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ON THE FINER STRUCTURE AND BLOOD SUPPLY OF THE SYNOVIAL MEMBRANE, WITH SPECIAL REGARD TO ITS PHYSIOLOGICAL CIRCULATION

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The blood supply of joints represents an old field of investigation in medical literature. Well-known is the richness of the blood supply in the synovial membrane, explaining the frequent participation of this structure in pathological processes. It was the latter fact that directed the attention of authors to the necessity of studying the physiological and pathological circulation in the joint. Despite detailed studies by many of them, knowledge of this topic is still deficient.

It is not intended to give a comprehensive review of the data accumulated by the investigators of this question ; relying on my preparations and the results of my experimental work I much rather wish to fill some of the deficiences of the problem of the finer structure and the blood supply of the synovial membrane with new details, which not only differ from those already published, but may be conducive to the clarification of the morphology of the articular capsule's vascularization and of the physiological conditions governing articular absorption.

In a previous paper [10] we have pointed out, in agreement with others [3], that the synovial membrane has a selective excretory activity, since parenterally administered penicillin and streptomycin attain various levels, very low in comparison with the blood level, in the synovial fluid of the knee- and elbow-joints of dogs. The successful demonstration of the presence of this barrier was the primary reason for working out in detail the finer circulation and the histology of the synovial capsule.

The examinations fall into three parts. In part A, the completely differentiated articular blood supply has been examined in adult mammals ; part B deals with the ontogenesis of articular blood vessels ; part C presents an experimental study of the physiological conditions of articular absorption.

Methods

The large (knee-, elbow-, shoulder-, and hip-) joints and the small (carpal-, ankle-, and digital-) joints of the extremities of 47 animals (39 dogs and 8 cats) have been subjected to examination. Supravital preparations have been made after injecting warm, diluted India-ink through the aorta of adult animals, and through the umbilical vein of foetuses. Part of the preparations has been clarified according to Spalteholz and studied in its entire mass ;

the rest has been examined in the form of thick (20 to 50 μ) sections, or thin ones stained with haematoxylin-eosin. In some cases, the injected individual layers of the synovial membrane have been separated and their blood vessels so prepared. In addition, the exact blood supply was studied in isolated preparations of villi and folds. Finally, the morphological conditions of articular absorption have been closely examined, within 17 hours after intra-articular injection of Azocarmine G, by observing how the dye, absorbed into the vessels, had settled.

A

Although it is known from the studies of *Gitis* [8] that the synovial membrane is closely connected with the epiphyseal blood vessels and that as regards blood circulation the meta-diaphysis represents a separate unit, the present paper is limited to deal only with the blood supply of the layers of the articular membrane. Several authors emphasize [4, 8,12] that the number of vessels differs in the different parts of the synovial membrane. Particularly *Kositsin* [12] asserts that the villi are exceedingly rich in blood vessels, and on this account holds them responsible for certain metabolic processes.

On the basis of my preparations it may be stated that, at variance with the data in the literature, as regards its blood supply, the synovial membrane consists of four layers (Fig. 1). Let us examine in the following the vascularization of each of them.

1. Stratum villorum et plicarum

This is the innermost layer of the articular membrane, containing the vascular plexuses of the villi and folds, i. e. the plexuses that do, and those that do not give rise to villi (Fig. 2). *Möllendorf* [16] had taken the typical villi to be avascular and even more recent researchers state that the villi are often devoid of vessels. According to my own studies there are no avascular villi to be encountered.

It may be seen in the sections that the afferent arterioles forming the plexus of the villi pervade the stroma singly or dividing into several branches (afferent vessels), the division arising at the base of the villi. Some afferent vessels form a fine glomerule (synovial glomerule) with an ampullary dilatation at the apex. The confluent afferent arterioles then leave the stroma as a more thick efferent vein, singly or dividing into several branches (efferent vessels) (Fig. 3). But as a rule the said arterioles do not penetrate up to the tip of the villi ; instead we find a synovial cellular process of several layers ; these avascular cellular processes might have been the structures misleading other authors.

According to Kositsin's findings [12], the afferent arterioles and efferent veins of the villi in the knee joints consist of from 2 to 4 trunks. My preparations, however, show that a considerable part of the villi, just in the knee joint, contain only one vascular trunk each. It is exactly this type of villi to which a primary significance can be attributed in the process of absorption, which I shall discuss below, in part C (Fig. 17). Kositsin, too, found that vessels in the villi communicate with one another by frequent anastomoses.

According to my findings, the said arterioles of the villi do not give off branches, and accordingly they do not penetrate among the synovial cells covering the surface of the villi, but pass along their cellular row. The synovial cellular layer is avascular (Fig. 5).

No vessels can be demonstrated in the intercellular spaces among the synovial cells, but fine connective tissue fibres can be seen in them. In some areas even the latter are missing, the cells joining one another quite closely. These findings agree with the data of *Efskind* [7], who denies the existence of stomata between the cells and according to whom the synovial cells form a continuous membrane.

Unlike in the intestinal villi, no central lymph vessels can be seen in the villi of the synovial membrane, nor is any elastic fibrous system demonstrable in them [4].

As regards morphological classification, the villi may be simple, dividing or compound (Fig. 6).

Some afferent arterioles do not form glomerules, but extensive networks similar to them. These plexuses not forming villi correspond to the vascular system of the articular folds [8] (Fig. 7). The proportion of the two types of plexuses (villi and folds) is 1 to 4. Two types of folds can be distinguished. The less frequent adipose type occuring on fatty tissue and the areolar type on connective tissue. As regards vascularization, there is no difference detectable between them. The folds are situated islet-like. From the preparations it can be ascertained that villi are to be encountered in large numbers chiefly in the well protected areas of the synovial membrane, in the articular recesses and in the nests between the large, fatty folds. There are, however, areas of the synovial membrane which are completely devoid of folds or villi.

Similar to the villi, the above mentioned folds also contain a membrane of fine connective tissue ; this stroma of folds contains the likewise very rich and extensive vascular network.

It is interesting to note that my preparations show the number of villi and folds to be comparatively small in large joints, whereas in the small ones the synovial membrane is very rich in these elements (Fig. 7). The relation of villi and folds varies from joint to joint. My experimental studies made in collaboration with *Kelentei* [10] have likewise confirmed that the individual joints secrete identical substances in different manners. In addition, it has been observed that the viscosity of synovial fluid differs in the individual joints of the extremities.

2. Stratum capillare

My preparations reveal that underneath the above discussed layer and embedded amongst fine, non-meshed, parallel-placed, collagenous bundles

there is an uninterrupted, coherent *capillary* layer possessing an elastic lamina [4]. Despite the fact that this layer constitutes both morphologically and functionally an independent system entirely separate from the blood vessels in the stratum of villi and folds, it is nowhere discussed as a separate layer, but the synovial stratum, which underlies it, is considered as the second layer (Fig. 1).

On closer examination even this layer proves to be a double one, the deeper-lying, moderately fine portion containing the system of precapillary arteries and postcapillary veins, while the more superficially placed, finer portion the delicate capillary network formed by these vessels. My studies show the bulk of this network to consist of veins. This venous plexus has an important part to play in absorption, which I shall discuss in part C (synovial plexus). In Fig. 8 it is easily discernible how the venous network continues into postcapillary veins. Neither was it difficult to differentiate in the preparations the closely intermeshed, sinuous system of arterial capillaries from the characteristic pentagonal and rounded-off oblong system of the veins.

Comparatively few of the synovial cells of this layer can be encountered amongst the fine, parallel lying, collagenous fibres, the arrangement of which differs sharply from the irregular, interlaced, collagenous system of the subsynovial layer (Fig. 11). In contrast with the subsynovial layer, in the capillary stratum lymph vessels are exceedingly scanty [5].

3. *Stratum subsynoviale*

According to my examinations, the third layer, the one underlying the stratum fibrosum, consists of loose connective tissue interwoven with fatty tissue and contains the basal arterial and venous systems.

The arterioles originating from the aforementioned basal arteries either participate directly in the formation of villi, or become part of the vascular plexuses not forming villi, and of the fine pre- and postcapillary and capillary system of the second stratum. The basal veins, on the other hand, drain the veins of the villi and folds. The large veins unite the efferent veins of from 3 to 5 villi and from thickset trunks ; at the same time, they drain the venous blood of the second layer from the fine post-capillaries (Fig. 1).

From the basal vessels the said arch-like veins detach themselves on the border of the stratum capillare. In this subsynovial layer there is a profuse lymphatic system, with two morphologically and functionally separate strata, a superficial and a deep-lying one. According to *Efskind* [7], the former is the site of absorption, the latter that of transmission. In its meshy and irregular spaces the synovial connective tissue contains numerous phagocytes and reticuloendothelial elements.

4. *Stratum fibrosum*

This is the fibrous layer containing the large articular vessels, which thread their way obliquely through the layer and unite in a vortex, similarly to the vorticose veins (Fig. 9). In some places the collagenous fibres form spaces through which many vessels pass directly into the synovial membrane (Fig. 9).

The above discussed layers of the blood vessels of the synovial membrane can readily be distinguished in my injected preparations (Fig. 13).

The classification of the synovial membrane according to types is known from the literature [11]. Since the individual types are characteristic of one kind of joint and as, according to my findings, vascularization differs in the different types, it is obvious that the individual joints should differ as to physiologic conditions and function. It is now proposed to resort to a brief characterization of the individual types of membrane.

a) The areolar type of membrane. This can be found in freely moving joints. It contains abundant connective tissue loose in texture, and is rich in both blood and lymph vessels, possessing a vast absorptive surface. Of this, proof is afforded in my experimental observations (see part C). To this type belong first of all the villi and the folds (Fig. 10).

b) The adipose type of membrane. This in encountered primarily in the large joints. It is characterized by a synovial cellular layer resting on fat pads and by the absence of the subsynovial layer. The villi in it present are less in number, but abundant in cells and rich in cellular processes. Thus it is devoid of a subsynovial vascular system, but has a profuse capillary one. This is proved by the fact that, according to my experimental studies, it plays the primary part in absorption (Fig. 11).

c) The fibrous type of membrane. This is pre-eminently met with on intra-articular structures and is characterized by the absence of the first stratum. In other words, this type of membrane represents those surfaces of the synovial membrane which are free from villi and folds. The other layers of this type are also of but poor vascularization. The absorptive surface is not significant.

The distribution of the various types of membrane differs from joint to joint.

The mucous bursae communicate freely with the joint cavity. They are really distentions of the synovial membrane. Their lining consists of a synovial layer, and the vascularization of their wall is identical with that of the synovial membrane. As stated by me in 1950 [14], they may be regarded, both histologically and functionally, as collateral cavities of the joint cavities.

Finally, the corpus adiposum genus has been subjected to a study. It has been found to contain a coherent, uniform, venous capillary network arranged in two layers, corresponding to the stratum capillare. This network is drained by 2 or 3 venous trunks. Most of the capillaries are veins. These findings have

been adequately confirmed by my absorption experiments (see part C) (Fig. 12).

B

In the following I propose to deal with the ontogenesis of articular vascularization. It is known that the synovial villi develop in intrauterin life by way of proliferation [13]. The earliest preformed synovial membranes are devoid of villi and folds. In man, only a few villi are present at birth [1]. Differentiation of the synovial membrane is a comparatively slow process [6].

It has been demonstrated in the course of my studies that at the middle of intrauterin life in mammals there are present only anlagen of villi, in which it is not possible to distinguish between afferent and efferent venous trunks; vessels in the embryonic (capillary) stage form an undifferentiated, diffuse convolution and there is no synovial glomerule observable. The convolution comprises only a few vessels, which are uniform in calibre (Fig. 14).

Differentiation of blood vessels in the villi and folds begins in the second half of intrauterin life; it becomes well-marked and is completed during extrauterin life. In the newborn, the afferent and efferent vascular system are already distinguishable, but only in some places will they be typical and vessels in the synovial membrane are rather poor (Fig. 15). These findings have been confirmed by the investigations of *Gitis* [8], who by means of the transillumination method has demonstrated that in 1 to 4 years old children the arteries of the capsule and the synovial membrane are but poorly developed. Marked development of the vessels from the arterial network of the capsule becomes noticeable at the age of 5 years. In the individual joints, according to their nature, the number of villi grows with age. My studies show that the development of articular folds is similar to that of villi.

It is worth mentioning that in the course of investigations made in collaboration with *Kelentei* [10], we have found no synovial barrier in newborn dogs, in which there are as yet no villi. The barrier evolves in the cours of extrauterine life simultaneously with the differentiation of the villi and folds.

C

Finally, experimental investigations have been conducted for studying the morphology of the process of absorption in the joint under physiological conditions.

Within 17 hours following intraarticular injection of Azocarmine-G solution into the knee joint of the dog, the different surfaces of the synovial membrane show different absorptive conditions. Staining is most marked on the surface of the areolar membrane containing an abundance of villi and folds and located in the corpus adiposum genus, the fossa intercondylica, and the recesses of the knee joint. It is equally conspicuous in the marginal membrane underneath and

over the patella. The stain is to be found in the second capillary layer (plexus synovialis) and in the villi (Figs. 16 and 17). Accordingly, the main absorptive surface for the mentioned diffusible dye are the layer of villi and folds in the areolar and adipose membranes and the capillary network.

The delicate venous system of this network is collected by postcapillary veins of greater thickness (venae colligentes), well discernible in Fig. 16. This layer alone can constitute the absorptive surface for the dye used, since there are no lymph vessels in the villi, and the fat pads contain but few of them [5]. These findings confirm to the clinical appearance of tuberculous processes in the joints, as they show a special tendency to localization in the said areas of the knee joint.

Another observation is that the synovial cellular layer takes no part in absorption, there being no vessels in it.

In the knee joint there was no staining visible on some of the surfaces lacking a synovial membrane. These surfaces have, accordingly, no share in the absorption process.

Discussion

In a previous paper based upon experimental investigations made in collaboration with *Kelentei* [10], selective excretion by the synovial membrane was insisted on, it having been demonstrated that excretion of certain antibiotics differed in the synovia of the knee- and the elbow-joint. The present investigations tend to show that the distribution of the villi varies from joint to joint and that different types of synovial membrane, characteristic of the individual joints, participate in different ways in the process of articular absorption. According to this, the morphological basis of the differences in the functioning of the various joints should probably be sought in the structural differences of the synovial membrane.

The observations also reveal that the development of the synovial barrier runs parallel with the differentiation of the villi and folds in the synovial membrane. In newborn dogs, in which the synovial blood vessels are still poor and undifferentiated and only part of the villi and folds have developed, the membrane of the knee joint does not yet show signs of selective excretion.

Studies concerned with the excretion of antibiotics into the joint, and with the therapy of experimental arthritis [2], are in progress. Besides, in collaboration with *Bölönyi* investigations are being conducted into the phylogenesis of articular blood supply.

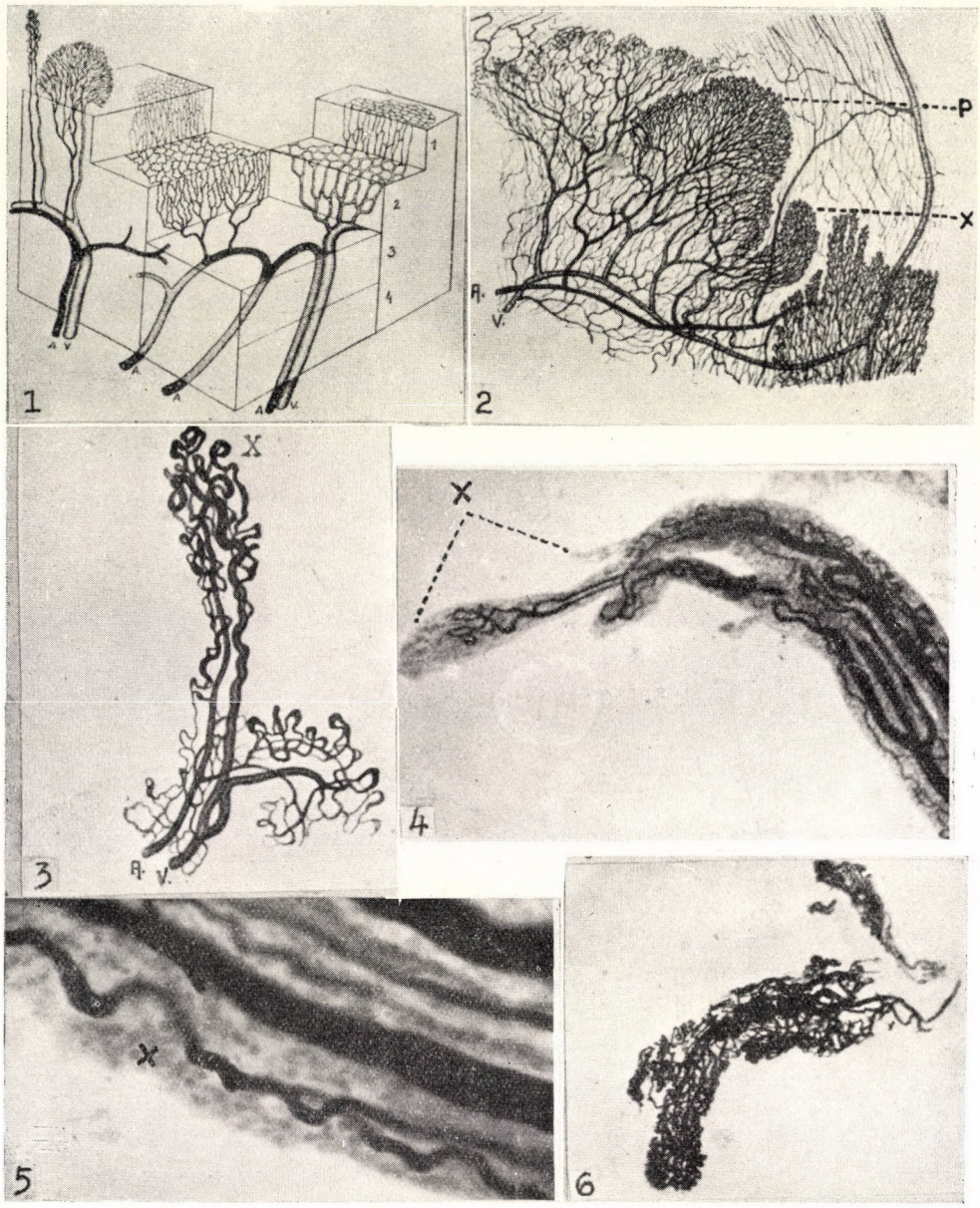

Fig. 1. Layers of the synovial membrane. (Roughly outlined; India-ink injection) 1. Stratum villorum et plicarum 2. Stratum capillare 3. Stratum subsynoviale 4. Stratum fibrosum A = artery; V = vein (elbow joint of dog). *Fig. 2.* Vascular plexuses that do and do not form villi. (Roughly outlined; India-ink injection.) A = artery; V = vein; X = villus; P = fold) (Knee joint of dog). *Fig. 3.* Blood supply of villi, in rough outline (India-ink injection; ×50). A = afferent vessel V = efferent vessel X = synovial glomerule. *Fig. 4.* Avascular cellular process. (Isolated villus; India-ink injection) X = cellular process of villi. (Elbow joint of dog; haematoxylin-eosin staining). *Fig. 5.* Avascular synovial cellular layer. (Isolated villus; India-ink injection) (Elbow joint of dog; haematoxylin-eosin staining). X = synovial cellular layer. *Fig. 6.* Compound diverging synovial villus (low power).

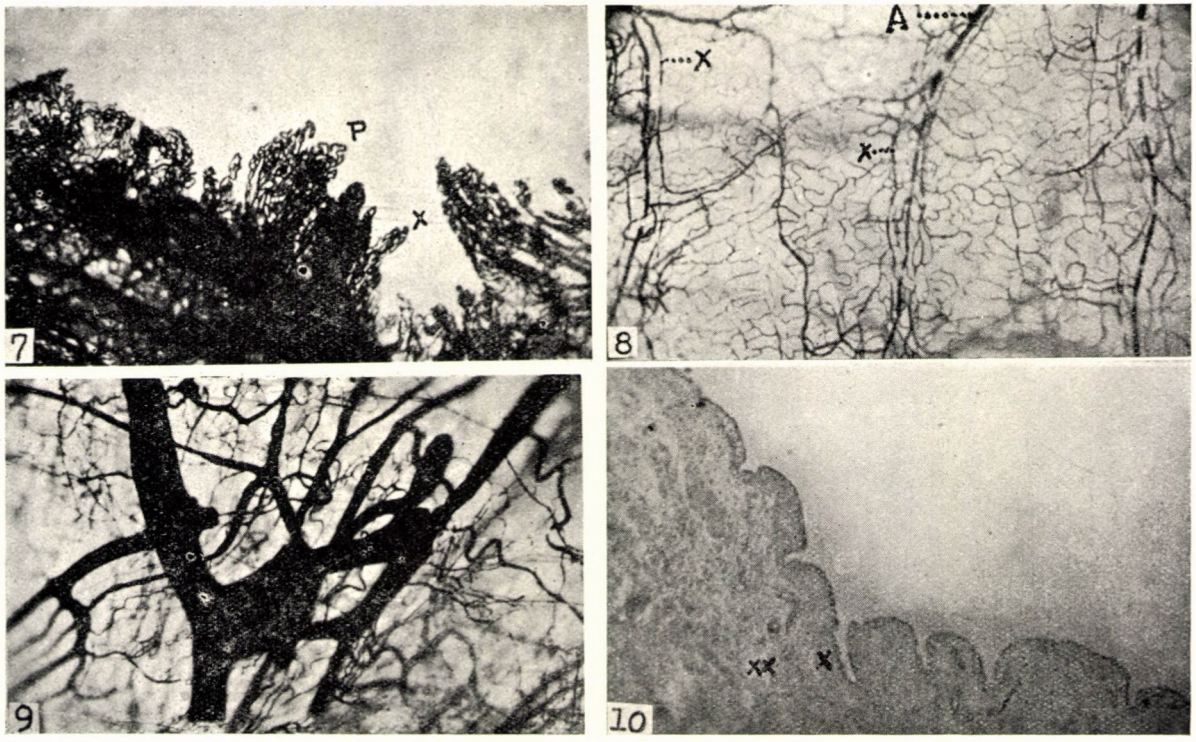

Fig. 7. Synovial villi and folds. (low power). (India-ink injection ; carpal joint of cat) X = villus ; P = fold.
Fig. 8. Absorptive venous capillaries of stratum capillare (plexus synovialis). (×60). A = artery ; X = post-capillary vein.
Fig. 9. Veins of stratum fibrosum. (India-ink injection) (low power).
Fig 10. Areolar membrane (Haematoxylin-eosin staining). (×90). X = stratum capillare ; XX = stratum subsynoviale.

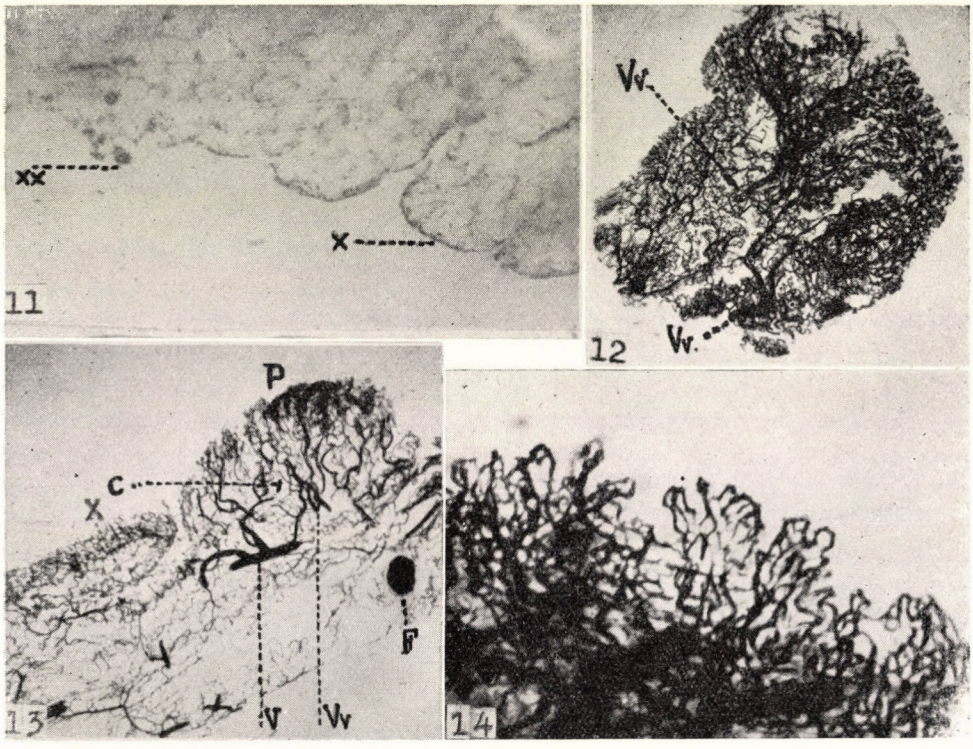

Fig. 11. Adipose membrane (Haematoxylin-eosin staining). (×80). X = stratum synoviale ; XX = villus (cellular).
Fig. 12. Corpus adiposum genus (India-ink injection). Vv = venae colligentes.
Fig. 13. Transverse section of synovial membrane (India-ink injection ; 200 μ) P = layer of folds ; C = capillary layer (plexus synovialis) ; V = basal vein ; Vv = efferent vessels ; F = vein of stratum fibrosum ; X = villus
Fig. 14. Villus anlagen (India-ink injection ; elbow joint of cat).

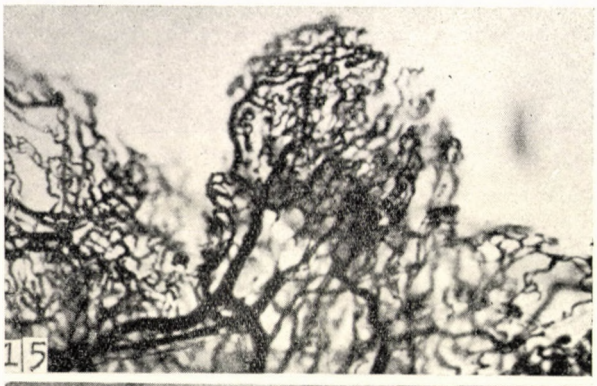

Fig. 15. Synovial villi of newborn dog (India-ink injection ; elbow).

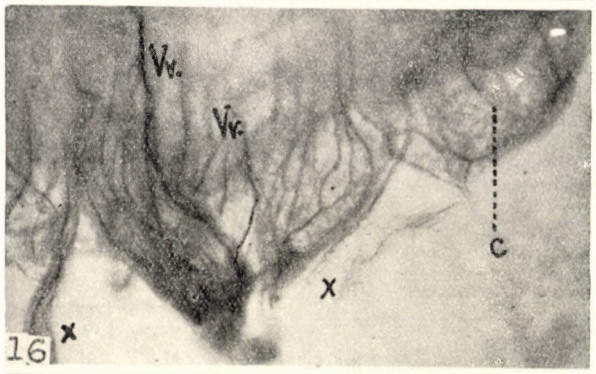

Fig. 16. Absorption of Azocarmine G in folds C capillary layer (plexus synovialis); Vv = venae colligentes ; X = villi

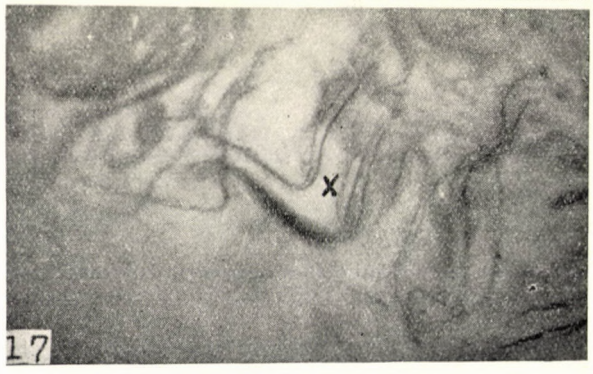

Fig. 17. Absorption of Azocarmine G in villi X = villi

Summary

There are no data in the literature to throw light upon the blood supply of the articular capsule. In order to clarify this problem the joints in the extremities of 47 animals (dogs and cats) have been examined.

In the first part (A) of the present study the vascularization of the synovial membrane has been studied on specimens injected with India-ink. It has been established that, at variance with the descriptions in the literature, there are four layers to be differentiated, viz :

1. The stratum villorum et plicarum, containing the vascular plexuses of the villi and folds. The afferent arterioles invading the villi form glomerules and leave as efferent veins. The majority of the vessels give rise to vascular plexuses which do not form villi. These plexuses constitute the articular folds. The distribution of villi and folds differs from joint to joint. No avascular villi have been found.

2. The stratum capillare. This layer not mentioned in the literature contains the delicate, venous capillary network (plexus synovialis) which plays a decisive part in the absorption of diffusible substances.

3. The stratum subsynoviale. A layer of connective tissue loose in texture, underlying the fibrous stratum and containing the basal arteries and veins from which the vessels of the aforementioned layers arise arch-like.

4. The stratum fibrosum. This is a membrane of fibrous connective tissue.

The vascular systems of the different synovial membranes seem to be characteristic. The areolar membrane contains first of all the villi and the folds and plays a primary part in absorption. The adipose membrane has no subsynovial layer but a very rich capillary one. This layer participates also primarily in absorption. The fibrous membrane possesses neither a layer of villi and folds, nor has it an active share in absorption.

In the second part of the study (B) it has been established from preparations made after injecting India-ink through the umbilical vein that in the dog and the cat there is only a villus anlage to be encountered at the middle of the intrauterine life. Differentiation of the blood vessels in villi and folds becomes marked and is completed in extrauterine life only.

In the third part (C) it has been established, on the ground of absorption studies made after intra-articular administration of Azocarmine G solution, that in the knee joint of the dog the absorptive surfaces are primarily the villi and folds and the capillary layer of the areolar and adipose type membranes (plexus synovialis).

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ТОНКАЯ СТРУКТУРА И КРОВОСНАБЖЕНИЕ СУМКИ СУСТАВА С ОСОБЫМ УЧЕТОМ СУСТАВНОГО КРОВООБРАЩЕНИЯ

Э. Хидвеги

Р е з ю м е

Детальное кровоснабжение сумки сустава нам неизвестно из литературных данных. Автор исследовал суставы конечностей 47 животных (кошкек собаки). В первой части исследований (А) были выработаны кровеносные сосуды сумки сустава (на основании препаратов, инъицированных разбавленной тушью). В отличие от существовавших до сих пор литературных данных, автор различает с точки зрения кровоснабжения четыре слои :

1. *Stratum villorum et plicarum*, содержащий сплетения кровеносных сосудов ворсинок и складок. Афферентная артериола, проникая в субстанцию ворсинки, образует там клубочку, и удаляется в виде эфферентной вены. Большинство кровеносных сосудов образует сплетения, без образования ворсинок. Эти последние являются суставными складками. Распределение ворсинок и складок различное по суставам. Автор не нашел аваскулярных ворсинок.

2. *Stratum capillare*. Этот слой, о котором не имеются литературных данных, содержит капиллярную сеть тонких вен, которая играет решающую роль в рассасывании диффузибильных веществ (plexus synovialis).

3. *Stratum subsynoviale*. Рыхлый соединительнотканевый слой, прилегающий к фиброзной капсуле. Этот слой содержит базальные артерии и вены, и из него происходят дугообразные кровеносные сосуды вышеприведенных слоев.

4. *Stratum fibrosum*. Волокнистая соединительнотканевая сумка.

Согласно исследованиям автора сосудистая система различных сумок суставов является весьма характерной. Ареолярная мембрана содержит в первую очередь ворсинки и складки, и играет первичную роль в рассасывании. Адипозная мембрана не обладает субсиновиальным слоем, но ее капиллярный слой весьма богатый, и она принимает участие, в первую очередь, также в рассасывании. Фиброзная мембрана не имеет слоя ворсинок и складок и не участвует в рассасывании.

Во второй части своих исследований (Б) автор установил на препаратах, полученных путем инъекции тушью через *vena umbilicalis*, что у собак и у кошек в середине внутриматочной жизни встречаются лишь ворсиночные образования. Дифференцировка кровеносных сосудов ворсинок и складок становится выраженной и заканчивается только в течение внематочной жизни.

Автор на основании исследований рассасывания, внутрисуставным применением красительного раствора азо-кармина-G, в заключение устанавливает, что с точки зрения рассасывания активными областями в коленном суставе собаки, в первую очередь, являются ворсинки и складки, или же капиллярный слой *(plexus synovialis)* мембран ареолярного и адипозного типа.