

# Vascular Patterns As Related to Function

SECOND CONFERENCE ON MICROCIRCULATORY  
PHYSIOLOGY AND PATHOLOGY

# Vascular Patterns As Related to Function

SECOND CONFERENCE ON  
*Microcirculatory Physiology and Pathology*

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## CONFERENCE ON MICROCIRCULATORY PHYSIOLOGY AND PATHOLOGY

In this issue of *ANGIOLOGY* the papers and initial discussions presented at the Second Conference on Microcirculatory Physiology and Pathology are published. The Microcirculatory Conference, "Vascular Patterns as Related to Function," was sponsored by the American Association of Anatomists and held in Philadelphia on April 5, 1955. The members of the Conference are pleased to have the proceedings published in *ANGIOLOGY*, The Journal of Vascular Diseases, and grateful to the Editor, Dr. Saul S. Samuels, for the kind invitation to submit the proceedings of future Conferences. By way of introduction to the readers of *ANGIOLOGY*, a brief account of the origin and objectives of the Conference is presented.

Within the last five years, various groups of investigators utilizing cinephotomicroscopic, micromanipulative and related techniques for *in vivo* studies of blood circulation have recognized the need for intergroup efforts. Several factors have contributed to this point of view: first, recognition of the potential value in mutual exchange of scientific information among morphologists, physiologists, biochemists, pharmacologists, pathologists and clinicians working in the basic and applied aspects of microcirculation; second, recognition of the advantages of inviting representatives of other disciplines to meet and cooperate in research projects of mutual interest; third, the merits of group publication; fourth, the need for stimulating young research workers in this field; and fifth, the desirability of opportunities for social as well as scientific interchange among workers in microcirculation.

Although the biohistorical beginnings of the Microcirculatory Conference are difficult to trace and evaluate, the influence of Dr. Eliot R. Clark, Emeritus Professor of Anatomy at the University of Pennsylvania, is clearly demonstrated by his work on living blood vessels since the early nineteen-hundreds, and in particular by the large number of young men who were trained in the microcirculatory field and helped by him. Throughout this period Dr. Clark has been aided immeasurably by his wife and scientific collaborator, Eleanor Linton Clark. The late Dr. August Krogh, Professor of Zoophysiology at Copenhagen, Nobel laureate, and author of "Anatomy and Physiology of the Capillaries," was a pioneer contributor in the microcirculatory field, and was responsible for significant concepts pertaining to blood capillaries. Dr. Krogh was influential in stimulating investigators including several senior members of this group such as Dr. Brenton R. Lutz, Boston University, and Dr. Melvin H. Knisely, University of South Carolina. Dr. Robert Chambers of New York University, renowned for his cell surgery and micromanipulative skill, has also paved the way by his research activities and by stimulation and training of young investigators now active in microcirculatory studies.

As a consequence of the efforts of many, the Conference on Microcirculatory

*(Continued on p. 392)*



## SELECTIVE DISTRIBUTION OF BLOOD THROUGH THE TERMINAL VASCULAR BED OF MESENTERIC STRUCTURES AND SKELETAL MUSCLE<sup>1</sup>

B. W. ZWEIFACH, PH.D. AND D. B. METZ, B.S.

The structural characteristics of the smallest blood vessels have been described in considerable detail, both in the living state and after fixation and staining, by numerous investigators. No particular emphasis was placed on the arrangement of the various vascular elements as discrete organic units around which the functional behavior of the bed was organized. In much of the earlier work, the peripheral vascular bed was depicted as an indiscriminately arranged network of capillaries which unite with one another to form venous channels (1). These findings were based chiefly on areas such as the interdigital web of the frog and the cutaneous and mesenteric structures in various mammals. Our own detailed studies of representative mesenteric structures, where the vascular bed in its entire extent could be visualized, led us to conclude that the unique arrangement of the muscular constituents of this unit served as an important determinant of the local distribution of blood through the capillary vessels (2). A fundamental concept of peripheral circulatory homeostasis was advanced on the basis of three sets of observations: (a) a distinctive architectural pattern in which centrally located thoroughfare or preferential channels served as the parent vessels for the distribution of capillary offshoots and eventually as avenues for the return of blood to the venous system; (b) a progressive loss of musculature along the terminal extensions of the arterioles which rendered the most distal ramifications of the arterial system non-muscular; (c) a graded reactivity to vasoconstrictor or vasodilator stimuli concomitant with the formation of progressively smaller blood vessels, making the precapillary units the most highly reactive constituents of the system. Observations on the tongue and undersurface of the skin of the frog and the small intestine and omentum of the dog, cat, and rat appeared to substantiate the primary significance of a similar interplay of structural and functional factors in the capillary circulation (3).

Clark and Clark in the ear of the rabbit (4), Grafflin (5) in the urinary bladder of the frog, and Nicoll (6) in the wing of the bat were unable to detect anatomical thoroughfare channels leading from arterioles to venules. Each of these structures are in themselves highly specialized appendages and there remains to be established the extent to which the structural features of any particular bed can be taken to be representative of other areas. Furthermore, there have appeared in the literature numerous generalizations concerning the preferential channel organization in vascular beds other than the mesentery, without direct evidence for this extrapolation. Our recent studies have been designed to resolve these issues by providing direct observations of the circulatory pattern in five impor-

<sup>1</sup> This study was supported in part by a research grant (H-1244) from the National Heart Institute of the National Institutes of Health, United States Public Health Service, and by a grant from the Life Insurance Medical Research Fund.

tant tissues of the rat—namely, skin, skeletal muscle, urinary bladder, mesentery and intestinal wall. These studies (7) have demonstrated a diversity of structural characteristics especially in parenchymatous tissues. All of these areas were found to possess certain common features, referable to the periodic restriction and expansion of the circulation during periods of functional activity. In addition to the features previously noted in the mesentery, an important factor was the presence in the extensive capillary networks of the skin and skeletal muscle of numerous anastomoses between all of the arterial vessels, as well as between venous channels. These cross connections have been described in the past in such areas as the intestinal wall (8), and more recently have been pointed out as important structural considerations by Nicoll (9) in the bat wing.

The basis of our original approach to the problem was the premise that certain broad generalizations concerning the functional characteristics of the terminal vascular bed could be obtained by an intensive study of the circulation in a representative tissue, such as the mesentery. The extent to which these structural and functional features were incorporated into the vascular bed of other tissues, such as skeletal muscle, skin, etc., could then be projected against this frame of reference.

In general, the capillary bed proper has been found to be made up not of a series of uniform vascular structures, but of an admixture of muscular and non-muscular vessels of capillary dimensions. The muscular components occupy a central position, in many instances directly through to the venous side. The circulation through the large network of non-muscular capillaries is therefore dependent upon the contractile activity of the muscular capillaries. In this hierarchy of structural components, the precapillary sphincters just proximal to the capillaries represent the actual unit controlling the extent of blood flow through the capillaries.

In addition to structural considerations, a number of unique functional characteristics contribute to the local regulation of blood flow. The muscular components of the capillary bed represent the most highly reactive units to chemical vasoconstrictor and vasodilator influences. This extreme sensitivity imparts to these structures a considerable degree of independence from the circulation as a whole, especially as concerns locally elaborated agents. A further functional attribute is the presence of an intermittent ebb and flow of blood through the capillary bed, frequently irregular in its periodicity but altered with striking regularity in various situations. This periodicity has been shown to develop as a consequence of the spontaneous opening and closure of the precapillary sphincters, in conjunction with comparable changes in the caliber of the parent metarteriolar vessels. The term "vasomotion" has been applied to this phenomenon to set it apart from the wave-like patterns of constriction and dilation exhibited by the larger blood vessels. This dynamic process clearly serves as a supplementary factor, contributing actively to both the distribution of blood and the effectiveness of the return to the venous system, over and above that provided by the systemic pressure *per se*.

The fundamental tenets of this concept of peripheral vascular homeostasis are

thus: (a) a structural organization of the capillary bed, with centrally placed muscular units achieving the finer regulation of blood flow; (b) a high degree of reactivity to chemical influences, chiefly of local tissue origin; (c) the phenomenon of vasomotion representing a modulating influence between systemic and local regulatory influences. These several facets of vascular behavior have been found to be incorporated in different degrees into the homeostatic operation of particular vascular beds.

The general features of the structural and functional organization of the terminal vascular bed can best be appreciated in a comparatively uncomplicated structure such as the mesentery. With repeated subdivision of the distal continuation of the small arteries in the mesocecum of the rat, each successive branch acquires a less prominent muscular coat. The point at which blood begins to be fed into the capillary bed proper varies in different regions. For the most part, no direct flow of blood into the capillary channels occurs until the parent vessels are approximately  $50\mu$  or less in diameter. In all instances the immediate junctional segment of the arterial branches to the capillary network continues to be muscular. In the sequence of subdivision, an arterial unit is reached where the smooth muscle coat becomes discontinuous and irregular. The terminal arterioles by definition constitute vessels which have only a single layer of smooth muscle and in which the supporting connecting tissue elements are almost completely lacking. Capillary branches originating from this segment of the tree have only an inconstant and scanty investment of muscle. Ultimately, direct extensions of the terminal arterioles are encountered which have no muscle and distribute capillary side branches which likewise are non-muscular. The capillary bed, therefore, receives arterial blood from small arteries, arterioles, metarterioles and non-muscular extensions of the arterial system.

The distal continuations of the arterial vessels in the mesentery can usually be traced through to the venous side. These have been termed preferential or thoroughfare channels (fig. 1). In other areas, the arteriolar continuations join the venous circulation by a variety of pathways. In some instances, they lose their anatomical distinction and are connected to venous vessels by several capillary offshoots. This type of vascular distribution is seen in the skin of the rat and also in the cheek pouch of the hamster. In other structures, the greater part of the capillary network is made up of vessels which arise as abrupt offshoots of muscular arterioles and ramify indiscriminately. This pattern is atypical and restricted to particular areas such as the interdigital web and the urinary bladder. Another feature, not observed in the mesentery but readily apparent in skeletal muscle and skin, is the presence of extensive cross connections between small arteries and arterioles to form a series of arcades. The observations on skeletal muscle were made on the thin spino-trapezius muscle along the back of the rat. The central connecting link of the arcade receives blood from opposite directions and shows a reversal of flow at frequent intervals. In these tissues, the capillary bed proper is fed by metarterioles which come off at right angles from the arterial or arteriolar arcades. These metarterioles progressively lose their muscular investment to terminate either as non-muscular capillaries in close proximity to



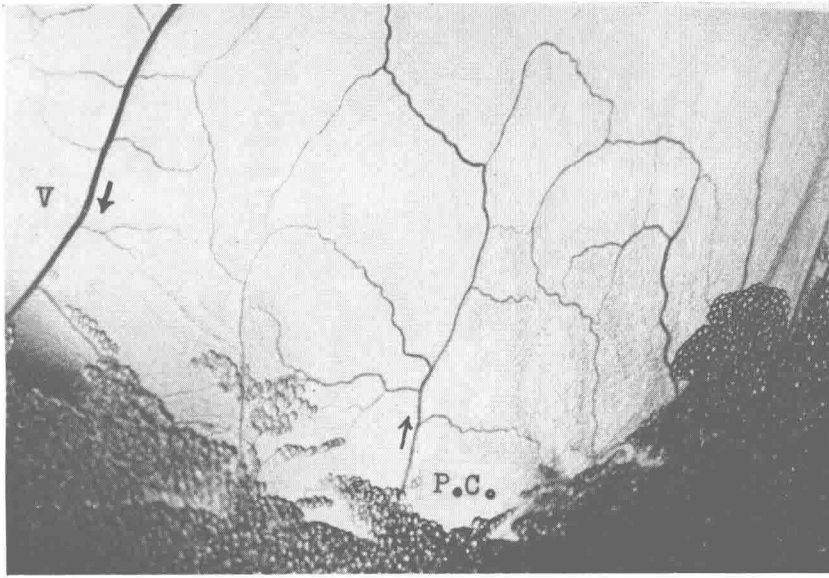


FIG. 1. Low power (8X) of vascular distribution in mesocecum of rat. Preferential channel of metarteriolar type (center of field) is the most common form of terminal capillary distribution between arterioles and venules. Capillary offshoots along entire course of metarteriole. Venule at extreme left.

the confluent tributaries of the collecting venules, or as preferential channels. Along the free margins of the skeletal muscle, the thoroughfare type of vascular distribution predominates. Direct anastomoses between arteries and venules of  $50\mu$  or less in caliber have also been observed in different tissues. These are most frequent in tissues such as the skin and wall of small intestine, although occasional direct shunts have been encountered in vessels between 20 and  $50\mu$  in diameter in the mesentery and skeletal muscle.

In the mesentery and serosa of the small intestine, where the majority of the arterioles terminate as preferential channels, this configuration is most apparent when observed in the living state. After death or tissue fixation, the arteriolar-venular pathways are more difficult to map out. In skeletal muscle, where interarterial arcades exist, the capillary bed appears as a discrete area completely circumscribed by several arterial cross connections (fig. 2). A number of metarteriolar branches leave the arcades to approach the center of the capillary area. These exhibit the conventional thoroughfare type of distribution for the greater part of their length and terminate as one or two short capillaries which unite with other capillaries to form venous effluent vessels. When threshold concentrations of epinephrine are applied, the muscular segment of the preferential channel becomes varicose, the sphincters shut down and a flow continues only through one or two final capillary ramifications. In essence, this situation is analogous to the anatomically complete channels in other beds and represents a structural feature basic to the local regulation of blood flow.

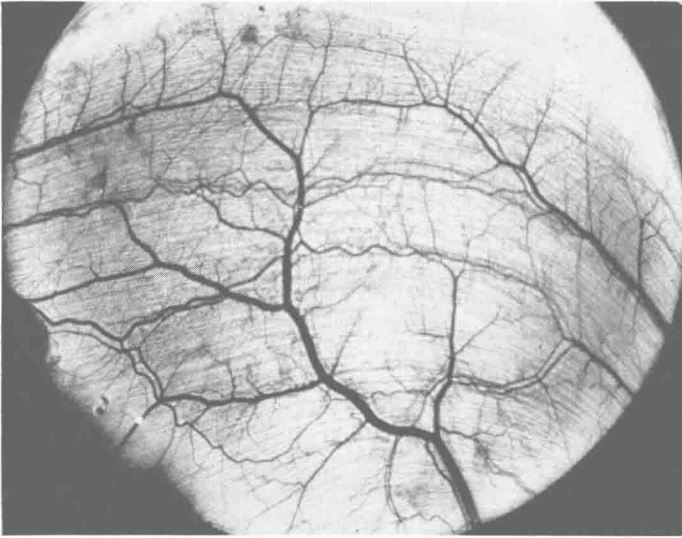


FIG. 2. Extensive network of arterial and venous vessels on surface of spino-trapezius muscle in rat (4X). Note frequent cross-connections between small arteries (light vessels), arterioles, and venules (dark vessels). Capillaries arise from metarteriolar branches of terminal arterioles and inter-arteriolar arcades.

In skeletal muscle, wide extremes exist in the volume of blood which perfuses the tissue during activity and during rest. This is accomplished by a unique structural arrangement of the small blood vessels. The skeletal muscle proper consists of groups of microscopic fibers bound as individual muscle bundles approximately 50 to 60 $\mu$  in diameter. In the final distribution of blood vessels to the muscle tissue, the capillaries lie directly on the surface of these small muscle bundles. The muscle as a whole is built up of discrete masses of these muscle bundles, anatomically separate from one another. The blood vessels which nourish the tissue, enter the muscle through these natural cleavage planes. In some muscles the various cleavage planes represent flat surfaces; in others the muscle bundles are arranged as irregular masses varying in thickness between 300 and 400 $\mu$ . Each of these muscle masses is surrounded by a network of arterial and venous vessels which interconnect freely with one another within the connective tissue cleavage planes. The muscle fibers proper are supplied with blood by branches of the metarteriolar type which arise from arteriolar arcades and penetrate the connective tissue to distribute capillaries directly contiguous with the microscopic muscle bundles (fig. 3). The capillaries are spaced at approximately 40 to 50 $\mu$  intervals running parallel to one another along the length of the muscle. In the region of the free edge of the muscle, the metarterioles can be traced directly back to be reconstituted into venous channels. As such, they represent preferential pathways which convey the most rapid stream of blood from arterial to venous side. In this area, the capillary branches given off by the metarterioles along their course, eventually rejoin its distal continuation or that of adjacent comparable channels. The collecting venules formed along the edge of the muscle

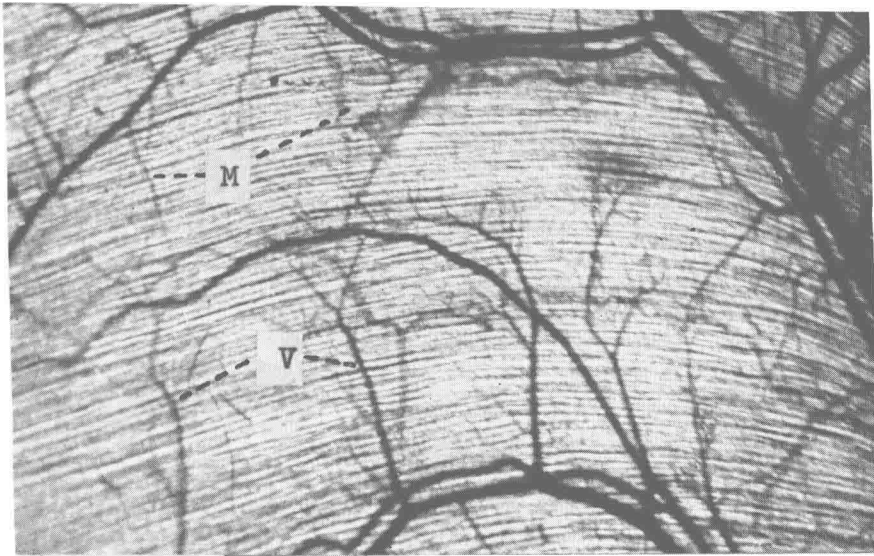


FIG. 3. Circulation in rat skeletal muscle (10X) showing mode of formation of metarterioles (M) and collecting venules (V). Extremely short interval between terminations of metarterioles and capillary tributaries of venules.

constitute the venous drainage of the remainder of the muscle circulation. Into this structure drain capillaries which originate as offshoots of the small arterioles, as well as those which arise directly from the arterial arcades. The larger venous channels (100 to 200 $\mu$ ) also cross-connect freely with comparable vessels to form a series of venous arcades which lie in the connective tissue cleavage plane previously described.

It should be emphasized that in all tissues so far studied, pathways for the continuous return of arterial blood to the venous system have been observed during conditions of hypotension or hemorrhage. Both physical and functional factors make it possible to restrict the capillary circulation to most direct pathways, without completely curtailing the return of blood into the venous circulation. Thus, in both skeletal muscle and the mesentery, with blood loss and a fall in blood pressure to 40 mm Hg, the tissue does not become completely ischemic. The side branches all along the parent stem are shut off without interfering with the forward movement of arterial blood through the main trunk. The distal tips of the metarterioles, being non-contractile, remain open and thereby continue to provide an effluent path to the venous system. Only the muscular precapillary sphincters close down completely. Most of the other structural units of the bed show a partial narrowing, especially those which in addition to smooth muscle contain connective tissue in the vessel wall. This type of preferential flow is readily demonstrated in experiments where threshold doses of vasoconstrictor agents are applied topically. The metarterioles may assume an uneven varicose appearance, but continue to be perfused with blood which circulates only through one or two distal capillary ramifications and enters into confluent venous chan-

nels almost immediately. The metarterioles which arise from the central portion of the intra-arterial arcades most frequently show an active flow of blood during periods of otherwise complete capillary ischemia.

Following hemorrhage and a fall in blood pressure to about 60 to 70 mm Hg, a rapid flow continues through the arterial arcades and their most direct vascular interconnections. In most instances, direct connections between arterial and venous vessels can be demonstrated, although on a minor scale. For example, a particular artery about  $200\mu$  in size which ramifies in a circumscribed muscle area, may have as many as 15 to 20 major branches. Of this number two or possibly three offshoots can be traced directly to the venous side of the circulation. The remaining 18 or 19 branches terminate as arterial arcades at the level either of 100 or  $50\mu$  arterioles.

In addition to the structural features which facilitate shifting of blood from the interior of the muscle bundle to the surface cleavage planes, there exist a variety of factors which permit selective distribution of blood within the tissue proper. Thus, single capillaries or groups of capillaries can be seen to be cut off spontaneously from the active circulation. Closure at the junctional sphincters appears to develop spontaneously as a consequence of changes in blood pressure and possibly of local vessel tone. Spontaneous vasomotor changes are also observed in the arterial vessels, including the arcades, and in the muscular venules. These excursions, however, rarely develop to the point of complete curtailment of blood flow through the vessel. Actually, during periods of hypotension and diversion from the capillary network, the flow through the small arterial and venous channels remains as rapid as that observed at normal blood pressures with the entire circulatory bed in an active state.

#### SUMMARY

The structural makeup of the terminal vascular bed in skeletal muscle was observed in the spino-trapezius muscle of the rat adjacent to the midline attachment to the spinous processes of the vertebra. The larger blood vessels are distributed along the connective tissue cleavage planes of the muscle, in which they anastomose freely with comparable elements to form a series of arterial and venous arcades. The capillary bed proper arises from metarterioles which terminate abruptly as a series of capillaries or as preferential channels. The latter type of thoroughfare vessel is most common along the edges of the muscle. During periods of reduced blood flow, the circulation persists through the arteriolar and venular vessels in the cleavage planes, while the interior of the muscle is ischemic. An intermittent capillary circulation comparable to that in other tissues is readily apparent.

*Dept. of Biology  
New York University*

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## DISCUSSION

ELIOT R. CLARK, M.D., Sc.D. (HON.)

We can agree in general with the description by Zweifach and Metz of muscular and non-muscular vessels of capillary dimensions, and their view that it is the muscular vessels, whether arterial or venous, that control the circulation through the capillaries. We agree also that mammalian endothelium is essentially non-contractile, and that the type of adventitial cell found on true capillaries is non-contractile. We also admit the greater motor activity of the muscle cells on the more distal arterioles, including the so-called "precapillary sphincters," as well as the occurrence of unsynchronized contractions that produce marked local effects upon the circulation. All these have been described in our accounts of behavior of vessels in the rabbit's ear chambers. We also agree that it is not proper to carry these observations over to other organs and tissues, or from one animal to another. For example, a fairly extensive study, through cranial windows, of the pial circulation in the rabbit, carried out by Mr. Wentzler in our laboratory, revealed an almost complete absence of constrictions and dilatations, either synchronized or non-synchronized.

Regarding the "preferential channels" which Zweifach and Metz find so important in the selective distribution of blood through the capillaries of the mesentery and the muscles, this, too, while undoubtedly true for these structures, should not be applied generally, as they also insist, until observations have proved their presence elsewhere. They recognize that "preferential channels" are not found in a number of tissues and organs in which the peripheral circulation has been watched microscopically. However, it looks very much as if Spanner had found "preferential channels" in the intestinal villi, although he calls them arterio-venous anastomoses.

It seems to us from what is known about circulation in a considerable number of tissues and organs, that there are differences in many, and that each organ must be treated individually. The rabbit's ear, for example, is provided with

hundreds of arterio-venous anastomoses—that is, short, direct connections from artery to vein, with characteristic extra thick muscular walls, many of them with epithelioid cells thought by many to be modified muscle cells. These operate somewhat in the same manner as the preferential channels. Furthermore, the last fifteen years have witnessed the finding of arterio-venous anastomoses in a considerable number of organs in which they had not been previously found, such as kidney submaxillary glands, stomach and intestines, and spleen. These have been added to those found in the coccygeal bodies, penis, fingers and toes of humans; and in addition the nose, tail, and tongue of other mammals. Again, Knisely has described “sphincters” in the mouse’s spleen and the frog’s liver, the latter and half the former being at the venous end of the capillary.

Zweifach and Metz mention “arterial arcades” as important structures richly present in striated muscle, although they do not explain their importance. Such arcades in striated muscle have been described by Spalteholz. About 1870 Cohnheim brought out the fact that there are some organs in which there are “arcades” formed by anastomosing arteries, and others in which anastomoses are few or small. The latter type are called end-arteries, and the importance of the difference lies in the results of arterial plugging. In the absence of adequate anastomoses, that is, if end-arteries alone are present, plugs cause death of tissue, whereas if adequate anastomoses are present, blood reaches the tissue through detours. Their presence in the rabbit’s ear is so rich and so well known that we have not especially featured them. But we have, we believe, been able to work out some of the factors that are responsible for their formation, or failure to form, and have presented this study at the Montreal meeting of the American Association of Anatomists. A complete paper is nearly ready for the publisher.

May I add that we have the greatest respect and admiration for the splendid work that Dr. Zweifach and his co-workers, particularly Dr. Chambers, have done in the study of the behavior of peripheral vessels. May I add further that the “We” that I have used has not been an editorial “We,” but is meant to include Mrs. Clark and other co-workers.

*Wistar Institute of Anatomy and Biology  
Philadelphia 4, Penna.*



# VASCULAR PATTERNS AND ACTIVE VASOMOTION AS DETERMINERS OF FLOW THROUGH MINUTE VESSELS

PAUL A. NICOLL, PH.D. AND RICHARD L. WEBB, PH.D.

Of the sites where living cells and tissues may be observed, we feel that the wing membrane of the bat offers a most advantageous arrangement for studies on the vascular system. Shortly before the turn of the century, the advantages of this area were exploited. Since then it has been used only by a few investigators interested in vital studies. For many years the web of the frog's foot was preferred as a natural area for studies on the vascular system. While significant knowledge of the vascular pattern in amphibia has been gained by earlier investigators, certain critical points have been overlooked because of the difference between the amphibian pattern and that of the mammalian vascular system. Probably the most significant error in this respect has been in the conception of the capillaries. Investigations by Clark and Clark indicated such pitfalls and led to the development of a new technique of direct study on the rabbit ear, resulting in a more accurate conception of blood vessels in the mammal.

In scanning the program of the first Microcirculatory Conference held in Galveston, one is impressed by the examples of ingenuity employed in preparing the mammalian tissues so that the vascular system can be observed directly (1). Each has its special advantages in gaining an insight into the behavior of the vessels under study.

In formulating the present paper, we have omitted a detailed description of technique and special methods, since they were described exhaustively in the first conference (2). When the central theme of a vascular study is the analysis of a fundamental mechanism of capillary behavior, the advantages of the bat wing technique are most evident. Specific adaptations of the circulation following long term subjection to altered physiological or pathological states are not suitable problems for this particular approach.

We claim no originality in the selection of the bat as an experimental animal. We do wish, however, to emphasize that because of the simplicity and accessibility of its blood and nerve supply, the necessity for devising complicated methods is minimized. As an example, studies on the normal activity of these structures can be made without resorting to surgical procedure involving the use of anesthesia. These data are invaluable when comparisons are to be made with other experiments.

## OBSERVATIONS AND RESULTS

### *Vascular arcuate systems*

The arcuate configurations on the arterial side begin with arteriolar vessels (2). Each system consists of anastomotic vessels of approximately equal diameter. Since 2 or sometimes 3 distinct arteriolar arcuate systems can be identified in

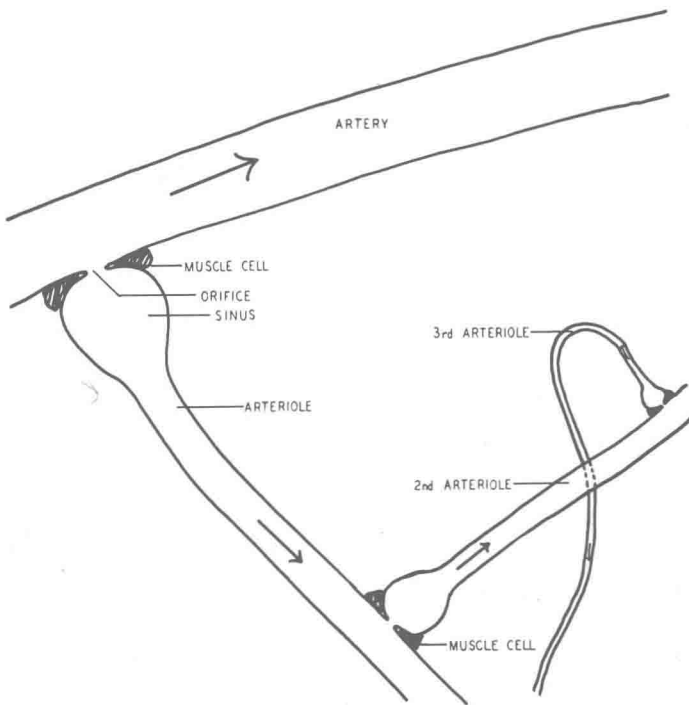


FIG. 1. Indian Club origins of arteriolar vessels. Many instances where origins of all three arcuate systems may be found in close proximity are seen in these wing membranes.

these vascular beds, the parent vessel can be either an artery or a large arteriole. All origins of an arcuate system show 2 characteristic features. One is their angle of origin from the parent vessel which is always  $90^\circ$  or less in reference to the forward direction of flow in the parent vessel. The second feature is the appearance at the origin where the vessel exhibits a dilatation as compared to its average diameter elsewhere, while the actual orifice from the parent vessel is smaller than its average diameter. This formation has been aptly termed "Indian Club" (fig. 1) and is a functional configuration dependent on the tonus exhibited by the muscle cells in the wall. The relative diameters of the orifice, dilated bulb and vessel may show considerable difference when tonus varies in the muscle cells or as they contract actively. Within any arcuate system, no sinuses are found at the junctional points, and angles of branching have no specific relation to flow patterns. Terminal arterioles are vessels of varying length and complexity that feed the extensive capillary net. They may arise from any of the arcuate arterioles or occasionally from a small artery. The majority of them, of course, originate from the smallest arcuate vessels.

Capillaries form extensive nets with numerous terminal arteriolar feeders and equally numerous drainage channels (fig. 2). Thus, specific or preferential flow paths within the capillaries are not observed in these subcutaneous minute vascular beds. Such conditions, if they exist in other minute vascular fields, must

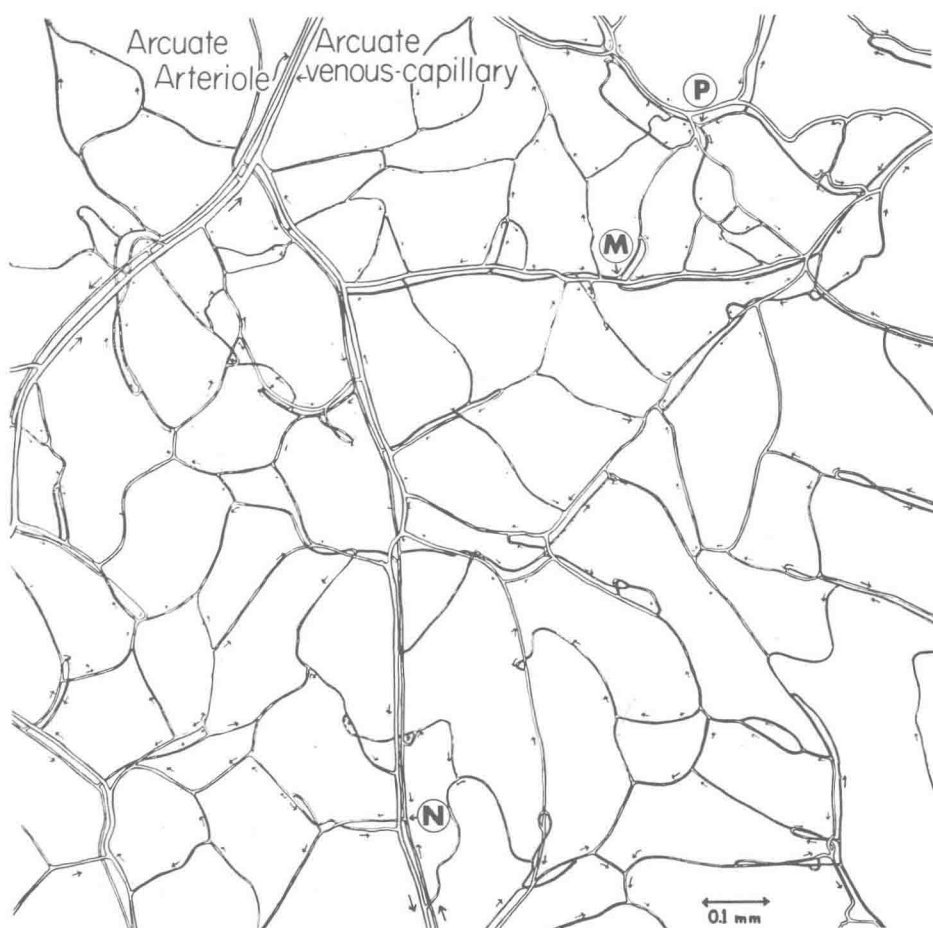


FIG. 2. Arcuate patterns of arterioles and venous capillaries and the connection of terminal arterioles with the capillaries. Arrows indicate flow direction at time sketch was made. Note points N, M and P where flow from two directions meet in the arcuate arterioles.

represent specialized relationships in those sites. They should not be ascribed to a fundamental organization of capillary structure (3). The distribution of flow from any particular terminal arteriole within the capillary net usually is not extensive. Local conditions within the minute vessels determine the actual flow path and are changing constantly.

The drainage channels are formed by the joining of the capillary structures and show frequent anastomotic connections. This leads to the development of an arcuate pattern of venous capillaries, which roughly parallels the arcuate arteriolar vessels (fig. 3). They differ from the smaller capillaries only in size and probably show the same permeability. Claims have been made that their permeability is greater than that of the smaller capillaries (4). Vasoreactive agents