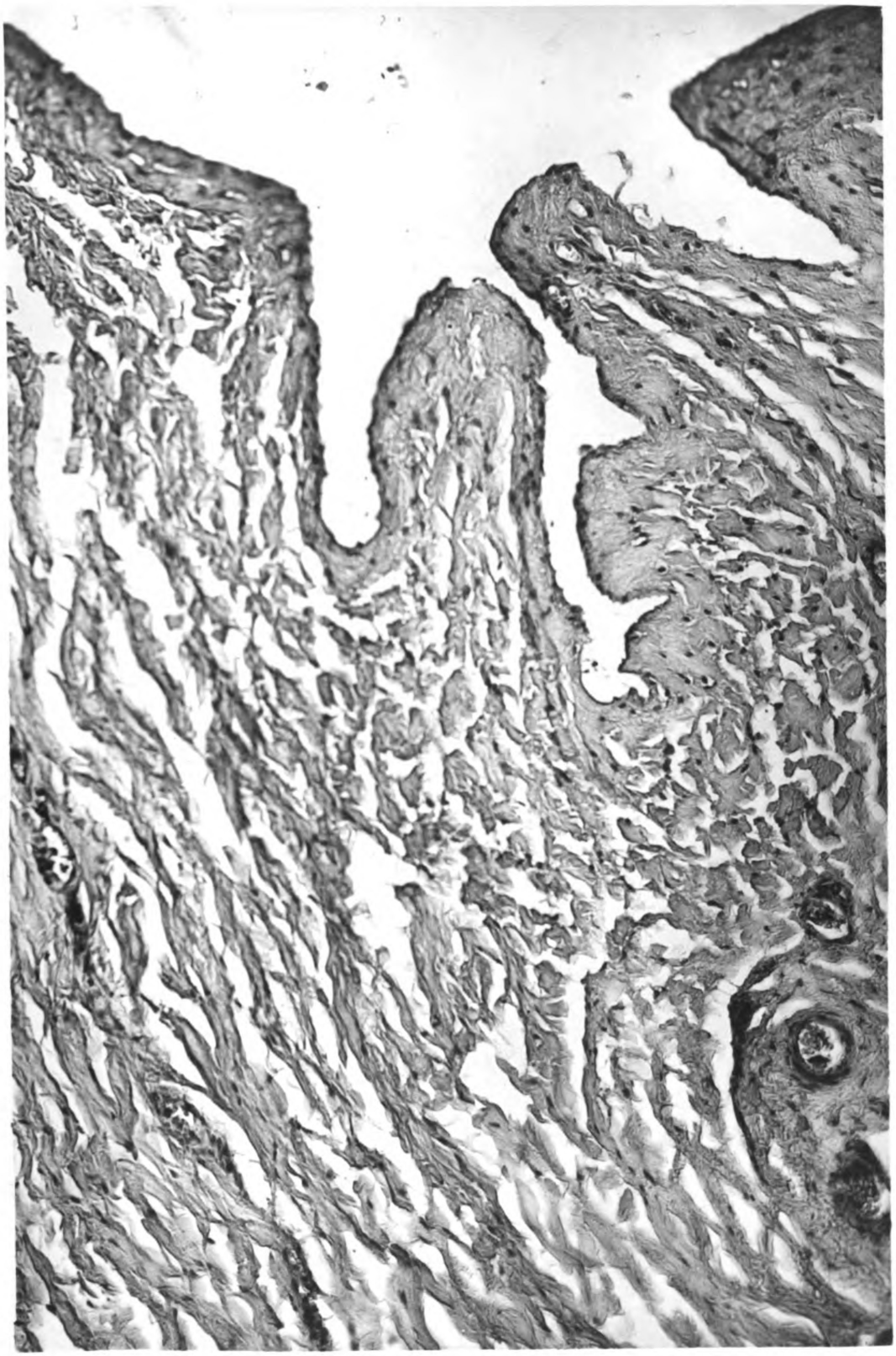


PLATE VI

Section of the loose areolar subsynovial connective tissue and synovial membrane of the coxofemoral joint. Toluidine blue; x 963.

1. Smooth muscle.
2. Lumen of metarteriole.
3. Ovoid synovial membrane cell.
4. Surface showing the absence of synovial membrane cells.

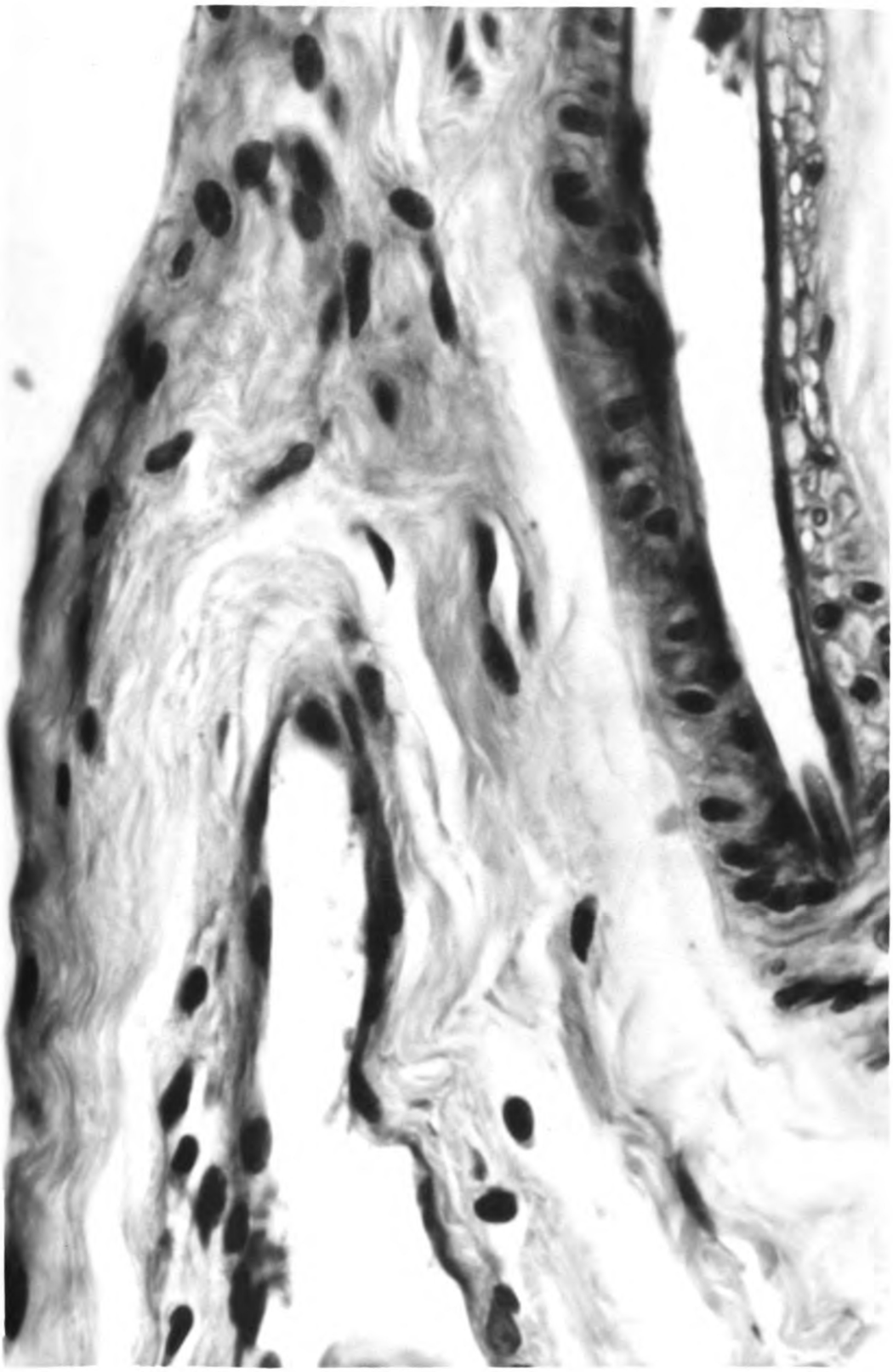


PLATE VII

Transverse section of the dense fibrous type synovial membrane and capsule of the stifle joint on the craniolateral surface of the femur. Periodic Acid-Schiff; x 1120.

1. PAS positive synovial membrane.
2. Nucleus of a synovial membrane cell.
3. Dense fibrous subsynovial tissue.

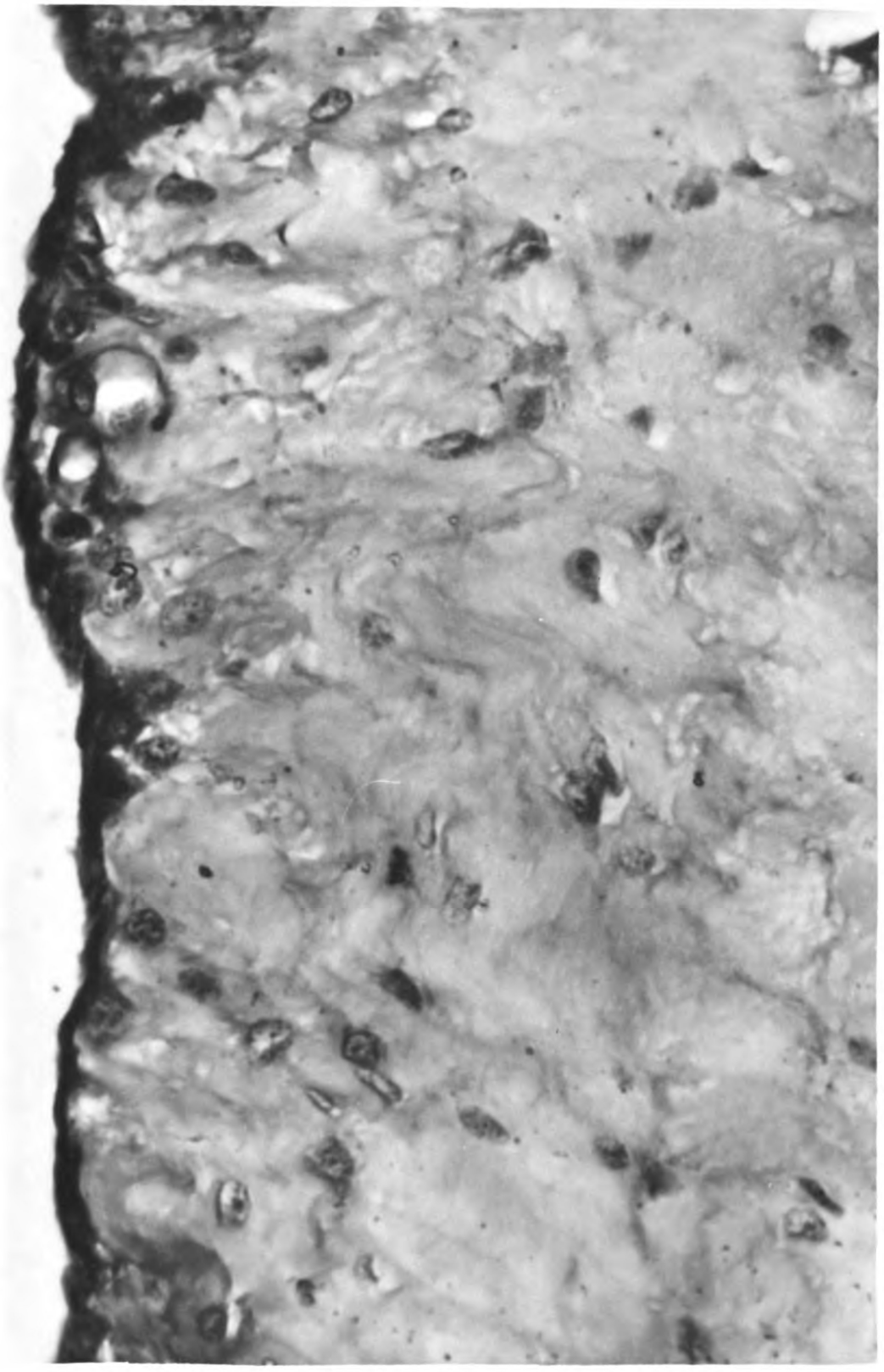


PLATE VIII

Cross section of a nerve in the periphery of the medial side of the stifle joint capsule. Gomeri's reticulum stain; x 225.

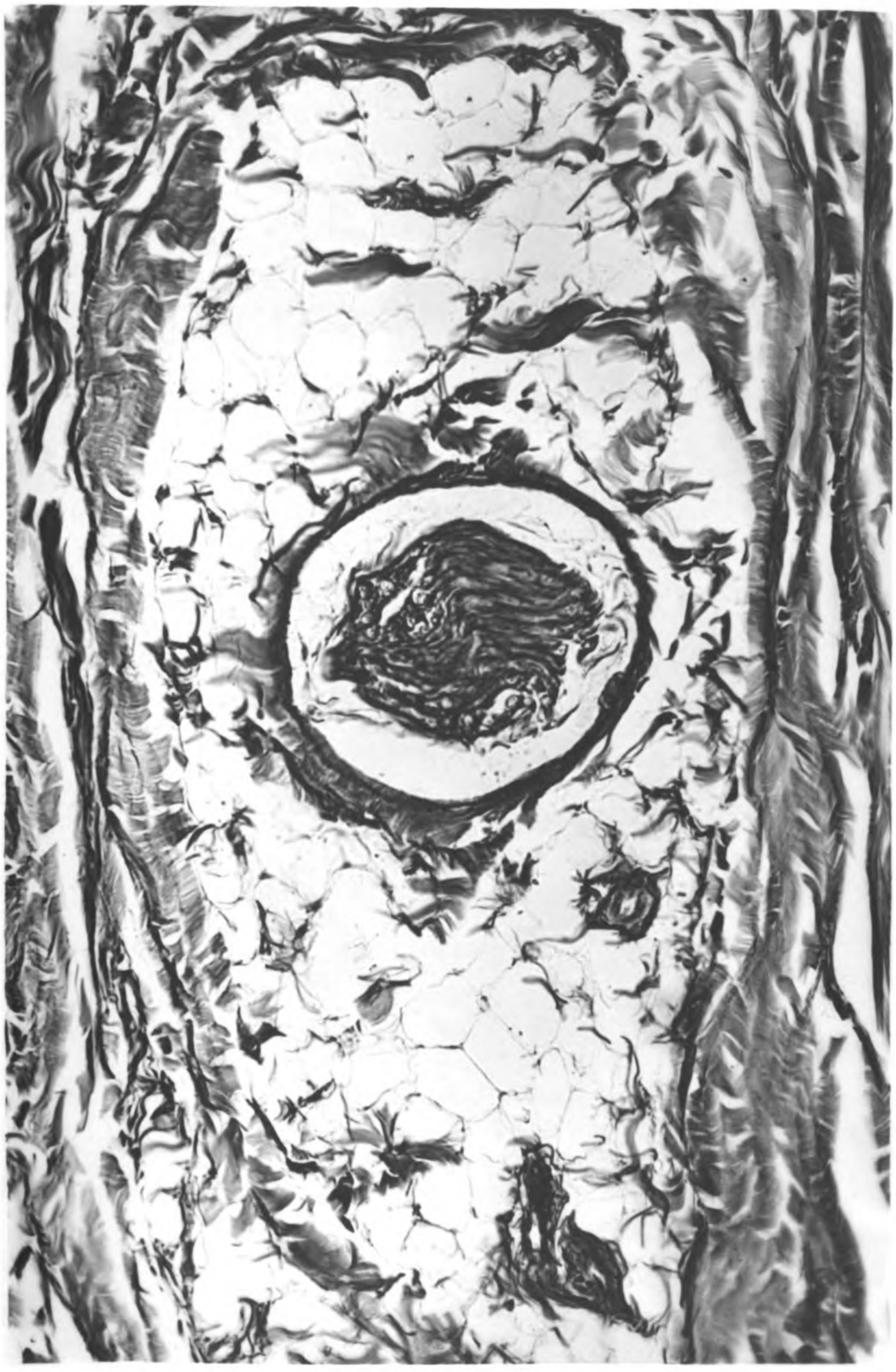


PLATE IX

Transverse section of the parapatellar fibrocartilage denoting the absence of a synovial membrane. H and E; x 483.

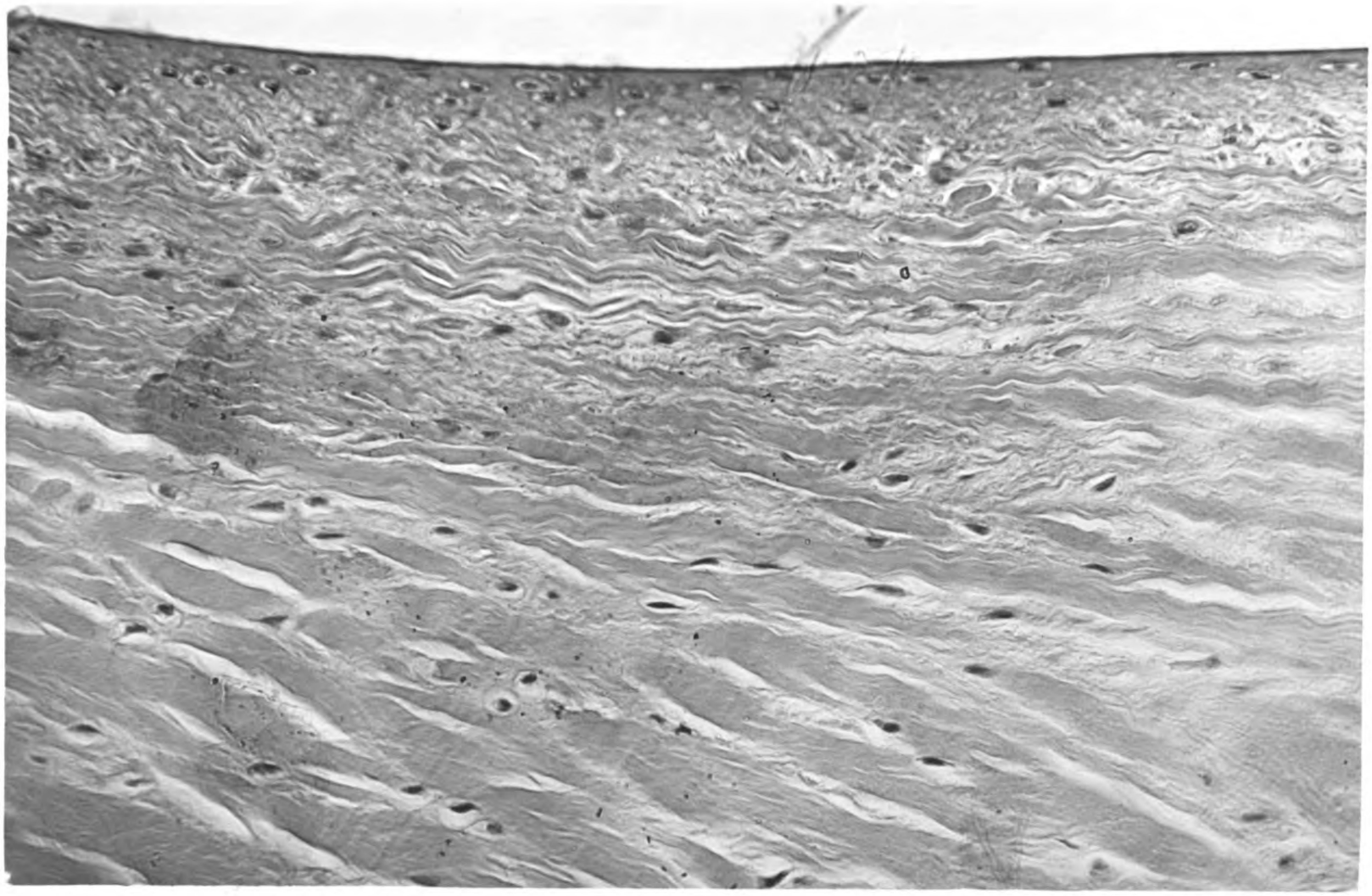


PLATE X

Section of the parapatellar fat pad and the parapatellar fibrocartilage proximal to the patella. H. and E.; x 250.

1. Parapatellar fat pad.
2. Parapatellar fibrocartilage.
3. Synovial membrane.

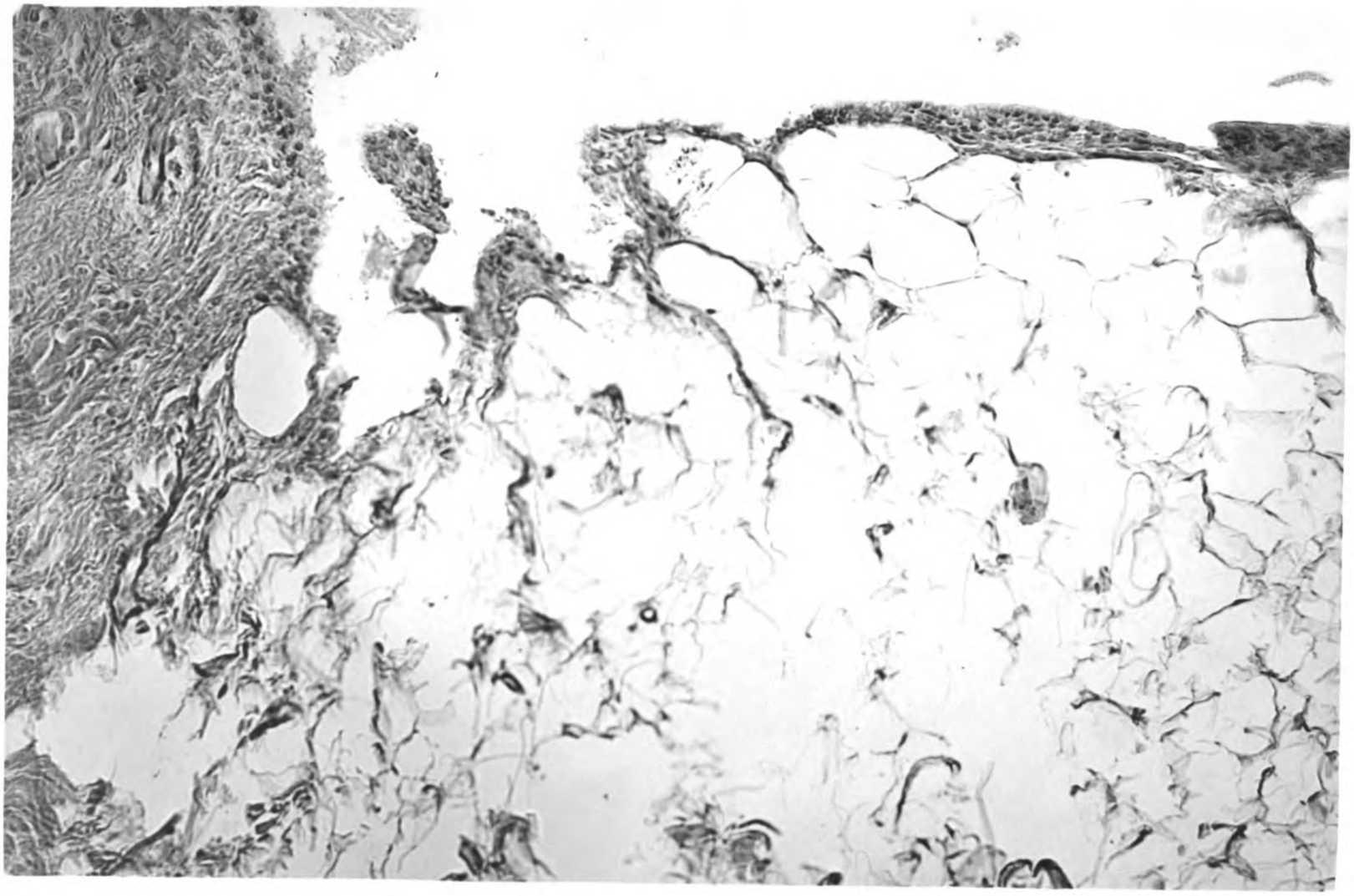


PLATE XI

Longitudinal section of the union of the sheath and tendon of the long digital extensor muscle at its area of attachment. Gomori's reticular stain; x 208.

1. Tendon of the long digital extensor muscle.
2. Sheath of the tendon.
3. Cavity of the long digital extensor muscle.
4. Main chamber of the joint.
5. Loose areolar type synovial membrane.

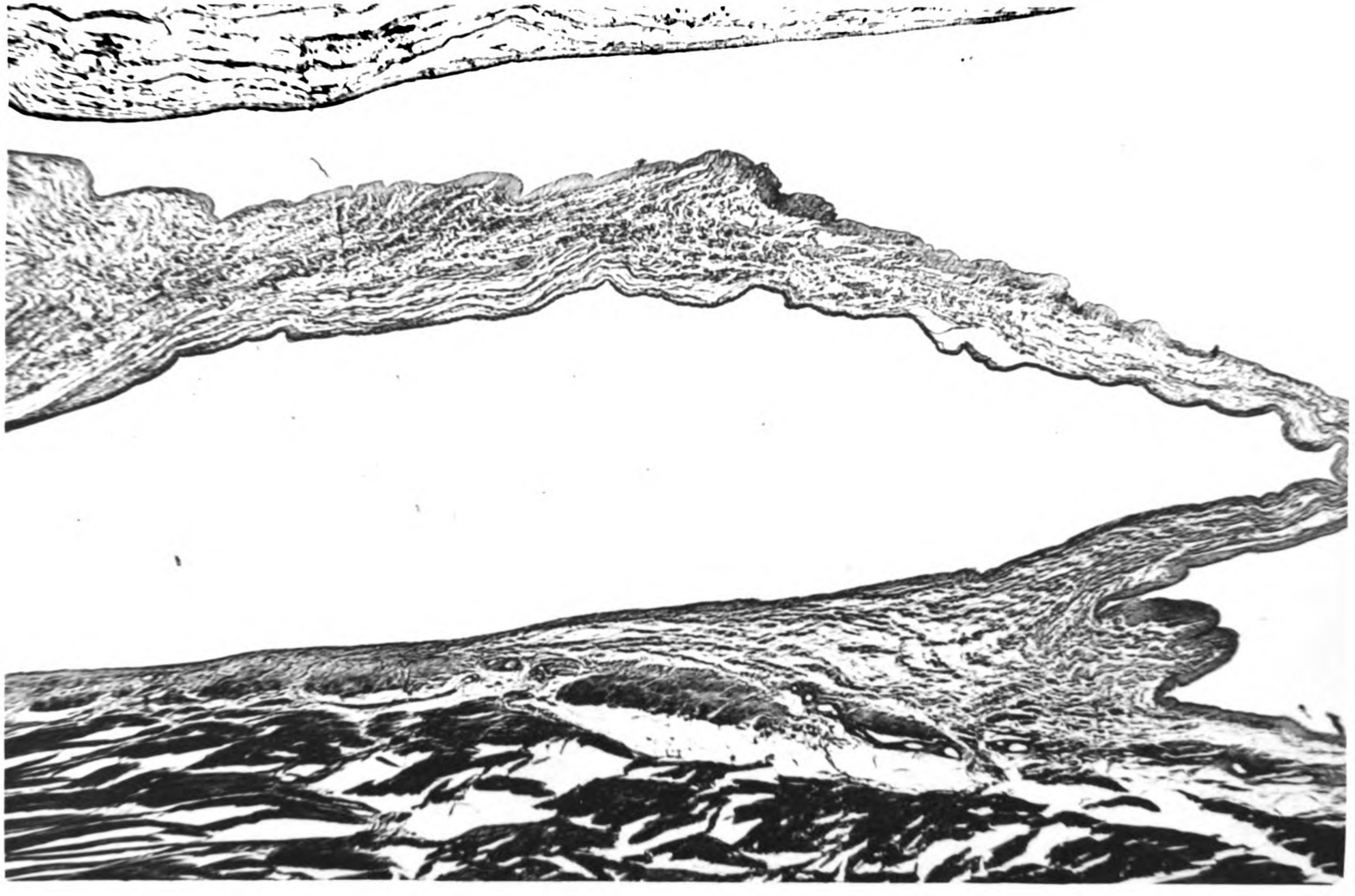


PLATE XII

Section of the area of transition of the loose areolar type synovial membrane and the medial fabella. H. and E. ; x 178

1. Fabellae.

2. Loose areolar type synovial membrane.

S

I

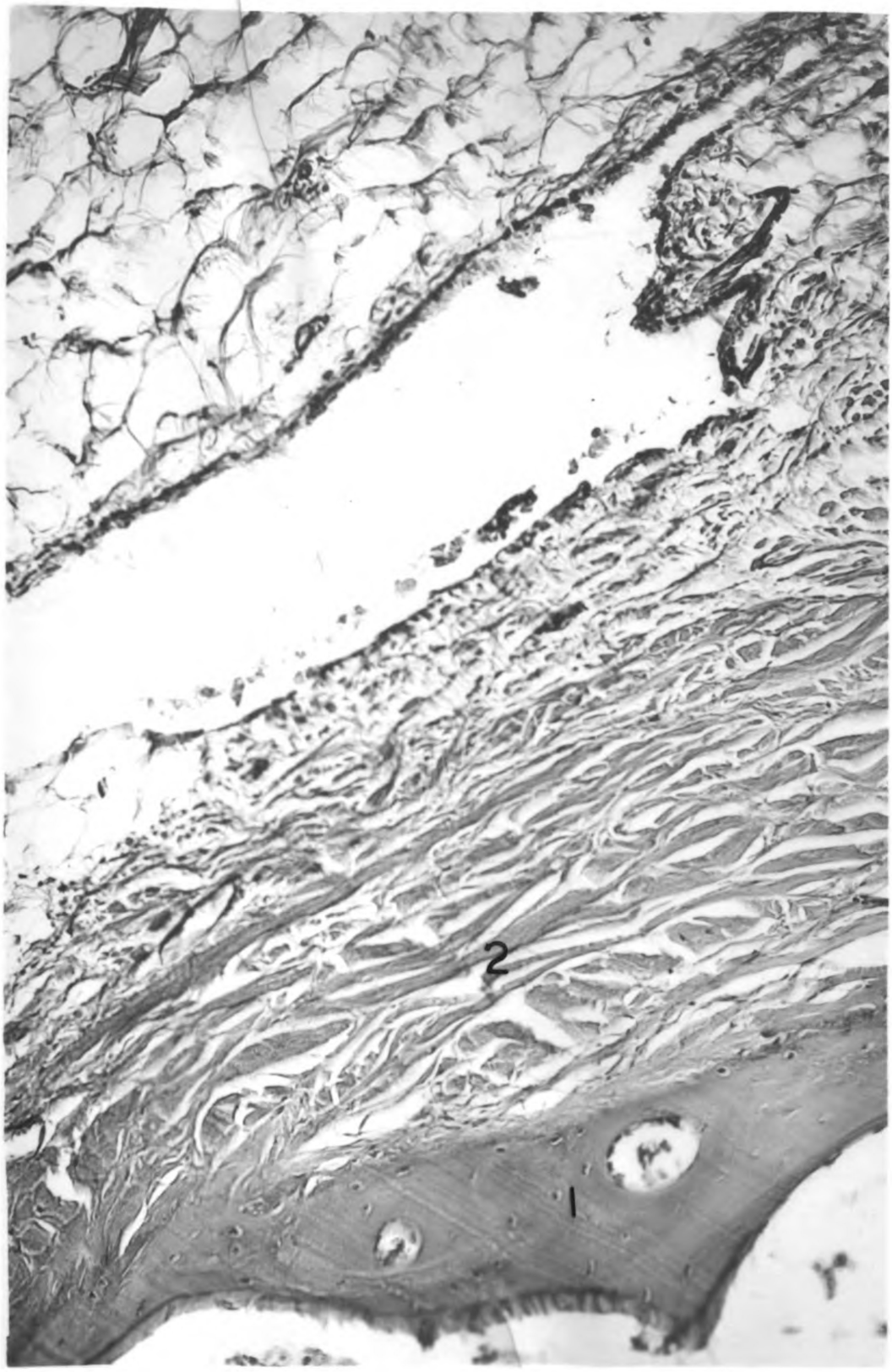

2
1

PLATE XIII

Section of the medial fabella devoid of synovial membrane. H. and E.; x 335

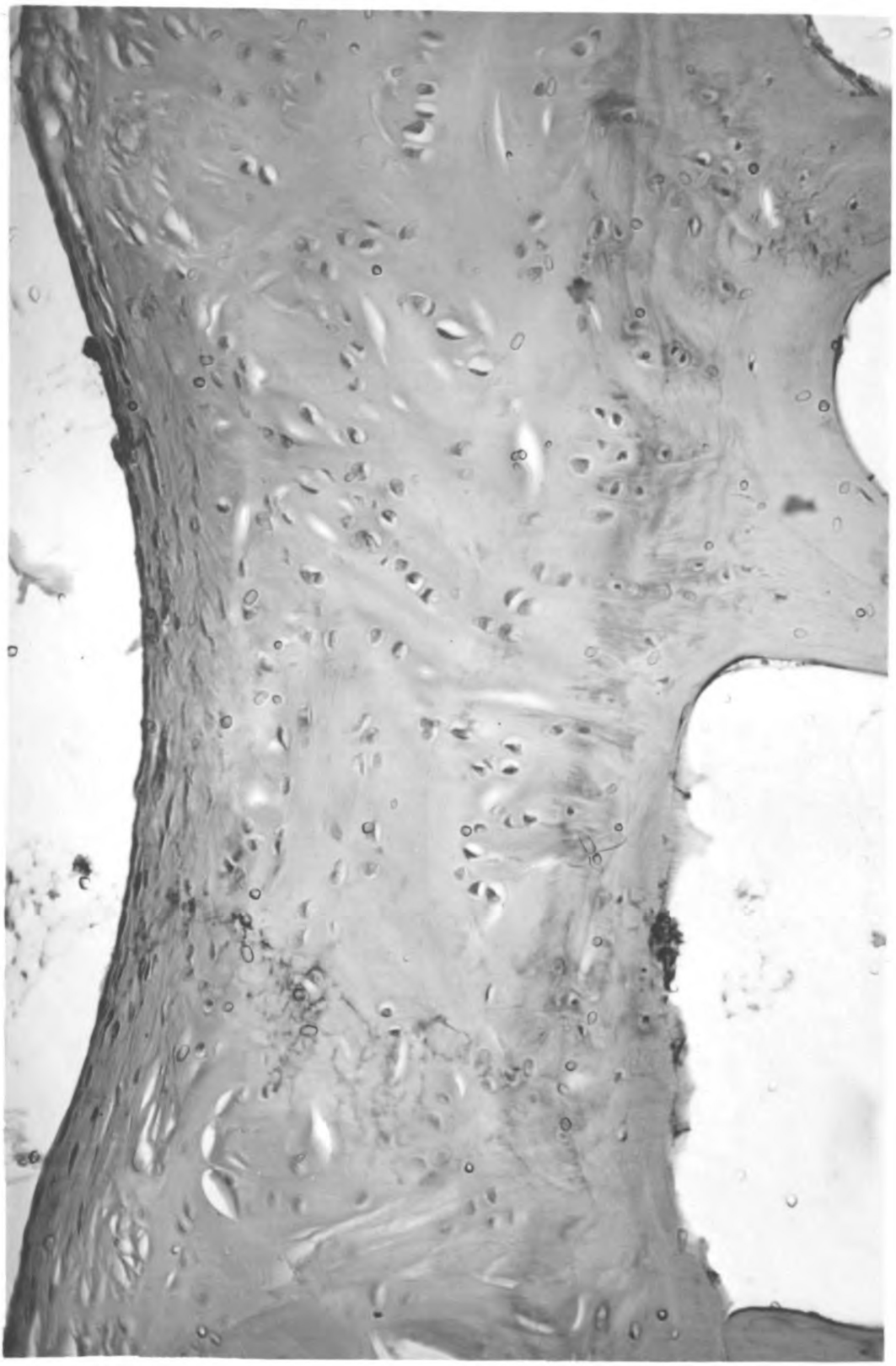


PLATE XIV

Transverse section of the transitional area of parapatellar fibrocartilage and synovial membrane. H. and E.; x 169.

1. Fibrocartilage.

2. Synovial membrane cell.


2
2

PLATE XIV

Transverse section of the transitional area of para-patellar fibrocartilage and synovial membrane. H. and E.; x 169.

1. Fibrocartilage.

2. Synovial membrane cell.

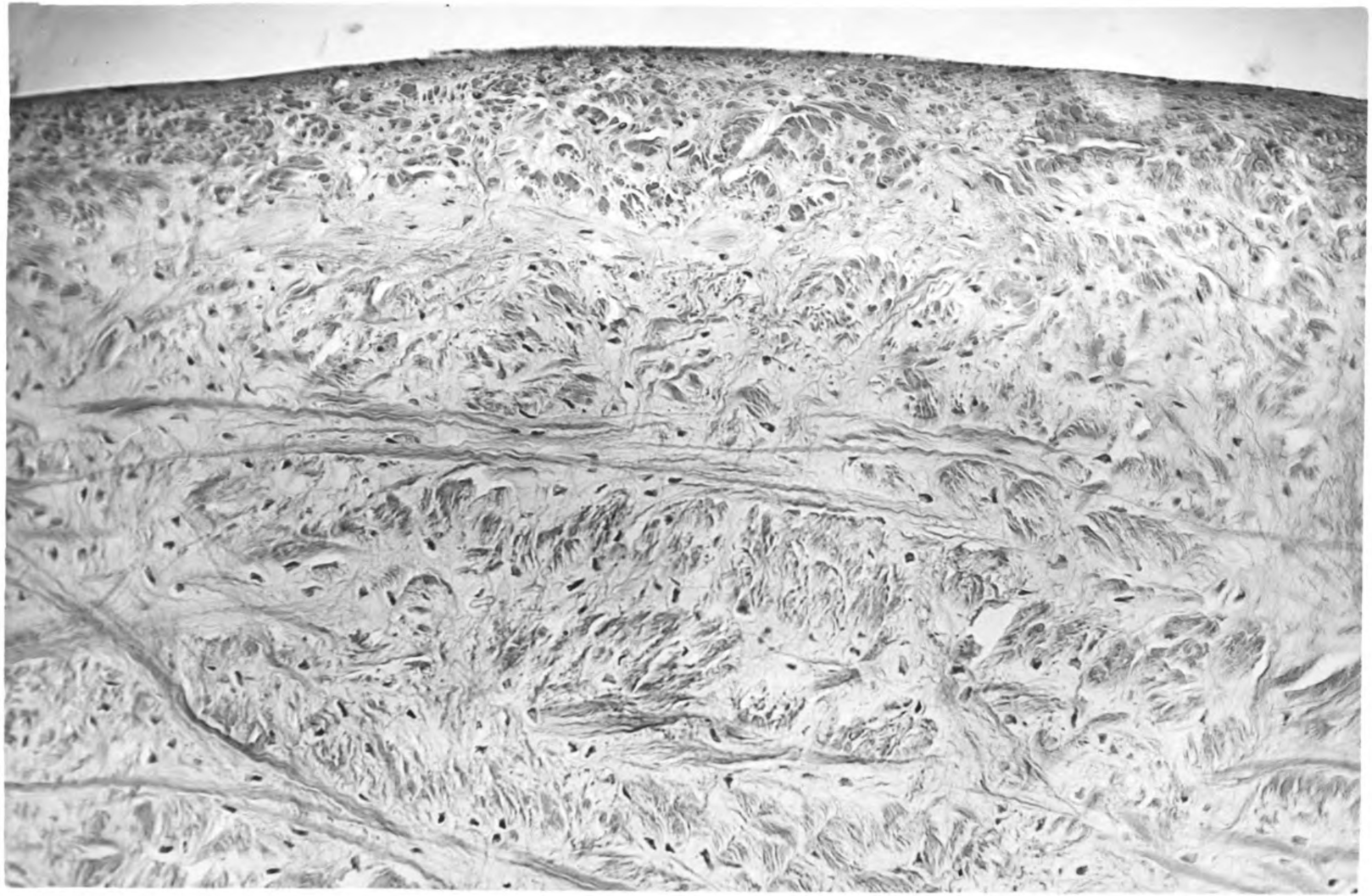


PLATE XV

Section of loose areolar type synovial membrane over the cranio-lateral surface of the stifle joint. Crossman's modification of Mallory's trichrome; x 178.

1. Pedunculated villus.
2. Synovial membrane cells.
3. Adipose tissue.
4. Loose areolar connective tissue.

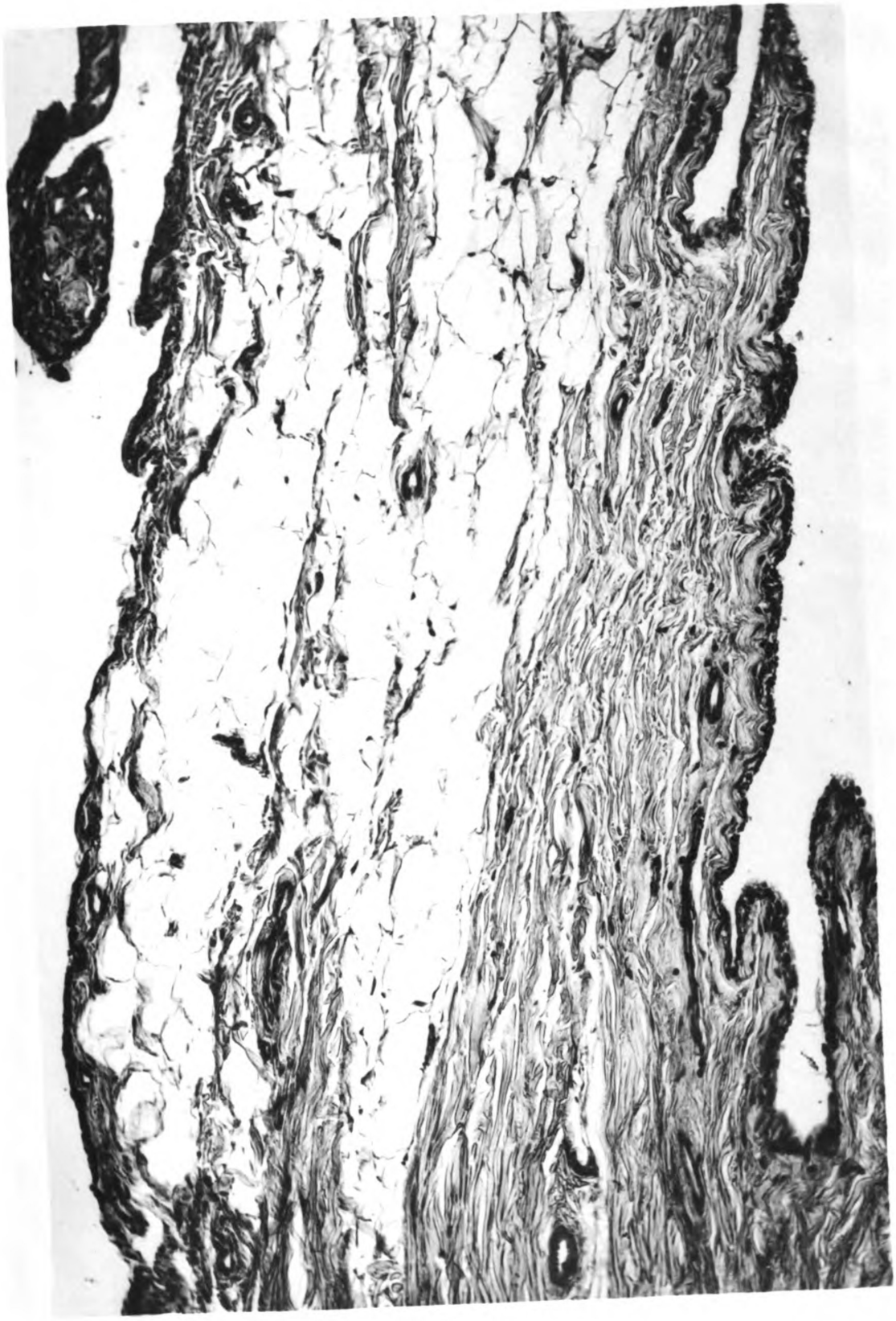


PLATE XVI

Transverse section of loose areolar type synovial membrane of the stifle joint proximal to the patellar surface of the femur. H. and E.; x 840.

1. Pedunculated villus.
2. Capillary with endothelial nucleus.
3. Synovial membrane cell nucleus.

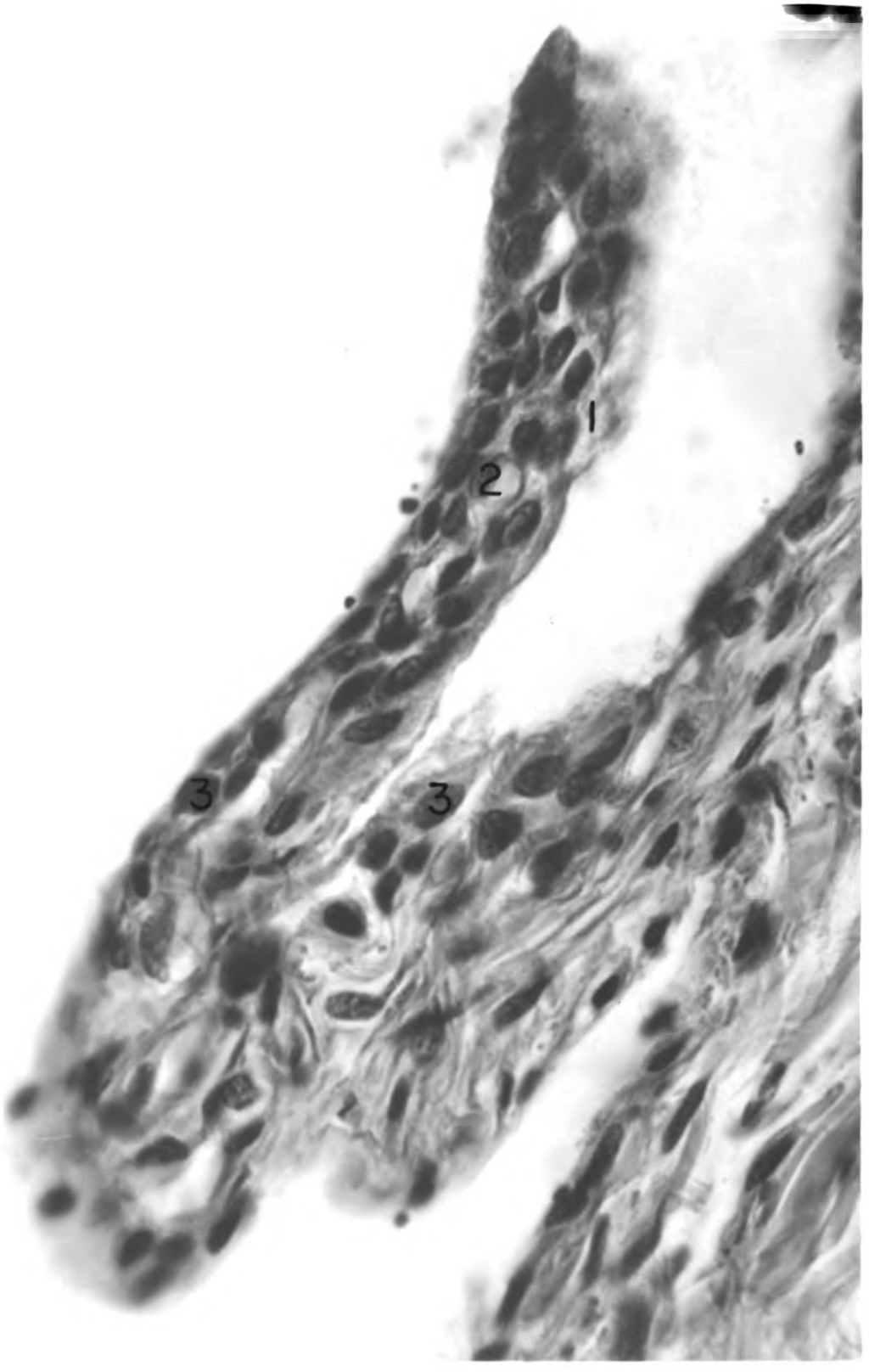

1
2
3
3

PLATE XVI

Transverse section of loose areolar type synovial membrane of the stifle joint proximal to the patellar surface of the femur. H. and E.; x 840.

1. Pedunculated villus.
2. Capillary with endothelial nucleus.
3. Synovial membrane cell nucleus.

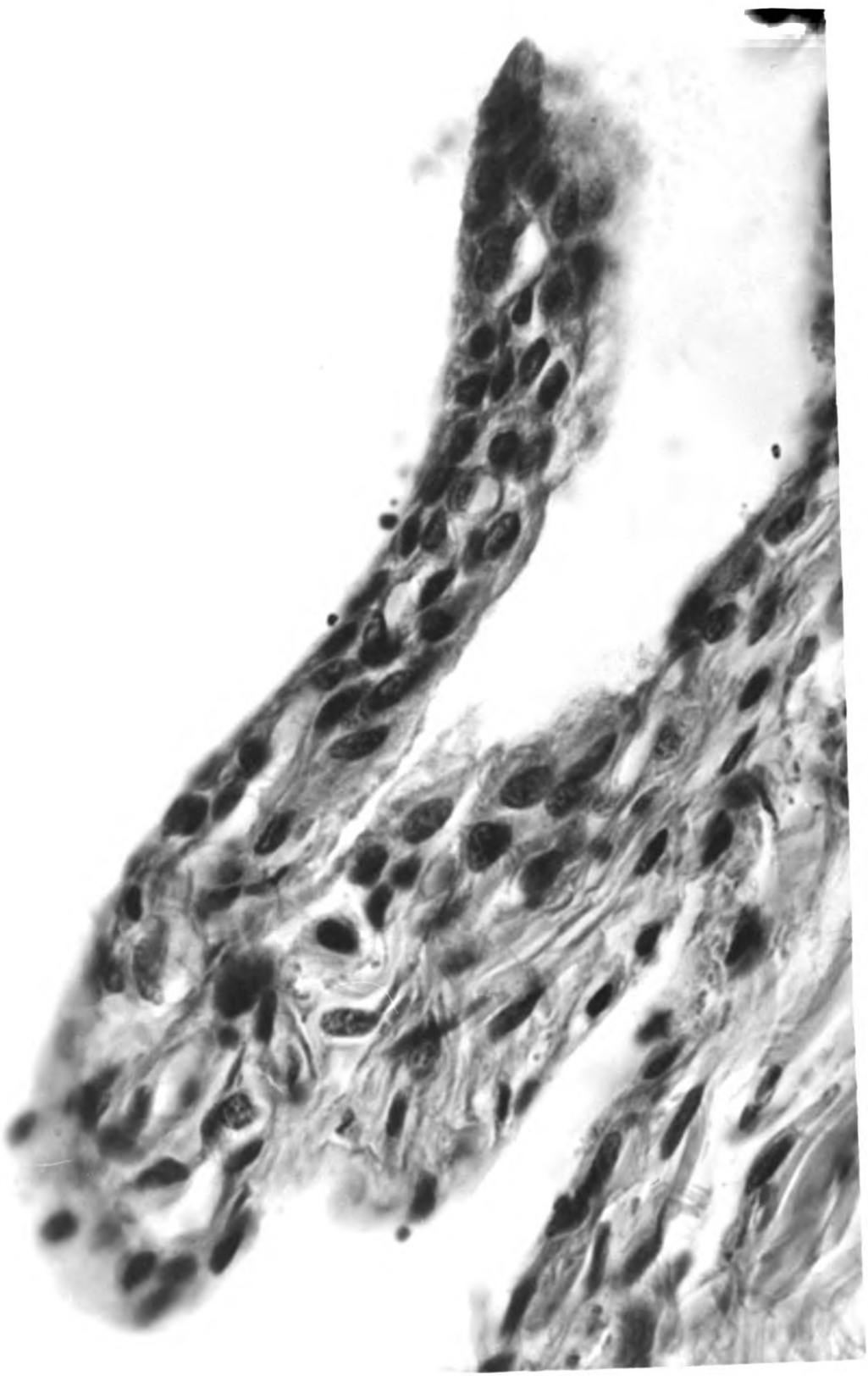


PLATE XVII

Section of loose areolar type synovial membrane of the stifle joint over the cranio-lateral surface of the femur. H. and E.; x 194

1. Secondary villus.
2. Arteriole.
3. Adipose tissue.
4. Loose areolar connective tissue.

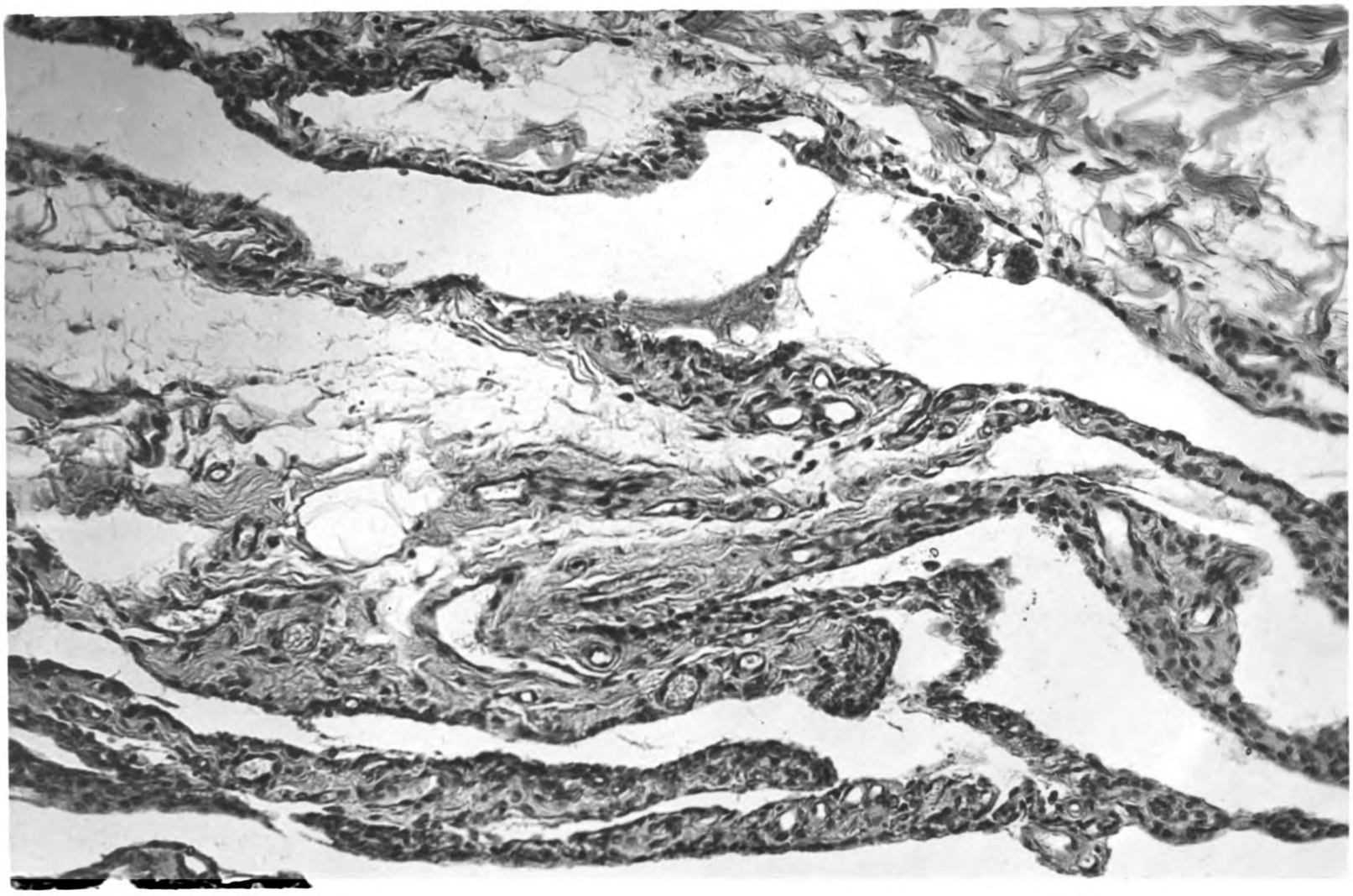


PLATE XVIII

Transverse section of prepatellar fat pad of the stifle joint. Crossman's modification of Mallory's trichrome; x 186

1. Prepatellar fat pad.
2. Synovial membrane.
3. Villus extending from the prepatellar fat pad.

PLATE XIX

Section of false "cell-rich" area of the synovial membrane of the coxofemoral joint. Toluidine blue; x 208.

PLATE XX

Section of loose areolar type synovial membrane of coxofemoral joint. Periodic Acid-Schiff; x 712.

1. PAS positive synovial membrane.