ABSTRACT

MICROSCOPIC ANATOMY OF THE
INTEGUMENTARY SYSTEM OF THE HORSE

by Amir Hossain Talukdar

The microscopic anatomy of the integumentary system of the horse is not adequately described in the available veterinary literature. This investigation was undertaken with the view of filling this void.

For this histologic study, skin specimens from 35 areas of two stallions, two geldings and two mares were obtained from freshly killed normal animals two to seventeen years old. A few additional sections were obtained for the histochemical studies of glycogen and periodic acid-Schiff (PAS) positive substances and for frozen sections to study the nerve endings of the lip. For routine paraffin sections, the specimens were fixed in formalin-acetic acid-alcohol. For histochemical study, 10% formalin was the fixative of choice.

The following stains were used for histologic study: (1) Harris hematoxylin and eosin, (2) Gomori's aldehyde fuchsin for elastic fibers, (3) periodic acid, silver, orcein and aniline blue for all the fiber components of the dermis, (4) Bielschowski-Gros for the revelation of nerve endings and (5) Domici's mast cell stain. For histochemical studies Bauer-Feulgen technic was used for glycogen and periodic acid Schiff reagent for PAS positive substances.

The surface of the skin contained ridges and grooves. The hairs erupted in the grooves and formed rows on the surface. The average skin thickness of general body skin was 3.8 mm. The epidermis consisted of 3 layers: stratum germinativum, stratum granulosum and stratum corneum; the stratum lucidum was absent. Keratohyalin granules were observed in the cells of the suprabasal layer of the epidermis and increased gradually until the cytoplasm of the cells of the stratum granulosum was completely filled. Basal epidermal processes anchored the epidermis with the underlying tissue. The basal layer also contained dendritic melanocytes in addition to germinative cells. The dermis consisted of two well demarcated layers: the stratum papillare and the stratum reticulare. The collagenous fibers in the papillary layer were fine and loosely arranged, but in the reticular layer were compact and tended to form a third layer in the lower part. An extensive network of elastic and reticular fibers was present in the superficial part of the papillary layer and penetrated the PAS positive basement membranes. A modified dermal region extended from the posterior part of the dorsum to the end of the croup with lateral extensions over the gluteal regions. While the dermal thickness of the general body skin, excluding the croup, was 3.7 mm that of the croup was 5.5 mm. As in cattle the hairs occurred singly. The medulla of the hair contained two layers of rectangular cells which were attached to adjacent cells by desmosomes. The larger hair follicles contained follicular folds similar

to those observed in the other domestic animals. The cells of the external root sheath of the hair follicles were strongly PAS reactive and contained glycogen. Usually two sebaceous glands, larger in the regions with fine hairs, were associated with each hair follicle. The upper lip and hoof margin contained large, branched sebaceous glands. Sweat glands were the apocrine type containing a brush border on the luminal side and canaliculi at the basal part of the intercellular space. Both an apocrine and canalicular secretory mode has been proposed. Numerous arterio-venous anastomoses were present in the lips, nostrils and coronary border. In this study arterial cushions were observed only in the dermis of the lips and thigh. Morphologically, four different types of nerve endings were present in the lips: lamellated endings, capsulated end organs, free nerve endings and non-capsulated balls. In addition, nerve nets were demonstrated on the hair follicles.

MICROSCOPIC ANATOMY OF THE INTEGUMENTARY SYSTEM OF THE HORSE

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A THESIS

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

DOCTOR OF PHILOSOPHY

Department of Anatomy

1967

BISMILLAH-IR-RAHMANER-RAHIM
(Holy Quran)
Begin in the name of Allah the most gracious and merciful.

VITA

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ACKNOWLEDGMENTS

The author wishes to sincerely express his deep appreciation and gratefulness to Dr. M. Lois Calhoun, Professor and Chairman of the Department of Anatomy, for her untiring guidance, supervision, encouragement and valuable advice during the course of this investigation and the preparation of the manuscript. A sincere note of gratefulness is extended to Dr. Roger Brown for his help in procuring the specimens and to Dr. Carles Titkemeyer for his timely advice and help. The author is greatly indebted to Dr. Al. W. Stinson for his suggestions and guidance in the technique of photography and preparation of the manuscript and to Dr. Esther Roege for very useful help in microtechnique.

The entire faculty and staff of the Department of Anatomy has been most co-operative and helpful during the course of this investigation. Special note of thanks to Dr. Arlene Seaman for supplying many valuable references relating to the subject. A note of thanks to the members of the graduate committee for their co-operation and useful criticism in the course of this investigation. Special thanks are due to those who helped in typing. The author is grateful to his wife, Shaida, for her continuous encouragement and for taking the long and lone responsibility of rearing the children.

With great pleasure the author acknowledges the financial support of the government of the United States (AID) and the East Pakistan Agricultural University, Mymensingh.

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INTRODUCTION

There has been considerable progress in the study of the histology and histochemistry of the skin of both man and laboratory animals during the last few decades. With the exception of sheep, very little attention was paid to the histology and histochemistry of the domestic animals. A better understanding of the function of the skin of man resulted in a remarkable improvement in the diagnosis of dermatological problems. Since dermatology is a very important branch of veterinary medicine, the Department of Anatomy of Michigan State University has taken the lead to investigate the integumentary system of domestic animals.

The histologic study of the skin of the horse is the latest in the series of studies on the skin of domestic animals. This department has already completed research on the skin of the mongrel dog, (Webb and Calhoun, 1954); cattle, (Goldsberry and Calhoun, 1959 and Sinha, 1964); eye adnexa of sheep and goat, (Sinha 1965); cat, (Strickland and Calhoun 1960 and 1963); swine, (Smith and Calhoun 1964, Fowler and Calhoun, 1964, and Marcarian and Calhoun, 1966); rat, (Holmes 1960); Goat (Sar and Calhoun 1966); and sheep, (Kozlowski 1966).

The skin of the horse, in particular, has received so little attention that no comprehensive histologic studies are available. Smith (1888) investigated the skin of the horse more thoroughly than any one else during that time. Since then, investigation on horse skin has been limited to

isolated areas only; for example on the sweat glands (Evans et al. 1957, Takagi and Tagawa, 1959, 1961 and Aoki et al. 1959); on the groups region (Schönberg 1926 and Odoni, 1951) and some contribution on the skin in general (Szelingrowski, 1962).

The horse has had the distinction of becoming the constant companion of human beings through the course of history and civilization. It is one of the first animals to have been domesticated. Although most of the work of the horse has been replaced by modern mechanization, the importance of the horse in sports and recreation continues at a high level. The horse industry, even in this most mechanized country, is valued at $3.5 billion (Sandifer, 1966). It is hoped, therefore, that this investigation will be very helpful for a proper diagnosis and treatment of the diseases of the skin of the horse, an old companion of human beings.

REVIEW OF LITERATURE

An extensive search for literature related to the skin of the horse was most discouraging as insufficient amount of work has been undertaken on the skin of the horse in particular.

General Feature

The skin consists of (a) epidermis--epithelial layer, (b) dermis--connective tissue layer, (c) subcutis--loose connective tissue layer with panniculus adiposus.

Smith (1888) categorized the horse into two groups, race horses and cart horses and observed thin delicate skin with short fine hair in race horses. He observed that the skin of the horse differs in appearance depending upon its position. Around the lip it is closely attached to the muscular structures below and the whole lip is felt as a muscular mass. Behind the angle of the mouth, the skin is exceedingly thin and supple and is nearly the thinnest of the body; over the head and cheek it is thin and never has fat beneath that part covering the external masseter muscle. On the side of the neck the skin is still thin, but at areas where the mane grows it is much thicker and more firmly attached below. Over the back and loins the thickest skin is found. It is also thick down the quarter but inside the thigh and up to the groin is the finest skin covering the body. The skin over the limb is of medium thickness. On removing pigmented hairs from the skin, the integument is black but in the

area of white hair it is pink.

According to Ellenberger (1906) and Krölling and Grau (1960), the skin of the horse is 1-5 mm in thickness and differs according to individual, body region, age, sex and race. Ellenberger (1906) found the thickest skin on the tail and around the penis. The skin of the horse is thinner than that of cattle but thicker than that of other domestic animals. Trautmann and Fiebiger (1957) stated the skin is very thick on the tail. Sisson and Grossman (1953) stated that the greatest thickness of the skin occurs at the attachment of the mane and on the dorsal surface of the tail.

The dermis contains smooth muscle associated with hair follicles. Smooth muscle fibers are found in the dermis of the scrotum, and penis and in the nipple and areola of the breast of man (Montagna, 1962). All authors agree that integumentary appendages such as hairs, horns, claws, nails, hoofs and cutaneous glands grow directly from the epidermis and are an integral part of the skin.

Epidermis

The epidermis covers the entire outer surface of the body and consists of stratified squamous epithelial cells. According to the position of these cells in the epidermis, they may be cuboidal, columnar, fusiform, or polyhedral. Scattered between the lower cells of the basal layers are the dendritic melanocytes, the cytoplasm of which produces melanin pigment (Montagna, 1962).

The properties of the epidermis shows topographic differences. In the palms and sole of man, the thickest outer dead layer is compact, but in the epidermis of the general body surface the dead outer layer is flaky (Montagna, 1962). The epidermis is nonvascular and presents openings of cutaneous glands and hair follicles. The epidermis is characterized by a high degree of elasticity. Its free surface may appear smooth or show elevations caused by the underlying papillae (Trautmann and Fiebiger, 1957). On the nose and foot pad of the dog, the epidermis forms independent elevation (Trautmann and Fiebiger, 1957). In cat and mongrel dog, microscopic dermal papillae are covered by thickened epidermis (Strickland and Calhoun, 1963, and Webb and Calhoun, 1954). According to Ellenberger (1906), the epidermis of the horse is 15-80 u thick. The epidermis is thick on the forehead and on the borders of the natural openings. Smith (1888) observed in the horse that the epidermal elevations and depressions are extreme on the lip, straight on the mane and tail, and wavy on the general body surfaces. Szeligowski (1962) found the epidermis of horse skin comparatively thin. Strickland and Calhoun (1963), and Lovell and Getty (1957) found in cat and dog respectively the characteristic small hairless, knob-like projections of the skin, designated as integumentary papillae.

Electron microscopic observation revealed that the mitochondria, endoplasmic reticulum, and the submicroscopic cytoplasmic particulates of the epidermal cells gradually decrease

in quantity from the base of the epidermis to the stratum lucidum (Selby, 1957).

On the basis of histologic organization of the cells, the epidermis is generally divided from within outwards into stratum germinativum, stratum granulosum, stratum lucidum and stratum corneum.

Stratum germinativum: This layer is also known as stratum malpighii. On the basis of the cellular differentiation, this layer is divided into stratum cylindricum and stratum spinosum.

(a) Stratum cylindricum: This is a layer of columnar cells of varying height (Trautmann and Fiebiger, 1957), resting on the basement membrane (Copenhaver, 1964). The contour of the basal surface is undulating due to irregular topography of the epidermal ridges (Odland, 1966). Each basal cell is provided with several cytoplasmic processes which extend a short distance into the dermis (Odland, 1966 and Hu and Cardell, 1962). Copenhaver (1964) believed that these processes anchor the cells to underlying connective tissue. According to Trautmann and Fiebiger (1957), they penetrate the basement membrane. The nucleus of these cells is oblong and the cytoplasm has a fibrous appearance due to the presence of a large number of tonofilaments. Tonofilaments organize to form tonofibrillae (Hu and Cardell, 1962, and Selby, 1957). The cell membrane between the basal cells is folded considerably, giving the impression that the cells are compressed together (Hu and Cardell, 1962, and Copenhaver,

1964). The cells of this layer possess abundant RNA (Odland, 1966). The cells of this layer show mitotic frequency. (Trautmann & Fiebiger, 1957).

(b) Stratum spinosum: This layer, just above the stratum cylindricum, consists of varying numbers of polyhedral cells. The cells of the upper part tend to be flattened. The cells within the stratum germinativum are gradually changing their shape and cytoplasmic constituants through cellular differentiation. As the cells migrate upward, there is dimunition of cytoplasmic basophilia (Odland, 1966). The plasma membrane of the cells of the stratum germinativum in general are in apposition throughout most of their extent, but in the process of tissue preparations, they shrink and remain attached only at the point of the desomosome (Copenhaver, 1964). The connections to the adjacent cells are known as desmosomes. Electron microscopy shows that the point of apposition does not represent bridges of protoplasmic continuity (Copenhaver, 1964). Montagna (1962) stated that thickening of the plasma membrane at the point of contact in the desmosome constitutes two attachment plaques, one from each epidermal cell, about 750 ^{o}A apart. According to Selby (1957), tonofilaments are, for the most part, organized into tonofibrillae in the malpighian layer and appear to be equally plentiful in basal cells as in the cells of more superficial layers. The tonofilaments are attached at both ends to the cell membrane. At these points of attachment the desmosomes adhere so that the tonofilaments

of the whole epidermis are linked together. (Charles and Smiddy, 1957). The tonofilaments do not pass through the cell membrane (Hu and Cardell, 1962).

The mitosis may occur in the cells of the spinous layer (Trautmann and Fiebiger, 1957). Mitotic frequency is greatest during sleep (Odland, 1966; Trautmann and Fiebiger, 1957). According to Bloom and Fawcett (1962), mitotic figures in the Malpighian layer correspond with the intensity of desquamation in a region. This was also reported by Thuringer (1928). Variation of mitotic rate in the epidermis of rat was discussed by Bertalanffy, et al. (1965) during the growth, maturity, senility, and regeneration.

Stratum granulosum: This layer consists of 2-5 rows of flattened rhombic shaped cells with their long axis parallel to the surface of the skin. The cytoplasm contains numerous keratohyalin granules (Copenhaver, 1964). Electron microscopic examination has shown that the keratohyalin granule consists of a dense substance deposited about the pre-existing tonofilaments. The keratohyalin granules are actively synthesized in these cells (Odland, 1966). The tonofibrillae in some cases appear lacking in filamentous structure which is proposed as the macromolecular rearrangement (Montagna, 1962; Selby, 1957). When keratohyalin granules attain their maximum size, the cells of the stratum granulosum lose their nuclei and their organelles. The cells lose much of their water content and become flattened, emerging as fully keratinized cells in the stratum corneum (Odland, 1966).

Stratum lucidum: This is a shiny acidophilic layer of homogenous appearance (Trautmann and Fiebiger, 1957), in which cellular outlines are indistinct and nuclei are rarely perceptible (Odland, 1966). The cells of this layer are more firmly attached to each other and break when an attempt is made to separate them (Chamber and Renji, 1925). Copenhaver (1964), and Trautmann and Fiebiger (1957) stated that the cells of this layer are replaced by a substance known as eleidin. According to Odland (1966), the stratum lucidum is probably a reflection of high order of organization of keratin in the lowermost lamellae of the stratum corneum. The ultrastructure of the fibrils in this layer is altered but the hyalin fibrils terminate at the desmosomes, as do those in the cells of lower layers (Montagna, 1962). This layer does not occur in thin skin and is found only in the thick skin of the human species and some other mammals.

Stratum corneum: This layer consists of anucleate, broad, flat, scaly cells whose edges interdigitate with the edges of the adjacent cells (Trautmann and Fiebiger, 1957; Odland, 1966; and many others) which are constantly desquamated. The cells have definite horny membrane and are closely packed (Copenhaver, 1964) so that no desmosomes are present. The morphological changes occurring within the desmosomes are related to the eventual loss of cohesion (Selby, 1957). According to Keddie and Saki (1965), the normal surface of the horny layer is a more or less continuous sheet of intact cells. Parting of the cells in the usual process of desquamation is by the separation of a single

cell or a block of cells due to the lack of lateral adherance between the cell membrane, rather than disintegration of the containing wall of the individual cells. The cells of this layer are birefringent, a characteristic associated with the presence of the fibrous protein (Odland, 1966). Electron microscopic analysis revealed that the cytoplasm of these anucleate cells consists entirely of a highly organized mass of filaments about 70 to 90 ^{o}A, enclosed in an amorphous dense matrix (Odland, 1966).

The Pigment Cells of the Skin

Melanocytes, the dendritic cells of the adult skin, are the main source of skin pigments.

Origin of melanocytes: The melanocytes, according to Leydig (1876), Ehrmann (1885), Aeby (1885), and Rabel (1896), are of mesodermal origin. They also thought, on circumstantial evidence, that the macrophages of the dermis phagocytose the red blood cells and other cell debris in the dermis and then migrate to the epidermis. Here they discharged their contents as the excretory products of the dermis which, in turn, along with the epidermal cells, are pushed to the cornified layer and finally expelled, from the body. Block (1921) held the view that the melanocytes are of ectodermal origin and their fate is similar to that of the epidermal cells.

The most convincing and modern theory of the neural crest origin was possible to postulate after the dopa technique of Bloch (1927) was established. By this technique,

the site of melanogenesis was established and also the fact that the melanocytes were the sole producer of melanin pigments was proved. Shane (1939), by transplanting neural crest cells from white amphibians to black and from black to white, observed precisely the differentiation of the neural crest to the pigment cells. Similar experiments with tissue of the rat, mouse and chicken conducted by Willier (1953), Rowles (1940, 1947, 1953), Hopkins (1949), Hu et al. (1957), Shane (1944), Weissenfels (1956), and many others, both in vitro and in vivo, and placed the neural crest origin theory of melanocytes on a sound foundation. Rowles (1940, 1947, 1953) undertook perhaps the most convincing and elaborate experiments. She was not only able to show the neural crest origin of melanocytes which gradually migrated to the epidermis for functioning as adult cells but also proved that the immature melanoblasts migrate dorsoventrally. Their migration starts in the mouse embryo of 8-10 somites at the mesencephalic region and gradually spreads towards the caudal region. She found that the melanoblasts reach all the body regions of mouse embryo by the 12th day of gestation. Zimmermann and Becker (1959) studied the phenomenon of migration of the melanoblasts and their location in human fetuses of different age groups and reached the conclusion that the melanoblasts are of neural crest origin. They observed that the migration in human fetuses starts at about 10 weeks of fetal life and reaches the normal distribution at 14 weeks.

Okun (1965) postulated a theory through biochemical, histochemical and ultrastructural study that the melanocytes

and mast cells are of the same group and the melanocytes migrated from the dermis to the epidermis while the mast cells remained in the dermis. According to him, the entire dermis originated from the neural crest and thus the mast cells of the dermis and the melanocytes are of neural crest origin. In summarizing the neural crest origin theory, it postulates that when the two neural folds finally come together and fuse to form the neural tube, some of the cells at the two fusing edges break loose and move down between the tube and the overlying ectoderm and thus become separated from the ectoderm. These cells eventually form the pigmented cells, ganglion cells, and schwam cells. The pigmented cell precursors gradually migrate to the permanent sites and start functioning (Waddington, 1956).

Location of melanocytes in the skin: In man melanocytes usually appear in the dermis at the age of 10 weeks of fetal life (Zimmermann and Becker, 1955, 1959, and Breathnach, 1963 and Breathnach et al, 1963). At birth, all the melanocytes are functioning at the junction of the layer of pigmented basal epithelial cells and not infrequently abutt slightly into the dermis just below this general level. Each melanocyte perikaryon, in most instances, is slightly elongated horizontally and gives rise to a variable number of primary branches, usually 4-5. Billingham and Silvers (1960) observed that the branches diverge repeatedly, subdividing and becoming attenuated as they wave horizontally and upward between the Malpighian cells which separate them. In man

many extend as far as 100 u from the parent cell body. Each branch ends in a sort of swelling or button which is strongly dopa positive and intimately applied to the terminal pole of a Malpighian cell. The distribution of melanocytes and their mode of branching is normally such that scarcely a basal layer of cells is without contact with one of their end cups. Billingham and Silvers (1960) also stated that they are most densely concentrated at the summits and sides of the epidermal ridges. Bloch (1921, 1927), Odland (1966), and Krölling and Grau (1960) also stated, in general, the same principle of the location and branching of melanocytes.

During the development of the animal, while the basal cells of the Malpighian layer invaginate in the formation of the hair follicle, some of the melanoblasts, still undifferentiated, are included in the original follicular invagination (Chase, et al. 1951). These cells are the forerunner of the melanocytes of the bulb. Berry (1953) observed many branched pigment cells in the dermis of the scalp of newborn which are often associated with blood vessels. Zimmermann and Becker (1959) also observed similar dermal melanocytes in the dermis of newborn fetuses. The dermal melanocytes are common in the apes and monkeys (El Bahrawa, 1922; and Adachi, 1903). There are a large number of amelanotic melanocytes present in the outer roots of hair follicles at the middle and lower part. According to Reneto (1963), these cells are normally non-functional and they become functional if for some reason the epidermal melanocytes are lost. Melanogenic

cells identical to dendritic cells were observed by Chase, et al. (1951) in mouse skin on the surface of sebacious glands. He also stated that the dermal melanocytes are present in mice. Danneel and Cleffmann (1954) showed that the various species of rodents have the same pigmentary condition in the dermis as that of monkeys.

The fate of the melanocytes: The melanocytes first appear in the dermis at the third fetal month as immature melanocytes, the melanoblasts, and contain premelanin (Zimmermann and Becker, 1959). The melanoblasts settle in the epidermis and hair follicles at 5 fetal months in human fetuses and gradually mature to produce melanin pigments. From this time on throughout life they are invariably seen in the basal layer. The cells, or their replacement, function as melanin producers. Much evidence was available that they are replaced through regular mitotic and amitotic cell division (Billingham and Silver 1960, Masson 1948 and many others). According to these investigators, relatively undifferentiated melanocytes in the epidermis are capable of cell division. One of the daughter cells becomes a melanocyte and the other is pushed to the suprabasal layer where it also remains as a highly branched cell with clear cytoplasm, never produces melanin granules and contains a characteristic granule (Billingham and Medawar, 1953; Willier, 1953; and Masson, 1948). These non-melanin producing cells are known as Langerhans' cells. The cells that are present in the basal layer also appear clear in hematoxylin and easin sections, but they are dopa positive. On the contrary the

cells of Langerhans in the suprabasal layer may show some mature pigments (melanin) in their cytoplasm, but are never dopa positive (Billingham and Medawar, 1953) and contain a characteristic cytoplasmic granule revealed by gold chloride.

The suprabasal dendritic clear cells occur up to the stratum granulosum in the epidermis and are considered by many to be the cell division product of the melanocytes, which have been pushed up in the process of degeneration (Billingham et al. 1960). Zelickson (1965) observed that the Langerhans' cells have characteristic granules which are different from the melanin granules. It was thought that both the endoplasmic reticulum and the Golgi complex play a major role in melanogenesis. Alteration in either or both of these organelles might account for the relatively different structure of the granules and that the Langerhans' cells are the transitional cells. The Langerhans' cells become effete dendritic cells. The effete form of the cells is thought to be related to lysosomes which have been associated with hydrolytic enzymes of the cells. When the lysosomes membranes rupture, release of the enzyme lysin occurs.

Pigments and Pigmentation

Edward and Duntly (1939) found five pigments and in addition an optical effect which are responsible for the color of normal skin. The pigments are: melanin in the deeper layer of epidermis; an allied diffused substance, melanoid, present throughout the whole epidermis; carotine found in

the stratum corneum as well as in the fat of the dermis and subcutaneous tissue, and reduced and oxyhemoglobins found in the vessels of the dermis and subcutaneous tissue.

The colored races owe their characteristic colors only to the variations in amount of melanin and melanoid. General plan of the pigment distribution is identical in the two groups. Therefore, the color of the skin is attributed to the functional activity of the melanocytes. Melanocytes are stimulated in the presence of sunlight. When an individual is exposed to sun continuously for a few days, melanin production is stimulated; this continues even after a few days of its withdrawal. The melanin is considered to protect the underlying soft tissue against the injurious effect of the ultraviolet ray of the sun.

Hyperpigmentation of the skin is also associated with the action of pituitary hormones, particularly Melanin stimulating hormone (MSH), and adrenal insufficiency as in Addison's disease (the lack of adrenocortical hormones which normally inhibit the release of MSH from the pituitary). Besides, noradrenalin, adrenalin, hydrocortisone, progesterone, estrogen, androgens and thyroin have all been cited as having some effect on pigmentation (Billingham and Silvers, 1960). In pregnancy, for example, hyperpigmentation is observed accompanied by increased excretion of MSH. Hyperpigmentation appears in women at the time of menstruation (McGuire and Lerner, 1963). Copenhaver (1964) stated that certain patches of human skin are specially rich in pigment, for example, circumanal region, the areolae, nipples, the axilla, labia

majora, the penis and the scrotum. The pigment is stored as fine granules within the cells of the germinative layer. The pigments have the tendency to spread from the dark skin to the white skin area as observed by Billingham and Silvers (1960). According to Chauveau (1873) the deep layer of the skin of the horse is composed of soft nucleated pigmented cells. Ellenberger (1906) observed that the skin of the udder of the horse is highly pigmented. Trautmann and Fiebiger (1957) stated the epidermis of domestic animals, except albinos, bear pigment either diffusely or in patches. The pigment granules are present in highest concentration in the stratum cylindricum. They gradually decrease in the more superficial layers of the epidermis. Melanoma, a pathologic condition which occurs in gray and white horses, was mentioned by Chauveau (1873) and described in detail by Hadwens (1931).

On histologic study, it is found that the pigments are usually in the processes of the melanocytes or in the cytoplasm of the Malpighian cells. They form a characteristic supranuclear cap in the Malpighian cell layers (Odland, 1966; and Krölling and Grau, 1960). The melanocytes themselves remain relatively clear though occasionally some pigment may be found in the cytoplasm. It is generally assumed that tyrosine, indirectly, and 3,4-dihydroxyphenylalanine, directly, are the precursors of the melanin pigments (Calvery, et al. 1946). According to Copenhaver (1964), the production of melanin pigments is due to the activity of the enzyme tyrosinase, which appears as a polypeptide. On being activated

by ribosomes they are transferred to the Golgi complex, where they are condensed and packed into units surrounded by membranes. These protyrosinase molecules are arranged in an orderly manner as the membrane bound lamellar units. The units of this stage are known as premelanosomes. When protyrosinase becomes activated as tyrosinase (perhaps with tyrosine), melanin biosynthesis begins and the unit which now contains melanin in addition to tyrosinase is known as a melanosome. The melanin pigments continue to increase in the melanosome complex until the latter is transformed into amorphous melanin granules which do not contain tyrosinase. This differentiation of melanosomes is accompanied by a change in their intracellular position. The premelanosomes appear in the Golgi complex, the melanosomes in the basal portion of the processes and melanin granules chiefly in the peripheral portion of the processes.

Keratin and Keratinization

Keratin is a modified protein and forms the cornified layer of the epidermis--horn, claws, hair, hoofs, chestnut and nails. In the process of keratinization, the epidermal cells undergo a drastic transformation to form the horny tissue consisting of dead cells. The keratin molecule is believed to consist of closely packed polypeptide chains which are held together by the disulfide bond of cystine; the resistance to solvents and enzymes being associated with the close packing of the chains (Montagna, 1962). Thus, the

horny tissue of the cornified cells is well established by -S-S- bonds and some free -SH groups. The major part of the hair, horn, hoof, feather, nail and stratum corneum of the skin is made up of albuminoid proteins. The keratin of hair, nails and other cutaneous appendages contains from 3 to 5% sulfur, while that of skin contains 1 to 3%, nearly all of which is cystine (Hawk, et al. 1947, cited by Montagna). Calvery, et al. (1946) discussed the constituents of keratin. They were of the opinion that the keratins are fibrous structures possessing the phenomenon of elasticity and regular intermolecular folding into grid-like structures composed of polypeptide chains with -S-S- and possibly other cross linkage in the polypeptide grid. According to Menefee (1955) in the epidermis keratin is laid down in sheets, while in the hair it is formed into fibrils. The basis for the difference is thought to be the difference in pressures brought about by active growth of the two differently oriented tissues.

The keratin has been divided into soft and hard keratin. The soft keratin covers the skin as a whole. The formation of soft keratin is characterized by the epidermal cells that are becoming keratinized, accumulating keratohyalin granules in their cytoplasm. Hence, an area where soft keratin occurs, shows a stratum granulosum and the cornified cells of which it is composed, continuously desquamate from its surface. Hard keratin constitutes the nails, the cuticle, the cortex of the hair, feather, claws, the hooves, the horns,

etc. In this there is a gradual transformation from living epidermal cells into keratin. Hard keratin is solid and does not desquamate (Ham, 1961).

Keratinization is the process through which the cytoplasmic constituents are transformed into keratin, a horny albuminoid protein. The keratinization was divided into three forms by Matoltsy (1962): (1) Keratinization through the formation of amorphous cytoplasmic granules. (2) Through the production of cytoplasmic fibrils--hoof, hair, etc. (3) Both fibrils and granules. The keratohyalin granules which are present in the cells of the stratum spinosum are considered to be the precursor of keratin. Meirowsky and Behr (1948) stated that keratohyalin is not the by-product of keratinization but a prokeratin. The nucleus, cytoplasm and intercellular substances all take part in the process of keratinization. Then the nucleus passes through various stages of metamorphosis. According to Rothman (1954), the process of keratinization is not only the transformation of cytoplasmic proteins into keratin fibers but also a complete disintegration of the keratinizing cells. Rothman (1954) and Selby (1957) pointed out that the tonofilaments are the precursors of keratinization which themselves are fibrous in structure and are the crystallization center of the keratin formation. Keratinization starts very early in the periphery of the cell. According to Matoltsy (1962), the epithelial cells of the mammalian epidermis keratinize individually, and the process runs its own course in each cell. The main

constituents of the horny component of cornified cells are derived from cytoplasmic fibrils and keratohyalin granules. The keratohyalin granules disintegrate at an advanced stage of cell maturation and their material mixes with the fibrous cell constituents. Keratohyalin granules contain no -SH groups or -S-S- bonds. Matoltxy (1962) observed that the keratohyalin granules in the cells are closely associated with a fibrous cytoplasmic network. In the cells of the upper granular layer some of the nuclei appear to have degenerated, and the mitochondria occur in small quantity. In the cells of the lower granular layer, the nuclei are intact, mitochondria are abundant and the cytoplasmic particulates occur in large quantity. The keratohyalin granules show no preference with regard to location. The granules are from 1.5 to 4.5 microns in the upper cells and .2 to 1.5 microns in lower cells. The granules are not separated by the limiting membrane. Bern (1954) visualized keratinization as the holocrine transformation of epithelial cells. He observed abnormal transformation of epithelial cells after estrogen administration and vitamin A deficiency resulting from trauma. He thought that the local lack of inactivation of vitamin A is responsible for keratinization. In the process of transformation of the cells of the basal layer in which cytoplasmic fibrils accumulate, the cell division ceases, which means that the cell's synthetic activities are altered from producing materials needed for division to producing keratin precursors (Mercer, 1961).

Keratinization is not a degenerative phenomenon as a consequence of poor nutrition, of dissociation, or other deteriorating factors. Pullar (1964) found in tissue cultures *in vitro* that the skin cultured under strict laboratory conditions undergoes keratinization with the production of histologically normal keratinized cells. The keratohyalin differs chemically from keratin only due to higher content of cystine in keratin. The increase in cystine content is associated with the decrease in sulphydryl containing amino acids. The eleidin granules that occur in the stratum lucidum are thought to be the degenerative remnants of the nuclei and other cell elements (Ludford, 1924). Calvery, *et al.* (1946) described eleidin as a fibrous protein and an intermediate stage of the keratohyalin of the granular layer and of the keratin in the horny layer. Stratum granulosum and stratum lucidum are the transition layers between the acidic stratum corneum and slightly alkaline stratum spinosum. According to Trautmann and Fiebiger (1957), the keratohyalin granules are replaced by a stainable diffuse substance called eleidin in the stratum lucidum. They considered this process is not essential to keratinization. Rothman (1954) stated that the keratinizing cell loses most of its water. The water content varies greatly, mainly because all horny structures, being on the surface and hygroscopic, may take up moisture from the atmosphere. He proposed that the dehydration might require uncoiling of the polypeptide chains and the close packing of the fibrillary crystallites. While the lipids in

the cells remain bound to protein as lipoprotein, they appear separate in the horny structure. Nuclear decomposition was thought to be secondary to cytoplasmic keratinization.

As to the protein metabolism of keratinization, Calvery, et al. (1946) stated that the process differs from the protein metabolism of internal cells. There is selection of polypeptides, high in cystine and tyrosine containing large numbers of -S-S- bonds and there is straightening of the coiled polypeptide chains of the cell proteins of lower layers. The constant desquamation of the horny layer is a gradual process in which few cells are shed at a time. The gradual desquamation prevents the inward movement of material which happens to contact the surface of the skin. The process of cornification in the epidermis is constructed to serve as the barrier to the inward transfer of materials. The vital processes of the mammalian skin, whether these be secretion, excretion, or self-regeneration, all illustrate one principle, a process intended to exclude and expel materials rather than absorb or allow penetration (Calvery, et al. 1946).

Histochemistry of the Epidermis

Glycogen: In contrast to the stratified squamous epithelium of the mucous membrane, normal mammalian epidermis contains a relatively small amount of glycogen demonstrable with histochemical methods (Montagna, 1962). The glycogen is

found in the cells of the upper stratum spinosum (Montagna, et al. 1951). Glycogen-rich cells around the pilosebaceous orifice and the sweat duct may be found. Montagna (1962) believed that the demonstrable glycogen may be seen in the epidermis where the normal rate of keratinization has been slowed down or impaired.

Glycogen was first observed in the embryonic epidermis by Bernard in 1859 (Bradfield, 1951). He observed only a trace or an absence of glycogen in undamaged skin. On the other hand, glycogen was abundant in the regenerating epidermis but not in the basal cell layers. The epidermis becomes free of glycogen after the wound heals. In early human embryos, the epidermis is rich in glycogen except in rudiments of the developing hair follicles where it is absent (Montagna 1962, Berlin and Pridvizhkin 1965). The amount of glycogen in the epidermis diminishes as the fetuses gradually become older, and at 6-7 months of fetal life reaches a minimal concentration. The glycogen in the developing epidermis is rich in epidermal cells which are poor in RNA. Berlin and Pridvizhkin (1965) Bernard (1859), (cited by Montagna, 1962) found the fetal epidermis of pig, cat and calf rich in glycogen. According to Montagna, et al. (1952 and 1962), glycogen is seldom found in the areas of active mitotic activity such as in the lower layers of the stratum germinativum and in the hair bulb. Glycogen appears in the form of fibrils in the epidermal cells and external sheath of hair follicles which sweep from cell to cell along the

intercellular bridges (Montagna, et al. 1952). In general, there is inverse relationship between the presence of glycogen and the process of keratinization (Montagna, 1962). According to Rothman (1954), the most important sites of glycogen in the skin are the keratinized zones of epidermis and hair. The epidermis stores glycogen as long as the liver has not taken up this function. With the development of multiple layers in the skin, the amount of glycogen gradually diminishes. The epidermis also contains PAS positive, monoglycogen that is not hydrolyzed by saliva or diastase. The amount of PAS reactive materials may vary inversely to the amount of keratin present in a given epithelium (Montagna, 1962).

In the epidermis of laboratory mammals there are perinuclear lipid spherules, demonstrable clearly with sudan black. The distribution of the bodies corresponds to the osmiophilic elements in comparable tissues and the structural pattern is similar to that of the Golgi elements in other tissues (Montagna, 1950; and 1962; and Baker, 1946).

Enzyme activities in the epidermis: With appropriate histochemical methods, large numbers of active enzymes are found in the epidermis of the mammalian skin. The coverage in detail of all enzymes is beyond the scope of this paper. However, some very important enzymes that have been demonstrated will be summarized here.

Yoichiro (1965) demonstrated the localization of phosphorylase a, b and kinase in biopsy specimen of human skin. In the epidermis a weak to moderate activity of all three enzymes was observed. Cholinesterase activity of the nerve

fibers in the epidermis and the hair follicles was observed in human skin by Montagna and Ellis (1957) and in the skin of the dog, cat, rat, rabbit and guinea pig by Winkelmann and Schmidt (1959). Montagna (1962) stated that the finding of cholinesterase in the nerves investing the hair follicles, which subserves the touch, is evidence of the presence of cholinesterase in some sensory nerve fibers. In adult skin, only the small, presumably unmyelinated terminal nerves, have variable amounts of cholinesterase. The large, recognizable myelinated nerves rarely show a reaction (Montagna, 1962). Succinic dehydrogenase, carbonic anhydrase monoamine oxidase, phosphorylase, dermopeptidase, phosphomidase (in keratinizing cells) B-gluconidase and esterases, are the important enzymes present in the epidermis (Montagna, 1962).

Cutaneous Innervation

Mammalian skin is the most elaborate sensory organ in the body. It receives the peripheral ramifications of the sensory fibers from the spinal or the cranial nerves, according to the body region. The nerves vary widely in numbers in different parts of the skin (Sisson and Grossman, 1953). Upon reaching their destination, the nerve fibers divide distal to the node of Ranvier into several twigs. They may or may not be myelinated (Trautmann and Fiebiger, 1957). The terminal fibers either end free in the epidermis and in certain parts of the corium or form special microscopic corpuscles of several kinds (Sisson and Grossman, 1953). Besides sensory innervation, the skin receives extensive

efferent supply from sympathetic branches of the autonomic nervous system. The efferent innervation, unlike sensory nerves, is limited to the sweat glands, arrector pilorum muscles and the blood vessels. This enables the organism to perform various physiological activities relating to the adjustment with the environment.

Near the skin, the large nerve trunks form a nerve plexus in the panniculus adiposus. Many fibers follow tortuous patterns to the papillary body where they form a superficial cutaneous plexus. A third, non-myelinated sub-papillary plexus is formed just beneath the dermo-epidermal junction (Montagna, 1962). All nerves innervating the skin pass through a cutaneous plexus and grow finer and finer (Weddell, et al. 1955).

Smith (1888) observed large branches of nerves in bundles of three or four in the deeper part of the horse's lip. These nerves are wavy while passing through the skin to the papillary region. In each dermal papilla there are as many as three nerve loops.

According to Wall (1964), there is a definite pattern of the sensory fibers to the skin. The nerve fibers of the neurons in the dorsal root ganglia and of the nucleus gracilis of the medulla oblongata converge to their respective cells. The cells act as points of convergence of fibers from different parts of the skin. Each cell subserves a larger area of skin than one afferent fiber. The fibers come together in the dermis where they form intricate

interconnected networks (Montagna, 1962; and Weddel et al. 1955), probably its principal sensory end organ (Winkelmann, 1960a, b). Each sensory nerve emerges from a wide variety of morphologically different end organs (Montagna, 1962).

The terminal fibers of sensory nerves do not unite. According to Cauna (1959) in simple receptors they end in free endings, filaments or terminal condensations, with or without ramification. In complex receptors, free endings are uncommon. Instead the nerve fibers increase their receptive surface by ramification into a neurofibrillar apparatus in the form of loose bundles, networks or end bulbs. The free nerve endings that are numerous in the epidermis reach up to the stratum granulosum. In addition there are innumerable numbers of fine nerve endings in the papillary region of the dermis. According to Cauna (1959), the nerve endings are extracellular. Endings in epithelia and in terminal corpuscles are intimately attached to the surface membranes of the related cells which may belong to receptor mechanism and play a part in discrimination of sensory modalities. Human hairy and hairless skin is devoid of intra-epidermal nerves, but the epidermis of the nose of certain quadrupeds contains nerves which grow continuously with the epidermis and undergo atrophy. On reaching the horny layer they end in fading filaments, in solid condensation or break into segments.

Axons have a fibrillar structure, neurofibrils in the receptors undergo degeneration and are continuously replaced by the expansion and growth of the terminal fibers. Loss and replacement of the neural material in nerve terminals is

a physiologic process which facilitates change of a nerve ending in its adaptation to changing functional conditions.

According to Weddell (1941), the nerve plexus below the epidermis consists of medullated fibers of various diameters and fine non-medullated fibers. The thick medullated fibers do not branch. They end in Meissner corpuscles. Smaller medullated fibers go to Krause's end bulbs. The fine fibers undergo repeated dichotomization within the nerve plexus and may give rise to a nerve net, which in turn gives rise to fine beaded terminals, scattered beneath and between the cells of the deeper layer of epidermis. The plan of the dermal nerve network varies with the density of the hair of the skin. In the hairy skin they are distributed mostly around hair follicles, sweat glands, sebaceous glands, and arrector pili muscles (Winkelmann, 1960a). Capsulated specialized end organs are found only in the dense connective tissue underneath the glabrous mucocutaneous epidermis, (Winkelmann 1957, 1959). Winkelmann (1959) stated that without the follicle the nerve net could form a ball and rise up higher in the dermis, simulating a mucocutaneous end organ.

Nerve Supply to the Hair Follicles

As a group, the hair follicles comprise the most important tactile organ in the mammalian skin and are heavily innervated by the dermal nerves. The nerves of the hair follicles and the dermal networks constitute almost all of the nerve tissue of the mammalian skin. The innervation of hair follicles is admirably suited to the tactile sensation

(Winkelmann, 1959). The hair shaft acts as a lever to increase the range of sensitivity following any minute mechanical change (Winkelmann, 1959; and Montagna, 1962). As to the sensory function of hair there are two types: (1) the general hairs of the body coat and (2) highly sensitive tactile hairs of the lower and domestic mammals. Both types of hair follicles are extensively supplied by nerve fibers. As regards the supply to the general hairs, the nerve supply varies directly with the size of the hair produced by the follicles (Winkelmann, 1959). The arrangement of the nerve fibers that supply the follicles is essentially similar to that of the dermal nerve networks (Montagna, 1962 and Winkelmann, 1959). According to these authors, human follicles are surrounded by a collar of nerves. Stem nerve fibers reach the follicle just below the entrance of the sebaceous gland duct (Weddell and Palli, 1954, Weddell et al. 1955, and Montagna, 1962). They give rise to ensheathed branches which extend along the outer layer of the dermal coat, parallel to the hair (Weddell and Palli, 1954, Weddell et al. 1955). One series of stem fibers change direction and pass towards the middle layer of the dermal coat (Weddell and Palli, 1954), where they encircle the hair and give rise to the arborization of fine nonmyelinated fibers which interdigitate with one anoter and terminate freely. The remaining skin fibers lose their sheath as they pierce the vitreous layer of the follicle and give rise to fine axoplasmic filaments which lie parallel to the hair shaft and

terminate freely among the cells of the outer root sheath (Weddell and Palli, 1954, Singer and Salpeter, 1966, Copenhaver. 1964, Dixon, 1961, and Winkelmann, 1959). The fibers of the inner layer also end freely among the cells of the inner root sheath and in large hairs may terminate in small buttons (Montagna, 1962). The hair papilla does not contain any nerves (Winkelmann, 1959).

Tactile hairs: In the mammals with the exception of man, these stiff hairs occur around the face. These tactile hairs are also referred to as sensory hairs, tantacle and erroneously vibrissea (Montagna, 1962). Sinus hairs are not vibrissae (Trautmann and Fiebiger, 1957).

Smith (1888) observed tactile organs in the lips of the horse. The development of the tactile hair follicle and the nerve endings are not proportional to the size of the animals (Vincent, 1913). According to Vincent (1913), the rat has a far more developed tactile hair than the horse, ox or other rodents. Chauveau (1873) observed that these hair follicles are heavily innervated in the horse. Messenger (1890) described the nerve supply to the sinus hairs of mammals. Vincent (1913) gave a detail description of the nerve supply to these hair follicles and reported that the follicles are supplied by two sets of nerves. According to Smith (1888), the dermal nerves give off large branches to these hair follicles and to the external connective tissue sheath. He concluded that no part of the skin is as highly endowed with nerves as this sheath. According to Dixon (1961), who studied the sinus hairs of the upper lip of several mammals, there

are two sets of nerves--one set innervates the follicle from below through the fibrous capsule to spread out over the epithelial root sheath and the other derived from the cutaneous nerve plexus acts as the supplementory supply to the neck of the follicle. The clear description that has been given by Winkelmann (1959) about the innervation stated that two to five large nerve trunks penetrate the connective tissue sac of the hair follicle at its base. These trunks separate into myelinated subdivisions that run through the vascular sinus to the external root sheath of the hair follicle. At the external root sheath a coarse myelinated network is formed and extend towards the neck of the follicle where it forms a circular nonmyelinated network. Some of the nerves terminate in this area below the rudimentary sebaceous glands.

Nerve networks are found outside the connective tissue capsule at the neck and these nerves penetrate the capsule to join the nonmyelinated network.

As regards the terminal nerve endings in the hair follicle, the problems of network or bulb nerve endings has not been settled (Winkelmann, 1959). Tactile disks in association with hair follicles were also discussed.

Straile (1960) observed large hair follicles that show structural specialization sparsely scattered on the skin surface of rodents. Straile (1961) described in detail the follicles and their sensory function and termed them a tylotrich hair follicles.

The Organized Nerve Endings

In the skin of all mammals there are organized nerve endings which are usually found in the mucocutaneous junctions and the glabrous skin. They vary in shape and structure considerably (Montagna, 1962). In the human skin, Weddell and Sinclair (1952) observed numerous organized nerve endings in the finger, nipple, lip, labium major, clitoris, glans penis, and foreskin. In their observations they did not find any evidence of absolute morphological boundaries between one type of endings and the other. One region could be distinguished from another on a neurohistological basis. In the cat, Winkelmann (1957) observed similarities in end organs in the non-hairy skin. End organs were reported by Kawata (1943) in the horse hoof. Smith (1883) observed pacinian-like corpuscles in the lip of the horse. Pacinian-type end organs in the corium of the muzzle of the cow were observed by Sinha (1964). Kuntz and Hamilton (1938) described lamellated end organs in the skin of the cat's forelimb and human skin. Winkelmann (1957) and Strickland and Calhoun (1963) noted encapsulated end organs in the mucocutaneous junctions and the paw of the cat. Tactile disks were described by Winkelmann (1959) which were found to be very close to the hair follicles. Winkelmann (1960a) observed papillary nerves which had some distinct morphological characteristics in mucocutaneous junctions. He considered these a special type of nerve ending . These nerve endings are formed of nonmyelinated nerve fibers, do not possess a terminal expansion and are not lobulated. The

presence of capsulated end bulbs in the mucocutaneous junctions was described by Copenhaver (1964) and Singer and Salpeter (1966). Human digital touch corpuscles, Meissner's corpuscles, are described in all standard histology texts. According to Winkelmann (1957) the end organs in the ear are morphologically similar to those in hairless skin and he postulated a common physiologic function for them. These bodies are supplied by heavy myelinated fibers, and due to their superficial position he suggested acute touch as their function.

Frey (1896) conceived the skin as a mosaic of sensory spots, each of which subserves a single sensory modality. He recognized four primary modalities--touch, cold, warmth, and pain--and believed that each was associated with a morphologically specific nerve ending. He associated hairs and Meissner's corpuscle for touch, Krause end bulb with cold, Raffini corpuscle with warmth, and free endings with pain. Baird et al. (1942) associated pressure, warmth and cold with specific receptors, and pain with free nerve endings. The skin in general has a specific pattern of distribution of specialized endings. Usually, the number of hair follicles and the number of specialized endings in the skin are in inverse ratio to each other (Montagna, 1962).

Skin perceives so many madalities of sensations that it would be impossible for each of them to be subserved exclusively by an anatomically distinct end organ (Montagna, 1962). An attempt to demonstrate specific sensory perception by anatomically distinct nerve endings can be related to touch

(Montagna, 1962). Waterston (1933), considering various physiological findings, concluded that the nerve for touch in man does not convey pain producing impulses. Orimea (1961) and Miller, et al. (1960) (cited by Montagna 1962) and Winkelmann (1960a) considered that the specialized end organs are modified according to the region in which they grow and not according to the function that they serve. The only specialized organ which serves a specific function is the pacinian corpuscle for pressure (Montagna, 1962).

Dermis or Corium

The dermis lying between the epidermis and the subcutaneous tissue consists of dense connective tissue fibers which are arranged irregularly. It is well supplied with vessels and nerves, and contains the cutaneous glands, the hair follicles and smooth muscle (Sisson and Grossman, 1953). Two layers can be distinguished although they blend without distinct demarcation (Copenhaver, 1964). All of the three fibrous connective tissue components are present in both layers of the dermis. The most superficial layer of the corium is the papillary layer, narrower of the two zones, composed of fine collagenous fibers interwoven with fine elastic and reticular fibers (Rook and Walton, 1965). The superficial surface, beset with blunt conical prominences, the papillae project into the corresponding depression of the epidermis (Sisson and Grossman, 1953). The papillae contain loops of capillaries (Odland, 1966, and Trautmann and Fiebiger, 1957). The papillae are small and poorly differentiated in

the hairy skin. Wherever the hair coat is dense, the dermis between the hairs is either smooth or shows slight elevations and a few small folds (Trautmann and Fiebiger, 1957). The papillae vary considerably in size and number in different parts of the body (Odland, 1966). There are simple papillae, which may be long and slender or short and thick. Others are large and have a bifurcated end, especially at the mucocutaneous junction (Trautmann and Fiebiger, 1957). According to Ellenberger (1906), the papillary body is absent in hairy skin. Smith (1888) observed well developed papillae on the lips of the horse which gradually increase in length until the mucous membrane is reached. They are well supplied with nerves. In the mane, the corium is well developed and the papillae are mostly square topped. In the papillary body, widely separated delicate collagenous, elastic and reticular fibers, enmeshed with superficial capillaries, are surrounded by abundant viscus substances (Montagna, 1962). The hairs are accompanied by the cutaneous glands and the smooth muscle in the papillary layer (Schönberg, 1926).

The stratum reticulare is not sharply marked off from the stratum papillare. It is the deeper and heavier layer of the corium (Trautmann and Fiebiger, 1957). It is composed of dense, coarse, branching collagenous fiber bundles which form layers mostly parallel to the surface. Alternate layers are at an angle to each other (Montagna, 1962). In addition to collagen fibers, the reticular layer is composed of abundant network of coarse elastic fibers (Copenhaver, 1964).

According to Schönberg (1926), the reticular layer in the horse is poor in elastic fibers, the number of fibroblasts are not as numerous as in the papillary layer, and heavy blood vessels pass through the area. In the skin of the croup and the whole lumbar and sacral region, extending to the hip joint, there is still another wide layer of collagenous fibers underneath the reticular layer. He called this part "Spiegel" (mirror) as it glazes when tanned. Odoni (1951) described the histology of this layer and observed that the thickness of the corium of the area is 5340 u (papillare layer--2740 u and reticular layer--2600u), whereas in the general skin area the corium is 3420 u on an average (papillare layer--1640 u and reticular layer--1780 u). The collagen fiber bundles are thin and finely interwoven.

In many respects, the dermis of the horse is similar to that of the cow through its arrangement of connective tissue fibers and the network of fine elastic fibers (Ellenberger, 1906).

The Cellular Components of Dermis

In general, the cells of the dermis consist of the connective tissue cells. The cellular elements can be compared favorably with those of the cells of the subcutaneous tissue (Bloom and Fawcett, 1962). In normal skin fibroblasts are the most numerous cells with mast cells next in abundance. The cells are most numerous in the papillary layers rather than in the reticular layer (Montagna, 1962, Bloom and Fawcett, 1962, Porter, 1966). In addition to fibroblasts and

mast cells, the dermis contains macrophages, plasma cells and wandering cells from the blood (Montagna, 1962, Copenhaver, 1964). These authors reported dermal chromatophores are sparingly distributed in the dermis, particularly in heavily pigmented skin. Large numbers of undifferentiated mesenchymal cells are found in the dermis between the various dermal tissues (Robb-Smith, 1945). Under suitable stimuli, the reticular cells in the dermis may proliferate and differentiate to form various mature cells (Robb-Smith, 1945).

In this review, the description of the commonly occurring cells of the dermis only will be included.

Fibroblasts: According to Porter (1966) and Copenhaver (1964) the fibroblasts are responsible for fiber formation and also for ground substances. Their shape is determined by their environment. In the reticular layer of the dermis, they are usually very thin, long and compressed and in the papillary layer they are very large and resemble mesenchymal cells (Montagna, 1962). Under the light microscope, they appear ameboid and are spindle shaped, with processes spreading out from them. The cell membrane is extremely delicate and difficult to see under the light microscope. The nucleas is oval or spherical. The cytoplasm stains lightly with basic dyes buffered in acid range and generally appears homogenous. According to the above authors, the fibroblasts in the papillary layer are more basophilic. Fibroblasts enlarge following tissue injury and become particularly active in tissue formation (Copenhaver, 1964). Montagna (1962) maintained

that perhaps the fibroblasts are the stem cells from which arise all the other connective tissue cells. It is for this reason that some investigators call fibroblasts the relatively active cells while the fibrocytes are called inactive cells (Copenhaver, 1964).

Mast cells: The mast cells occur in varying numbers in all the connective tissue. Any connective tissue cell containing cytoplasmic granules which stains metachromatically with toluidine blue is a mast cell (Montagna, 1962). The mast cell tends to congregate along small blood vessels (Montagna, 1962, Porter, 1966, Copenhaver, 1964, Nicholas, 1963, and many others). The average mast cell count in human skin per cubic mm was 7225 (Mikhail and Milinska, 1964). In human skin they occur in the various layers of the corium in and around the hair follicles, even in some cases in the epithelial layer (Nicholas, 1963). All skin areas of the donkey, examined by Dozza and Rampichini (1963), contained mast cells, localized prevalently in the upper dermis, around vessels and in the papilla. Waldeyer (1875) observed much larger dermal connective tissue cells with basic staining granules, occurring usually on the perivascular zone.

The mast cells are large connective tissue cells with a central nucleus and ample cytoplasm with more or less densely packed granules (Hansen, 1957). The form of the mast cells may be round, oval, pyriform, spindle or star-shaped (Nicholas, 1963). The granules of the mast cells stain not only in a basic tone but also metachromatically (Ehrlich, 1879). The granules are highly refractile, more or less water soluble

and stain yellow when treated supravitally with neutral red (Montagna, 1962, and Porter, 1966). The granules may appear in the ground substance, either by a disruption caused by some violent physical action or a chemical reaction (Hansen, 1957).

Mast cells increase in number in several itching skin diseases. In the skin carcinoma of man and animals, they seem to form a barrier between the tumor and the normal tissue (Montagna, 1962). It is difficult to make a generalization in the mast cells of different animals as there are considerable species differences (Riley, 1959). The mast cells have been shown to produce heparin (Porter, 1966, and Holmgren, and Wilander, 1937) or at least an anticoagulant substance similar to heparin (Montagna, 1962). The mast cells contain and release histamine (Porter, 1966, Copenhaver, 1964, and Montagna, 1962) which is liberated from the cells into the surrounding tissue in response to allergic conditions. Serotonin, a vasoconstrictor substance, is also thought to be released by mast cells (Copenhaver, 1964, and Porter, 1966). Mast cells can increase by mitosis (Porter, 1966). All observations lead to the fact that they also form from the fixed connective tissue cells or nongranular precursors (Porter, 1966, and Bates, 1934).

Macrophages or histiocytes: These are also known as "resting wandering cells" as they resume their wanderings upon suitable stimulation (Trautmann and Fiebiger, 1957). They resemble fibroblasts (Copenhaver, 1964, Montagna, 1962, and Porter, 1966). They have sharper outlines than do fibroblasts; the cytoplasm is granular and the nucleus is condensed

and more basophilic. When they are activated, the entire cell becomes larger, with a prominant nucleus and the cytoplasm becomes granular vacuolated and contains ingested materials (Copenhaver, 1964, and Montagna, 1962). Though in normal skin they are not easily identifiable, when particulate matter has been injected into the skin, histiocytes can be recognized easily by their capacity to ingest particles (Montagna, 1962). They act as scavengers, engulf extravasated blood, bacteria and inert foreign materials. If the particle is large, several macrophages join together to form a foreign body giant cell, a multinucleated cell, to engulf the particle. The organic materials which they engulf are usually digested by proteolytic enzymes, and the foreign matter which resists digestion remains in the cytoplasm (Porter, 1966).

There are various conflicting opinions about the origin of the macrophages. According to popular belief, they belong to the reticulo-endothelial system, a system consisting of a group of cells having phagocytic activity. Montagna (1962) stated that the macrophages arise from a variety of different cells, such as fibroblasts, lymphocytes, skeletal muscle and Schwann cells. Chevremont (1948, cited by Montagna) observed that a surprisingly high number of macrophages appear spontaneously in cultures of skeletal muscle or of subcutaneous connective tissue. When the tissues <u>in vitro</u> are crowded in the flask, abundant transformation of muscle fibers to macrophages takes place. This was later confirmed by

Fazzari (1951). According to Porter (1966), monocytes of blood and macrophages of tissue are the different functional phases of the same cell type. They may arise by mitotic division, by activation of fixed macrophages, and by further differentiation of monocytes emigrating from the blood stream. From the above discussion it may be concluded that the macrophages may be differentiated from a variety of cells in the tissue according to the environmental condition in which they are functioning.

The Fibrous Components of the Dermis

The dermis is composed of all the three fiber components of connective tissue: 1. Collagen fibers, 2. Elastic fibers and 3. Reticular fibers. Their orientation, depending on the region, is different.

Collagen fibers: The collagen fibers vary considerably in their individual fiber thickness. The fibers are thickest in the reticular layer and are intermingled with a few coarse elastic fibers. The collagen fibers in the papillary layer are very fine and entwine with the medium to fine elastic fibers and fine reticular fibers. The collagenous fiber components are fibrils with diameters of 30-200 mu (Porter, 1966). The fibers are formed by submicroscopic fibrils. There are also subfibrilar units, the filaments and protofilaments (Bear and Morgan, 1957). The electron microscopic study of the fibrils was reported by Reed (1957). The fibrils appear to be composed of two sets of filaments which cross each other in spiral fashion.

The configuration suggests that the protofibrils, the coiled-coil system of three polypeptide chains, as indicated by the x-ray diffraction studies, are twisted together to form filaments (Reed, 1957). According to Borustein and Karl (1965), the isolated polypeptides show wide differences in amino acid composition, having different molecular weight and the primary structure of each chain appears to be unique throughout its length. The filaments are then organized together in a steep, spiral fashion to form two independent identical strands. The two strands then spiral around each other to make up the complete fibril (Reed, 1957). Highly refractile constricting fiber rings, the Henle's rings, were observed in large numbers in ox hide and calf hide. Since they did not stain with any common elastic fibers stain, it was concluded that the Henle's rings resemble non-swelling collagen (Felsher, 1966).

Orekhovitch and Shpikiter (1957) proposed a phasic derivation of collagen from procollagen which is usually present in the skin. The procollagen is higher in the skin of young animals and diminishes greatly as the animals become older. Grassmann (1955) suggested three stages in the formation of mature collagen. The tropo-collagen gives a periodic cross-striation of fibers of 2000 A^{o}, which is metabolically very active, and present in ground substance of connective tissue. The next stage, which is pro-collagen, is metabolically less active and present in newly formed collagen fibers which gives a periodic cross-striation of 650 A^{o}.

The final stage is the condensed fibers, metabolically very inactive with cross-striations of 650 A^{o}. This constitutes the principle mass of collagen fibers.

Elastic fibers: In addition to collagen fibers, the dermis is provided with a dense network of elastic fibers which are interwoven with the collagenous elements. In the region of the basement membrane, the elastic fibers are extremely delicate, whereas in the papillary layer they are much coarser. They are thickest in the reticular layer where the elastic networks are particularly abundant (Porter, 1966). Sinha (1964) described the elastic fibers in the lower strata of the corium of Holstein cattle. These fibers are all thick, abundant, and generally parallel the surface of the skin. Dick (1947) reported that in the deeper layer they may be arranged in bundles in man. They are condensed about the hair follicles and the sweat and sebaceous glands and from the papillary layer extend into the papilla (Bloom and Fawcett, 1962). The fine elastic net becomes greatly enlarged and the fibers are more numerous in connection with the origin of the arrector pili muscle. The fibers extend close to the epidermal cells and are spread over a considerable area in relation to the origin of each muscle (Dick, 1947). In general, the elastic fibers are very thin, highly refractile strands which branch and anastomose freely to form a taut network. When broken, they kink and curl as they recoil like tense wire. The elastic fibers are optically homogenous even at higher resolutions of electron microscopy (Porter, 1966).

Jerrett (1958) considered the skin *in vivo* a gel in which polypeptide macromolecules are oriented. The latter become the elastic fibers noted in the fixed tissue. He argued that the gel itself is elastic and the fibers may act as tightening agents. According to him, polymerization results from fixing agents and histological preparations show only artifacts.

Elastin makes up only 2% of the dry weight of human skin and its chemistry is not much advanced (Montagna, 1962). Hall, *et al.* (1955) suggested that the elastin could be considered in two phases--one amorphous and one fibrous, the former surrounding the latter and affording it protection against solubilization. This outer covering was described as containing a mucoprotein and its presence was regarded as the stabilizing factor for the fiber as a whole. Hall *et al.* (1955) postulated a theory that the enzyme elastase is also dual in nature, one enzyme being specific for the inner fibrous protein and the other for the outer amorphous mucoprotein. This introduces the possibility that mucopolysaccharides act also as a stabilizer in the sense of a protective sheath. According to Hall (1957), some of the collagen fibers do apparently convert completely to elastin. He considered that there may not be any single entity 'elastin' but rather a series of elastins differing in their amino-acid composition. Elastic fibers are isotropic but begin to show uniaxial birefringence when stretched 100 to 150% of their

original length, which suggests that elastin molecules lie in a randomly crumbled position and when pulled tend to go back to the original position (Montagna, 1962).

Reticular fibers: The dermis, particularly the papillary layer, contains a delicate network of freely branching non-elastic reticular fibers interwoven with the collagen and fine elastic fibers. They are also called argyrophilic fibers. They are very closely associated with the basement membrane at the dermoepidermal junction, around the hair follicles (Dick, 1947) on the wall of the blood vessels and surrounding the cutaneous glands.

Reticulin consists of fine (1-4) isotropic fibers which show true branching usually at right angles (Robb-Smith, 1957). In mature connective tissue, reticulin often appears to merge with collagen fibers and the angular branching which is seen in relation to the basement membrane between the connective tissue is very characteristic and predominant (Robb-Smith, 1957).

The electron microscope shows these fibers are made up entirely of very fine fibrils 200-300 A° in diameter (Porter, 1966). In the embryologic development and in the healing of wounds, the fine argyrophilic fibers which appear early are subsequently replaced by coarse fibers of collagen (Porter, 1966). There is an imperceptible emergence from the fine argyrophil reticular fibrils to the non-argyrophil collagen fibers (Robb-Smith, 1945). The only differences between collagen and reticular fibers probably is physical in nature

and only the fine fibers take up the silver stain (Mallory and Porter, 1927). The reticular fibers are probably procollagenous elements and do not constitute a separate type of fiber (Montagna, 1962). Therefore, the principle difference between reticular and collagen fibers is one of size (Porter, 1966). Also x-ray diffraction patterns of the fibers from the dermis of newborn rats are like those of the collagen of the adult (Bensley, 1934, cited by Montagna, 1962). On histochemical studies, the reticular fibers are strongly PAS reactive while the collagen fibers are mildly PAS reactive (Montagna, 1962, Copenhaver, 1964, Porter, 1966, and Robb-Smith, 1957). Both fibers are stained alike by acid aniline (Montagna, 1962). All these evidences suggest the reticulum as the precursor of collagen (Montagna, 1962).

The Ground Substance

The ground substance of the dermis is a semifluid, nonfibrillar, amorphous substance that fills the spaces between the fibers and cells. There is more ground substance in the papillary layer than the reticular layer (Montagna, 1962). Ordinarily in normal tissues, the gelatinous character of the ground substance prevents the spread of foreign substance (Porter, 1966).

The chemical composition of ground substance is very complex. Acid mucopolysaccharides are the most important components of the ground substance, which is mildly PAS reactive and metachromatic (Montagna, 1962). Acid mucopolysaccharide has been divided by Meyer, et al. (1957) into

two different types according to chemical composition: (1) non-sulphated mucopolysaccharide which consists of hyaluronic acid and chondroitin and usually occurs in connective tissue other than hyaline cartilage, and (2) sulphated mucopolysaccharide, which does not contain hyaluronic acid and occurs in cartilage. Besides mucopolysaccharides, ground substance contains neutral heteropolysaccharides, proteins, metabolites and antibodies (Montagna, 1962). Acid mucopolysaccharides in connective tissue may be concerned in regulation of the nucleation and growth of fibrils (Montagna, 1962).

The Basement Membrane

The basement membrane, a thin homogenous membrane is situated between the epidermis and the dermis. The basement membrane provides the mechanical basis upon which cells can develop complexities (Pease, 1958). It serves to anchor the epidermis to the dermis (Odland, 1958). The conventional basement membrane is known to be rich in mucopolysaccharides and strongly PAS positive (Hay, 1966, Mercer, 1961, and Pease, 1958). Frieboes (1920),(cited by Montagna 1962) visualized the basement membrane as a complex argyrophil reticulin. In general, the reticulin is a component of the mammalian basement membrane (Robb-Smith, 1957). The staining reaction of the basement membrane is not uniform (Lillie, 1952), but varies from place to place (Robb-Smith 1957, and Mercer, 1961). The reticular fibers in the basement membrane

form a dense network separating the epithelium from the connective tissue (Bloom and Fawcett, 1962). Thus, the basement membrane, visible under the light microscope, does consist of a continuous mesh of argyrophil fibrils (Montagna, 1962). According to Bloom and Fawcett (1962), when the ground substance surrounds certain structures or is at the base of certain epithelial structures, it is so modified that together with the enclosed reticular fibers it forms the basement membrane. Hay (1966) considered the basement membranes to be the product of the secretory activity of some of the epithelial cells which they underlie or other cells of the dermis.

Odland (1958), using the electron microscope confirmed the existance of a moderately dense homogenous membrane lying below the basal surface of the basal epidermal cells and not penetrated by dermal collagen filaments in the vertebrate skin. A membrane about 350 ^{o}A thick follows the basal contours of the epidermal cells and is separated from them by a space of 350 ^{o}A. No filaments, either epidermal or dermal cross this membrane (Montagna, 1962). In describing the general basement membrane, Hay (1966) divided it into (1) basal lamina, the most consistent dense filamentous sheet which attaches to the plasmalemma of the basal epithelial cells and the underlying reticular tissue; (2) the reticular lamina of the basement membrane which is composed of condensed ground substance and fine reticular fibers. According to Hay (1966), reference to the basement lamina as a basement membrane by the electron

microscopists, creates confusion because it ignores the reticular lamina which is usually the component seen under the light microscope.

It, therefore, may be considered as a two-layered membrane. The basal lamina is intimately associated with the cells of the basal layer and a reticular lamina composed of reticular fibers enmeshed with ground substances, associated with the dermis.

Dermo-epidermal Junction

The contact surface of the epidermis and dermis is wavy. Epidermal cones and ridges of different sizes, commonly known as rete pegs, but better called ridges (Montagna, 1962) project into the dermis. These ridges may be branching. There are corresponding furrows and ridges on the surface of the corium to fit exactly with the epidermal ridges and furrows. Thus, the dermis enclosed within the ridges of the epidermis forms the vascularized dermal papillae (Copenhaver, 1964, and Montagna, 1962). The network of epidermal ridges complement the dermal papillae, which are different in different parts of the skin (Ross, 1965). Montagna (1962) considered the characteristic regional differences in the architecture of the epidermal ridges and papillae are related to the arrangement of hairs and sudoriferous glands. The epidermal ridges tend to converge towards the ducts of sweat glands and hair follicles in a rosette pattern.

The cells of the basal layer send a number of delicate protoplasmic processes into the dermis (Montagna, 1962, Copenhaver, 1964, Odland, 1950, Trautmann and Fiebiger, 1957, and many others). These fine processes fit into the meshes of the reticular fibers of the basement membrane. Odland (1958) considered the processes variable in width and depth of penetration. The undulating cytoplasmic membrane of the basal cell is provided on all its basal surfaces with dense thickenings. Bundles of tonofilaments appear to attach to these thickenings.

Dick (1947) noted almost complete absence of fibrils or fibers under the epidermis of 5-year-old children. At 20 years a well developed fibrous plexus appears which increases and the individual fibers thicken as the individual becomes older. Most of these fibers are reticular fibers and are very closely associated with the cytoplasmic processes of the epidermal cells. Under light microscopy, these fibers appear to terminate in a bulbous end in contact with the basal epithelium. Reticular fibers possess no free endings, instead they form continuous networks. Odland (1950) concluded that the reticular free endings interdigitating with cell processes are actually the cut ends of the reticular meshes. In the papillae of an obliquely cut lip Dick (1947) observed that the fibers are wavy and just below the epidermis the short blunt ends reach the basal cells. He could not say that these fibers actually anchor the epidermal cells with the dermis.

The relationship between the elastic fibers of the dermis and the cells of the basal layer is also very intimate and these fibers could anchor down the epidermis (Montagna, 1962). The dermo-epidermal junction is easily separated by trypsin digestion (Medawar, 1941). According to Medawar (1941), the elastic fibers of the basement membrane play a major role in anchoring the epidermis with the underlying tissue. Pease (1958) concluded that definitive elastin is deposited within a precursor matrix of polysaccharides. Under some circumstances the basement membrane is attached with the underlying connective tissue by direct continuity with the elastic fibers. Comparing the photographs of skin stained for reticular tissue with those stained for elastic tissue, Dick (1947) stated that they have a very different arrangement and distribution, and are distinct from each other. There is no continuation of the fine elastic fibers to the basal cells, instead the reticular fibers led to the base of the cells. There is always a distinct space separating the epidermis from the fine elastic plexus.

Blood Supply

The skin has a very rich and efficient blood supply for the nourishment of the tissue, and temperature regulation. The skin also participates in the general blood pressure regulation. It receives about 10% of the total blood supply (Burton, 1966) which increases significantly during hot weather. The basic vascular distribution pattern is similar

in all the animals, though there is considerable variation in respect to number and size of the vessels occurring in different areas of the skin. The vascular pattern is influenced by the thickness of the skin, type and number of cutaneous appendages present and the relation to the skin of the underlying tissue (Montagna, 1962). In man, two arterial plexuses are present in the skin: (1) the cutaneous plexus and (2) the subpapillary arterial plexus. In the skin of cattle, Goodall and Young (1955) recognized three plexuses. The first lies below the corium, the second is at the level between that of the sweat glands and sebaceous glands, and the third extends from beneath the epidermis to above the second plexus and is a deep network of many fine blood vessels. Both the hair follicles and sweat glands are supplied with blood from the second plexus. Hair follicles and sebaceous glands also receive their supply from the third plexus. From the third plexus, being subepidermal, the terminal arterioles give rise to numerous twisted capillary loops lying in the dermal papillae. The papillae of the follicle receive their rich blood supply from the deeper arterial plexus (Odland, 1966). According to Zweifach (1959), the terminal branching of the arteries has a regular pattern of interconnecting links to form interarterial networks. The adjacent link in these meshes gives off cross branchings that are connected by arterial capillaries. The capillary branches underneath the epidermis come directly from the inter-anastomosing arterial arcades. The hair follicles and

straight portion of the ducts of eccrine sweat glands in man are accompanied by parallel longitudinal vessels that are interconnected by arteriolar and capillary cross-shunt and anastomoses (Montagna, 1962). The follicles of the skin of the horse are completely encircled by vessels and the dermal papillae contain 3-4 vessels (Smith, 1888). The hair follicles of cattle are also very rich in blood supply (Rook and Walton, 1965). The epidermis is nourished by nutrients from the vessels of the dermal papillae and sub-epidermal capillary system. The nutrients reach the cells by diffusion.

Venous blood drains via different channels from the superficial part of the dermis and reaches a venous plexus at the lower dermis at the level of the cutaneous arterial plexus (Odland, 1966).

Arterio-venous anastomoses: The presence of arterio-venous anastomoses in the dermis is of great importance to the histologist for its peculiar arrangement and structural development. These vessels short circuit, or act as a shunt, between arterioles and veins. They are of considerable importance functionally in the regulation of body temperature, providing a shunt to diminish flow through extensive areas of peripheral capillary beds, thereby decreasing loss of heat by convection and radiation from the peripheral vessels (Odland, 1966). The arterio-venous anastomoses usually show a long tortuous vessel which has an end artery just before the controlling metarteriole. In the course, there is a

glomus body arranged circularly (Burton, 1966) which contains special contractile epitheloid cells (Burton, 1966, and Copenhaver, 1964). The shunt empties into the venous system by a long tortuous vessel (Burton, 1966). Arterio-venous anastomoses in large numbers have been reported in the ear of the rabbit (Burton, 1966), in the human fingers and toes (Montagna, 1962) and in the external ears of the Rhesus monkey, cat, dog, guinea pig, horse, sheep, goat, and pig (Danial and Marjorie, 1956). Mention has been made of the presence of arterio-venous anastomoses in large numbers in the dermis of the coronary border, and hoof of the horse. They are also present in the papillae of the horse hoof (Clara, 1956).

Recently other anatomical peculiarities have been reported in the arteries leaving the main uterine arteries in rats and other species. These arteries have an arterial cushion, so that blood is withdrawn from the axis rather than near the wall (Burton, 1966). Forman and Moffat (1961), (cited by Burton 1966) concluded that in arteries with a cushion, hemoglobin concentration is greater than the main artery and for those without a cushion less than the parent artery. Such anatomical pecularities were reported in the arteries of the kidney also (Burton, 1966).

The Hair

The hairs are dead, horny, elastic structures, composed completely of packed keratinized cells, which grow out of

epithelial pockets, the hair follicles. In fur bearing animals, the hairs serve as an important organ of protection by insulation and tactile perception (Odland, 1966). The hairs traverse the dermis to varying depths (Copenhaver, 1964). The proximal part, or root, is set obliquely in the skin. The hair root is attached to an underlying dermal papilla by means of its knoblike, hollow proximal end called the hair bulb (Trautmann and Fiebiger, 1957). The morphologic characteristics of the hair vary from one species to another (Montagna, 1962), and even the angle and direction of the hair vary with the species and body region (Trautmann and Fiebiger, 1957). Hairs may be spiny, stiff, soft, long, short, thick, thin, woolly, colored, or white (Montagna, 1962). The skin of domestic animals is covered with hairs, except at the mucocutaneous junctions, foot pads, and the nose. The hairs are classified according to most authors into (1) cover hairs, (2) wool or lanugo hairs in sheep or undercoat hairs in the goat, carnivores and some breeds of swine (Trautmann and Fiebiger, 1957), (3) special or tactile hairs. Smith (1888) divided the hairs of the horse into three classes: (1) Temporary hairs, covering the general body surface, (2) Permanent hairs--the hairs of the mane and tail and (3) The tactile hairs or feelers. Sisson and Grossman (1953) divided the hairs of all domestic animals into two broad groups: (1) the ordinary coat hairs, and (2) the special hairs which are found in different places--(a) tactile hairs - about the lips, nostrils and eyes, (b) eyelashes or cilia, (c) tragi of the external ear,

(d) vibrissae of the nostrils. In addition in horses the mane (Juba) springs from the dorsal border of the neck and adjacent part of the withers; the foretop (cirrus capitis) from the anterior part of the mane; and the tail bears very large and long hairs except the ventral part known as cirrus caudae. Tufts of long hairs on the flexor surface of the fetlock surround a horny growth which is termed "ergot" (Chauveau, 1873). According to Smith (1888), the hairs of the mane and tail are thicker and coarser in texture in cart horses, whereas in the thoroughbreed horse they are comparatively fine. Breed differences in the development of these special hairs vary widely (Sisson and Grossman, 1953, and Chauveau, 1873). The hair types in different animals has been reviewed by Sinha (1964) in his thesis on the microscopic anatomy of the integument of Holstein cattle.

Arrangement of hairs: The arrangement of hairs and their pattern of distribution varies greatly from species to species. In horses and cattle, hairs erupt on the skin singly (Krölling and Grau, 1960). Hairs occur in groups in dogs, cats and pigs. There are usually three hairs in a group, of which one is the main hair and is longer than the other two. The hairs are arranged in groups of 3 in the pig (Smith and Calhoun, 1960, Ellenberger, 1906, and Marcarian and Calhoun, 1966) and dogs (Webb and Calhoun, 1954, and Lovell and Getty, 1957). In the pig each follicle contains one hair (Smith and Calhoun, 1964). In the cat, 12-20 hairs occur in a group and 2-5 groups around a large central guard hair. Each

Each lateral group usually contains 3 primary hairs surrounded by 6-12 lanugo hairs (Strickland and Calhoun, 1963). Thus, in carnivores a whole bundle of hairs projects from a common follicular opening (Trautmann and Fiebiger, 1957).

Development of hairs and hair follicles: Dry (1926) suggested 3 stages in the development of hairs in mice. The following terms may be used in discussing the development of hairs in any mammal. The terms are: (1) anagen--active proliferation period, (2) catagen--cessation of proliferation and pigment deposition and (3) telogen--the resting period.

During the development of the animal, the first indication of a follicle is an invagination of the basal cells of the Malpighian layer of the surface epidermis. These cells give rise to external root sheath cells. Some of the undifferentiated melanoblasts are also included in the original follicular invagination (Chase, et al. 1951). The follicular slope probably results from unequal growth on the opposite sides of the primodium (Colin, 1943). The terminal portion of the invaginated Malpighian layer becomes enlarged as the result of greater mitotic activity and it becomes indented from below by a cluster of connective tissue cells, the potential hair papilla (Odland, 1966). Here the hair bulb is established on the papilla. The bulb is the extension of Malpighian cells, the site of mitotic activity in hair proliferation (Chase, et al, 1951). According to Montagna (1962), the papilla remains attached to a basal plate of dermal cells by a narrow stalk. The pigment cells migrate to the upper

part of the bulb and the cells below the pigmented layer form the matrix of the follicle. A cone of keratinized cells appears in the center of the upper part of the bulb above the apex of the dermal papilla. According to Odland (1966), subsequent proliferation of the lowermost cells of the bulb results in the outward extension of the keratinized cone. This is the inner root sheath, which grows upward through the solid epithelial column and forms a keratinized lining for the hair canal through which the hair grows. The follicle becomes a tube formed by the outer root sheath around a keratin cord, the inner root sheath (Montagna, 1962). The cells of the hair matrix proliferate, which results in the outward displacement of the overlying matrix cells and forms the keratinized hair shaft. The hair shaft thus formed, extends through the tubular inner root sheath (Odland, 1966). According to Montagna (1962) the tip of the hair is always free of pigments and the first hairs formed have no medulla. A glassy membrane is formed around the lower half of the follicle, below the bulge. Two connective tissue envelopes also differentiate around the follicle. The cells of the connective tissue between the bulge and the surface differentiate in a band of smooth muscles, the arrectores pilorum muscles.

Replacement and regeneration of hairs: Shedding of hair takes place in most mammals at regularly recurring periods. In man, there is constant loss and replacement of hairs (Copenhaver, 1964). This is more obvious in animals that

live in the far north. The northern animals commonly grow a new coat for each winter and lose it for each summer (Ham, 1961). The horse changes its coat twice a year, once in the spring and again in autumn. In the spring a fine short coat is developed and in autumn the fine hair coat is replaced by long and often shaggy hairs (Smith, 1888). The ponies in Britain shed their coat between the end of March and end of May. This shedding of the winter coat may be delayed due to a cold season. The short fine summer coat lasts from June to August, the adult winter coat from September to May (Rook and Walton, 1965).

According to Bloom and Fawcett (1962) and Copenhaver (1964), when the growth of hair ceases, the multiplication of the hair matrix slows down and finally stops. The base of the shaft and the root gradually become thinner. The elements which cover the summit of the papilla become cornified and hair becomes club shaped. The root separates from the papilla, moves towards the neck of the follicle, and the hair either falls or is pulled out. The papilla become smaller, atrophic or disappear.

It is supposed that subsequent hair generations result from reactivation of dormant hair follicles stimulated by the proliferative activity of the hair germs (Odland, 1966).

The histologic structures of the hairs: The morphologic characteristic of hairs vary from one species to another, and even hairs of the same animal may differ markedly in various regions of the body. Hairs show great variations in

diameter and shape. Most hairs are round and oval but others are also flattened (Montagna, 1962). The hair is composed entirely of epithelial cells (Copenhaver, 1964). It consists of medulla, cortex, and cuticula.

The medulla is absent from the finer, shorter (Lanugo) hairs and the human scalp hairs (Copenhaver, 1964, and Trautmann and Fiebiger, 1957) and frequently fails to extend the whole length of the hair (Copenhaver, 1964). The medulla, when present, consists of one or more rows of cuboidal cells with shrunken nuclei (Odland, 1966). According to Trautmann and Fiebiger (1957) it is solid in the region of the root but, contains air vacuoles in the shaft. The medullary cells in the hairs of the horse are rectangular, separated by wide lighter streaks and the borders appear rough. According to Marshall (1902), a characteristic feature of equine hair is the presence of a medulla. The medulla has the tendency to disappear at irregular intervals on the hair shaft, leaving air spaces of all sizes. In thoroughbreds, ponies, and American chestnuts, the medulla is circular and pigmented (Glaister, 1931). The hair of the pig has practically no medulla (Montagna and Yum, 1964).

The cortex makes up the main bulk of the hair and consists of several layers of cells (Copenhaver, 1964). Towards the bulb the cells become soft, shorter, and finally become ovoid with spherical nuclei (Trautmann and Fiebiger, 1957, and Odland, 1966). These cells are derived from the undifferentiated cells of hair matrix (Odland, 1966). In the upper part of the root of the hair and in the shaft the cortex

consists of cornified, fusiform cells with elongated nuclear remnants (Copenhaver, 1964, Trautmann and Fiebiger, 1957). In colored hair the pigment granules are found in and between the cells which are formed by melanocytes during the growth stage of the hair cycle (Odland, 1966 and Copenhaver, 1964). Air may accumulate in the intercellular spaces and modify the hair cycle (Copenhaver, 1964). According to Odland (1966), electron microscopic studies show that the cytoplasm of the fully keratinized cortical cells consists almost entirely of low-density filaments enclosed by a dense interfilamentous substance.

The cuticle consists of a single layer of elongated, cornified, scaly cells, the free margin of which is serrated and directed towards the tip of the hair (Montagna, 1962, and Odland, 1966). According to Montagna (1962), the cells of the cuticle of the hair inside the follicle are interlocked with those of the inner root sheath. The arrangement firmly anchors the hair within the follicle.

Vincent (1913) considered the cuticle of the hair and the inner root sheath of the follicle as the continuation of the stratum corneum. The cortex corresponds to the stratum germinativum and the medulla to the stratum cylindricum of the epidermis.

The Structure of the Follicle:

The follicles are continuous with the epidermis. They are slanted and the diameter increases at the base where

they are dilated to form the bulb. The bulb encloses the soft loose dermal papilla. Montagna (1962) termed the part of the follicle between the opening of the duct of the sebaceous gland and the surface, the pilary canal. Although differences occur, the structure of the follicle in all mammals is similar (Montagna, 1962).

The follicle consists of the epithelial sheath which is the direct continuation of the epidermis, and the connective tissue sheath modified from the dermal connective tissue. The epithelial part of the follicle consists of the inner root sheath and the outer root sheath, and the hair remains in the center. The thickness of the outer root sheath is proportional to the size of the follicle (Montagna, 1962).

According to Copenhaver (1964) and Trautmann and Fiebiger (1957), the structure of the hair follicle described as follows:

The inner root sheath: consists of three layers, the cuticle of the root sheath, the Huxley's layer, and Henle's layer. The cuticle is a membrane similar in structure to the hair cuticle against which it lies. The free edges of the cells are directed towards the papilla so that the two cuticles interdigitate. The cells are nucleated in the deeper part and non-nucleated near the surface. The Huxley's layer is the middle layer, consisting of several rows of elongated cells. The cells of this layer are nucleated almost the whole length. They send processes to the Henle's layer (Montagna, 1962). The Henle's layer consists of a single layer of

non-nucleated cells. They are clear and rectangular. The cytoplasm contains longitudinal horny fibrils.

According to Montagna (1962), the cells of all three layers of the inner root sheath acquire trichohyalin granules. The cells in the cuticle do not acquire trichohyalin granules until they are about halfway up the follicle. The inner root sheath grows upwards with the hair from the papilla as far as the opening of the sebaceous gland, where it disintegrates.

The outer root sheath: The outer root sheath is the continuation of the Malpighian layer of the epidermis. The outermost cells, adjoining the glassy membrane are tall and arranged in a single row. These cells in the lower part of the follicle have minute basal cytoplasmic processes (Montagna, 1962). This layer is comparable to the stratum cylindricum of the epidermis. The rest of the cells are more polygonal in shape. They have spinous processes and resemble the cells of the prickle cell layer.

The connective tissue sheath: This sheath encloses the epithelial hair follicle. The layer is continuous with the connective tissue element of the hair papilla (Odland, 1966). The connective tissue sheath contains dense layers of collagenous fibers investing the follicle. Dick (1947) observed the reticular fibers arranged in a radiate fashion around the follicle, as if holding the follicles in place. He also described the elastic fibers which form a fine net around the hair follicles. This sheath is composed of an outer

longitudinal layer of poorly defined and loosely arranged bundles of white fibrous tissue. The middle layer is thickest and composed of fine connective tissue fibers, arranged circularly. The inner layer is a homogenous narrow band, the glassy membrane made up of argyrophilic reticular fibers composed of PAS positive ground substance (Montagna, 1962, and Odland, 1966). In reality, this layer may be regarded as a basement membrane (Odland, 1966). According to Montagna (1962), this glassy or vitreous membrane is single-layered around the upper part of the follicles and two-layered where it is thickest around the lower third or half of the follicle. Only the outer layer is continuous with the basement membrane of the epidermis. In the lower half of the follicle the epithelial cytoplasmic processes and fine fibrils make a heterogenous irregular lamina.

Follicular folds: Follicular folds are circular folds, appearing in a vertical section of the follicle as corrugations of the inner root sheath of the hair follicle near the opening of the sebaceous glands. They were observed in the cat (Strickland and Calhoun 1963), in cattle (Goldsberry and Calhoun 1959 and Sinha 1964), in swine (Smith and Calhoun 1964, Fowler and Calhoun 1964 and Marcarion and Calhoun 1966), in goat (Sar and Calhoun 1966), and in sheep (Kozlowski 1966). Montagna (1962) observed these folds in the follicles of the rat, mouse and sheep. A similar loose, horizontal, reticulated collar around the emerging hair in the under portion of the pilosebeceous canal in the human follicle was observed by Montagna (1962).

Tactile Hair

The structure of tactile hairs in the horse was described by Smith (1888), in rats (Vincent, 1913), in pig (Smith and Calhoun 1964, Fowler and Calhoun 1964 and Marcarian and Calhoun 1966), in goat (Sar and Calhoun 1966), in cattle (Sinha 1964) and in sheep (Kozlowski 1966). The follicles of these hairs are richly supplied with sensory nervés. Blood vessels resembling erectile tissue form a system of cavernous sinuses around them (Vincent, 1913, and Montagna, 1962).

Arrector Pili Muscle

This bundle of smooth muscle originates from the connective tissue sheath of the lower part of the follicle, arches over the sebaceous gland and inserts in the upper dermis. In the cat, dog and in the follicles of the tails of most mammals, the arrector pili muscles are well developed (Montagna, 1962). According to Trautmann and Fiebiger (1957), they are thin on the coarse hairs or bristles of the pig and the hairs of the mane of the horse. They usually end in an elastic tendon. The arrector pili are absent in tactile hairs. They are thick in sheep and often double in the pig (Trautmann and Fiebiger, 1957). The muscle is often perforated by ducts of the tubular glands (Sinha 1964). Contraction of this muscle causes the hair follicle with the hair to assume a more vertical position than usual which forms a swelling on the skin surface, "the goose flesh" (Odland, 1966, and Copenhaver, 1964).

Histochemistry of Hair Follicles

From the staining and histochemical properties of the follicles many things may be learned about hair follicle activity. As has been observed RNA disappears from the cells of the bulb at the same rate that the proteinous fibrils accumulate, which indicates that RNA plays a role in the synthesis of proteinous materials (Montagna, 1962). Similarly, proliferative potentiality of the cells of different parts of the follicles, and the hair formation potentiality of the follicle in general may be ascertained by the Feulgen technique.

Glycogen in the hair follicles: Bolinger and McDonald (1949) observed glycogen in the hair follicles of man, rabbit and the phalanger. The globules of glycogen were observed at the level where the sebaceous glands connect with the hair follicles. Alkaline phosphatase and glycogen occur in the developing hair follicles but as the hair grows the phosphatase disappears while glycogen remains in the follicle. The special relation between the phosphatase and glycogen correlates well with the path of glucose entry into the tissue (Johnson and Bevelander, 1946). Glycogen occurs as a regular constituent of the outer root sheath of active follicles in the mouse (Hardy 1952). According to Montagna (1962), active hair follicles are always rich in glycogen. In the tactile hairs of the mouse Melarazno and Montagna (1953) observed abundant glycogen only in the external sheath. In the connective tissue sheath some glycogen is found inside

the cytoplasm of fibroblasts and extracellularly along the fibers. The inner layer of the vitreous membrane is PAS reactive but diastase resistant. The cells in the middle third of the follicle contain so much glycogen that only a flimsy framework of cytoplasm is left. The cells are gradually depleted of glycogen as they become keratinized in their inner margins. Storage of glycogen bears an inverse relationship to mitotic activity. Mitotically active cells and the cells which are rapidly synthesizing keratin do not contain demonstrable glycogen.

The Sebaceous Glands

The sebaceous glands are pear-shaped appendages of the hair follicle and open inside the pilosebaceous canal. Frequently the size of the glands varies inversely to the size of the associated hair follicle. (Trautmann and Fiebiger 1957, Montagna 1962, Copenhaver 1964 and Odland 1966). In most of the mammals they are widely spread over the body. Most animals have the largest glands in the mucocutaneous junctions of the lips, eyelids, vulva and perianal regions (Montagna, 1962, and Trautmann and Fiebiger, 1957 and Smith, 1888). The horse and dog have the largest sebaceous glands and the pig has the smallest (Ellenberger, 1906). In ungulates, as a rule, 2-6 glands open into one follicle (Trautmann and Fiebiger, 1957, and Krölling and Grau, 1960). This is more marked in the hoof margin (Ellenberger, 1906). In regions with long hair these glands are long and narrow (Smith, 1888,

and Trautmann and Fiebiger, 1957). In the horse, they are found everywhere on the skin and usually occur in pairs (Smith, 1888). Sebaceous glands are especially well developed in the horse (Sisson and Grossman, 1953, and Smith, 1888). In horses and dogs the glands are branched (Ellenberger, 1906) and occur on the posterior side of the follicle (Krölling and Grau, 1960). A sebaceous gland in domestic animals is a bilobular alveolar gland (Rook and Walton, 1965), but multilobular glands may also be present (Montagna, 1962, and Rook and Walton, 1965). They are holocrine glands. Regardless of their size, shape and location, their morphology is similar. According to Montagna (1962), the acini (termed alveoli by many) of each gland are attached to a common excretory duct that consists of squamous epithelial cells, continuous with the pilosebaceous canal (Copenhaver, 1964, and Montagna, 1962). In the glandular acini the cells show a centripetal enlargement, those in the center being large; the cells of the outer periphery are undifferentiated and resemble those of the epidermis (Montagna, 1962). The outer peripheral cells are a continuation of the duct cells and the stratified layer of the duct gradually diminishes to a single layer on the acini (Odland, 1966). In the ordinary histologic preparation when no fat remains in the cell cytoplasm, the cytoplasm appears as a finely reticulated meshwork of basophilic materials (Odland, 1966). The basophilia increases towards the periphery. This basophilic substance is abolished by ribonuclease which indicates that the material is ribonucleoprotein (Montagna, 1962).

The secretion of the sebaceous gland is known as sebum, which, in general, is believed to protect the skin against ultraviolet light, bacteria, and other foreign bodies and provide an insulating layer on the skin surface (Rook and Walton, 1965). The epithelial cells of the alveoli differentiate from the peripheral cells and are engorged with lipid materials. The lipid substance gradually increases in the cytoplasm of the cells, starting from the periphery to the central part where the cells become much larger and are gradually distended with lipid droplets. Secretion results from the disintegration of the cells, a holocrine mode of secretion. The sebum is thus the product of disintegration of the cells themselves (Copenhaver, 1964). The signs of disintegration of the cells such as nuclear pycnosis and coalescence of the lipid droplets, appear in the part of the alveolus nearest the duct (Odland, 1966). It is not only the cells themselves which are found in different states of maturation, but the alveoli themselves are also in different state of maturation. The alveoli in the same glandular unit may be found to contain lipids only in the central parts while others have lipids throughout the alveolus. Therefore, it was concluded by Montagna (1962) that the individual icinus is doomed to destruction once differentiation begins. Mitotic activity is abundant in the cells lying on the basement membrane close to the wall of the excretory duct. The new cells thus produced are pushed to the secretory region (Bloom and Fawcett, 1962). The mitosis may also occur directly in the peripheral cells (Montagna, 1962). According to Montagna

(1962), the sebaceous acini are in constant state of change; epithelial buds grow from the walls of the excretory ducts, they develop sebaceous kernels in their centers and then grow into new sebaceous units. Sebaceous kernels may develop anywhere along the acini outside or inside, where there are accumulations of undifferentiated cells.

The body of the gland is covered by a delicate connective tissue sheath (Ham 1961). Each acinus of the gland is surrounded by a complex network of arterial capillaries which adhere very closely to the basement membrane but never penetrate the acinus (Montagna and Nobeck, 1947). The sebaceous paranchyma of tarsal glands in horse and other mammals are surrounded by nerves rich in cholinesterase (Montagna and Ellis, 1959) while, in general, sebaceous glands are not surrounded by nerves (Montagna, 1962). Perhaps the secretory activity is influenced by temperature, sex hormones and age (Odland, 1966).

Histochemistry of sebaceous glands: The main constituents of the sebum, the lipid secretory product of sebaceous glands, consists of cholesterol, cholesterol esters, and phospholipids. The Golgi apparatus of the acinar cells is most intimately associated with the synthesis of lipid droplets in sebaceous differentiation. Montagna (1962) concluded that the sebaceous transformation occurs within the structures that correspond to the Golgi apparatus, either by chemical alterations of the substances of the membranes, or by a segregation of materials in the cytoplasm. According to

Ahmed (1965), the Golgi region is the center of sebum formation. The sebum differs from surface lipids as the latter contain free cholesterol and probably this originates from cholesterol esters through the action of nonspecific esterases. Using Sudan IV and Sudan black, Montagna and Nobeck (1947) demonstrated lipid substances, both in sebum and acinar cells of the rat. The large central cells which possess abundant lipid droplets contain large quantities of unsaturated glycerides, while the dying cells contain glycerides and cholesterol esters. Traces of lipid solvents and resistant lipid substances also are present. Alkaline phosphatase activity is abundant in the acinar cells. Peripheral cells contain more phosphatase than the central cells whereas RNA is limited only to the peripheral cells.

The sebaceous glands of all mammals other than man and higher primates do not contain any glycogen (Montagna and Ellis, 1959, and Parakkal, et al. 1962). The human sebaceous glands abound in glycogen (Montagna, 1962). In the sebaceous gland of man glycogen is associated with lipid storage. Sebaceous transformation takes place by a conversion of carbohydrate to lipids (Montagna, 1962, and Montagna, et al. 1952).

Development of sebaceous glands: The development of sebaceous glands is intimately associated with the hair follicle. According to Montagna (1962), two bulges on the same side of the hair follicle develop even before the follicle is fully differentiated. The upper bulge becomes the analge of the sebaceous glands and the lower bulge is the point where arrector pili muscles are attached.

The Sweat Glands

There are two kinds of sweat glands in domestic animals, designated as merocrine and apocrine. The secretory tubules of both kinds have basement membranes containing circular reticular fibers (Trautmann and Fiebiger, 1957). The skin of the horse is richly provided with sweat glands (Smith, 1888, Sisson and Grossman, 1953) and the glands are apocrine type only (Evans, et al., 1957). They are largest and most numerous in the lateral wing of the nostrils, the flank, mammary gland, and the free part of the penis (Sisson and Grossman, 1953). They are well developed on the general body surface (Smith, 1888) and form almost a continuous layer of glands in the flank (Ellenberger, 1906). The glands are small and less numerous in the mane, tail and limbs (Smith, 1888), and lie deep into the dermis in the mane and tail (Ellenberger, 1906 and Smith, 1888).

The apocrine glands: These are predominant in the skin of the entire body surface of all domestic mammals (Schiefferdecker, 1917, and Trautmann and Fiebiger, 1957). Usually one apocrine gland is associated with each hair follicle, except the tactile hair follicles (Trautmann and Fiebiger, 1957). In man, apocrine glands occur only in the axilla, mons pubis, external auditory meatus, circumanal region, areola, nipple, eyelids, labia minor, prepuce and scrotum (Montagna, 1962). The apocrine glands develop as an outgrowth of the hair follicle during embryonal life (Trautmann and Fiebiger, 1957, Montagna, 1962, and Odland, 1966). The duct may be separated later (Odland, 1966) and may open directly onto the surface of the epidermis (Montagna,

1962). The ducts, however, ordinarily open in the neck of the pilosebaceous canal (Odland, 1966, Montagna, 1962, and Trautmann and Fiebiger, 1957). The tubules of apocrine glands are wider than the tubules of merocrine glands. In sheep, pig, cat, and horse, the secretory tubule is glomiform, whereas in the ox, goat, and dog it is serpentine (Trautmann and Fiebiger, 1957). The coils of each gland are encircled by plexuses of capillaries (Ellis, et al., 1958).

The merocrine or eccrine glands: These are predominant in the skin of general body surfaces of man and many primates and secrete a watery sweat (Odland, 1966, and Trautmann and Fiebiger, 1957). Amongst the domestic animals this type of gland is seen only in the foot pad of the dog (Nielson, 1953) and metacarpal pads of cats (Strickland and Calhoun, 1963). The secretory portion of the merocrine glands consists of a narrow tube of uniform diameter, which is generally coiled into a spherical mess (Trautmann and Fiebiger, 1957). The ducts open directly on the epidermis, pursuing a tortuous course through the dermis and epidermis (Odland, 1966).

Histological Feature

Apocrine gland: As already mentioned, apocrine glands are the general type of glands found in the skin of all domestic animals. The histologic and the histochemical properties of these glands are quite different from that of the merocrine glands. They have extremely large lumina and the tubule may show sac-like diverticula (Hibbs, 1962, and Trautmann and Fiebiger, 1957). Where the secretory tubules

pass into the excretory duct they suddenly become narrow (Trautmann and Fiebiger, 1957).

The cells of the secretory tubules are irregularly columnar; the terminal portion of some cells is elongated and projects into the lumen (Montagna, 1962). Some of the tubules have a very wide lumen with low columnar to squamous types of cells (Trautmann and Fiebiger, 1957, and Montagna, 1962). The cytoplasmic membrane of the secretory cells adjacent to the lumen forms a brush border consisting of microvilli (Montagna, 1962, Hibbs, 1962, and Yamada, 1960). Takagi and Tagawa (1959) reported the presence of a brush border at the luminal end of the cells of the apocrine gland of the horse. The brush border disappears at the formation of the apocrine secretory projection (Kurosumi, 1959). According to Hibbs (1962), the secretory cells of the apocrine glands lie on rows of longitudinally oriented myoepithelial cells. Between the myoepithelial cells cytoplasmic projections from the secretory cells are in contact with the basement membrane. A large intercellular space occurs between the myoepithelial and secretory cells (Kurosumi, 1959, Montagna, 1962, and Hibbs, 1962). The apical cytoplasm of microvilli contains vacuoles and granules close to the luminal membrane (Montagna, 1962). The epithelium of the duct is double layered and cuboidal in man (Montagna, 1962) and cow (Sinha, 1964).

Composition of the apocrine secretion: The apocrine glands of domestic animals, except the horse, secrete watery sweat and the secretion is not fatty (Trautmann and Fiebiger,

1957). According to Montagna (1962), the apocrine sweat in man is milky, viscid and pale gray and the secretion from the gland is usually slow and scanty. The secretion of the sweat glands of the horse is proteinous or albuminoid (Trautmann and Fiebiger, 1957, and Krölling and Grau, 1960). The albumen is the chief protein but traces of globulin are present (Jirka and Katos, 1959). Evans, et al. (1957) claimed that the secretory cells of the horse sweat glands contain glycogen and produce a large amount of watery sweat while Takagi and Tagawa (1959) did not find any glycogen in the horse's sweat glands except a trace in the myoepithelial cells. Evans, et al. (1957) considered the sweat gland of the horse an intermediate form of gland between the eccrine and apocrine glands. Similarly, Montagna (1962) designated horse sweat gland as a different organ, though in broad terms it is apocrine like other mammals.

Mode of secretion: The application of histochemistry, cytochemistry and electron microscopic study has revealed so many facts about the apocrine glands that the earlier view of necrobiotic secretion has been altogether rejected. Schiefferdecker (1917 cited by Montagna 1962) proposed a theory of necrobiotic secretion in which the apex of the cell bulges out to form a bleb which subsequently breaks away and disintegrates to form the secretion. According to Montagna (1962), the cytoplasmic blebs that appear in the lumen in histologic section are really attached to the subjacent cells. The pinched off appearance is brought about by a dehydration and shrinking of soft cytoplasm. Frozen section studies under

phase microscope show the apical ends intact with the cell (Copenhaver, 1964). Hibbs (1962) observed in both secretory and resting glands, that the lumina are either empty or contain an amorphous material. No cellular debris or secretory granules are encountered. Anatomical evidence is lacking as to the necrobiotic secretion of the horses apocrine gland (Rook and Walton, 1965, and Takagi and Tagawa, 1959). It is strongly believed that the apocrine secretion occurs by a pinching off of the terminal globules of the microvilli or by an exudation of liquid substance through them (Montagna, 1962, and Copenhaver, 1964). This still remains apocrine in nature as the pinching off of the microvilli form the secretion. The secretion by disruption of the apical part probably may occur only under extreme conditions, if at all (Hibbs, 1962).

Merocrine or eccrine glands: These are simple tubules that extend from the epidermis to the dermis. The lower secretory part is coiled and the upper excretory part is straight or tortuous. The secretory part of the gland is lined by cuboidal to columnar type of epithelium (Trautmann and Fiebiger, 1957, and Copenhaver, 1964), lies on the basement membrane and is comparatively thinner than the basement membrane of apocrine glands (Montagna, 1962). Inside the basement membrane lies the spindle-shaped myoepithelial cells whose cell bodies are wedged in grooves between the bases of the secretory cells (Odland, 1966). The protoplasm of the secretory cells contains granules and fat droplets (Copenhaver,

1964). Distinct intra- and inter-cellular secretory capillaries are seen through which the secretory product is eliminated (Odland, 1966, Copenhaver, 1964, and Montagna, 1962).

According to staining characteristics, two types of cells are recognized in merocrine glands--clear cells and dark cells (Deleson, et al. 1958, cited by Montagna, 1962). Under the electron microscope both clear and dark cells were recognized in the sweat glands of the foot pad of the cat (Munger, 1960). The cytoplasm of the clear cells extends microvilli of uniform diameter into the luminal border and shorter microvilli into the canaliculi (Montagna, 1962, Munger, 1960, and Hibbs, 1958).

The transition between the secretory portion of the tube and the duct is abrupt (Montagna, 1962). The duct is lined with two layers of cuboidal cells (Odland, 1966, and Trautmann and Fiebiger, 1957). The cells of the luminal surface of the duct show low microvilli under the electron microscope (Montagna, 1962). The lumen of the sweat duct contains mucus which tends to form plugs in the spirals within the stratum corneum of the epidermal sweat ducts. The dark cells of the secretory coils are the source of mucus. The mucin granules are present in the cytoplasm of these cells (Lee, 1960).

Nerve Supply

Thick ribbon-like nerve fibers are distributed in the connective tissue surrounding the secretory tubule of the horse sweat gland. They ramify and give rise to fine, tortuous fibers, which form a terminal reticulum on the outer

surface of the myoepithelium of the secretory tubule (Takagi and Tagawa, 1961). The myoepithelial cells of the apocrine glands are supplied by the adrenergic fiber of the autonomic nervous system (Hurby and Shelley, 1954). The sweat gland of horses respond to intradermal injection of adrenalin and also show a response to acetylcholine (Evans et al. 1956). The apocrine glands of the horse are adrenergic. In the horse, increase in the blood adrenaline is the normal mechanism which causes sweating (Evans et al. 1957).

MATERIALS AND METHODS

Source of Animals

Skin specimens from 35 areas of two stallions, two mares and two geldings were obtained from freshly killed animals. The animals were from two to seventeen years old. A few additional blocks of tissue were collected from the veterinary clinics and pathology laboratory of Michigan State University for studying the effect of different fixatives on the skin, histochemistry of skin and the nerve endings and nerve fibers of the lips.

Technique

As soon as the animals were killed by pistol shot, the specimens of about 1 (one) square inch were collected and fixed in FAA for general study (Lavdowsky's mixture, Guyer, 1949). After three days the specimens were trimmed to about 4 x 10 mm size for vertical section and 5 x 5 mm for horizontal sections. They were left in FAA solution for 30 days. The specimens were than transferred through three changes of dioxane (Bucher and Blackely, 1936). The first and second changes were for two hours each and the third change overnight (about 15-20 hours). The tissue was infiltrated in vacuum under 20 atm. pressure for 30 to 60 minutes. The paraffin blocks were sectioned at 8 microns thickness.

The sections were stained with (1) Harris' hematoxylin and eosin for general study (Malewitz and Smith modification,

1955), (2) Gomori's aldehyde fuehsin (Gomori, 1950) for elastic fibers, mast cells and keratohyalin granules; (3) periodic acid, silver, orcein and aniline blue (Gurr, 1962) to study the relative distribution of the three fibrous components of dermal connective tissue; (4) Bielschowski-Gros method (Lillie, 1965) for nerve fibers and endings; (5) Bauer-Feulgen reaction for glycogen (Gridley mannual, 1960); (6) periodic acid Schiff for PAS positive substances of the skin; (7) Domici's Mast cell stain (Gridley manual, 1960); (8) Gomori's aldehyde fuchsin counterstained with Janus green to render all other tissue green except elastic fibers in dermis to observe their absolute density; (9) Bodian's method for nerve fibers and nerve endings (Bodian, 1936).

A special fixative, "Petrunkevitch's cupric paranitrophenol", (Gurr, 1962) was used to render the keratin, as well as the dermal connective tissue components, loose enough, to study the compactness of the dermal connective tissue. The fixative was found very satisfactory for the purpose. The epidermis and dermis were measured in microns by an ocular micrometer.

Body areas from which the skin specimens were taken.

Head

Upper lip 1
Lower lip 14
Nostrils 2
Upper eyelid. 3
Lower eyelid. 4

Forehead. 5
Ext. ear canal. 6
Pinna(at base). 7
Chin. 15
Submandibular region. .16

Neck

Dorsal Neck(center) . . 8
" " (base) . . . 9
Lateral neck. 17
Ventral neck(center). .18
Brisket 19

Thorax

Lateral neck(base). . .20
Post.thorax 21
Ventral thorax(Ant.). .32
" " (Post). .31
Back. 10

Abdomen

Flank 22
Vent. abdomen 30
Prepuce(Genital region)10A

Gluteal region

Croup 11
Lat. gluteal region . .23
Circumanal region . . .24

Tail

Root of the tail. . . .12
Tip of the tail 13

Pectoral limb

Brachium 34
Axilla 35
Chestnut 33

Pelvic limb

Thigh (Lat.) 25
Thigh (Med) 26
Chestnut 27
Ergot. 28
Coronary border. . . .29

RESULT AND DISCUSSION

General Features

Skin thickness: In the discussion, the term "general areas" refers to all areas except those designated, "special areas". The "special areas" include: upper lip; lower lip; nostrils; upper eyelid; lower eyelid; external ear canal; tail; chestnut; ergot; coronary border; dorsal neck; and prepuce as shown in the sketch.

The average skin thickness of the general areas was 3.8 mm, (about 4.1 mm in the stallion, 3.7 mm in the geldings and 3.3 mm in the mare). The skin of the stallions was thicker than both the geldings and mares (Table V). The total skin thickness varied according to age, sex, and individual from 1.6 to 6.4 mm, which compared favorably with Sisson and Grossman (1953), Krölling and Grau (1960), and Ellenberger (1906), where they stated the skin thickness varied from 1-5mm. On comparing the general skin of a 17-year old gelding with a 2-year old gelding, marked difference in thickness was observed (Table I). The thickest skin on the general body areas was on the croup (5.5 mm). Next, in order of thickness on the general skin areas was the back and gluteal region (4.5 mm), flank (4.4 mm), brachium (4 mm), abdomen and thorax (3.9 mm) and thigh (3.7 mm). This observation is in agreement with Smith (1888). The thinnest skin was on the pinna (2.5 mm) and submandibular region (2.6 mm). In agreement with Sisson and Grossman (1953) and Smith (1888), the thickest skin on

the special areas was on the dorsal surface of the tail (6.4 mm) and on the attachment of the mane (6 mm) (Table I).

The thickest epidermis was, in order of thickness, on the upper lip (757 u), lower lip (278 u), circumanal region (262 u) prepiece (245 mm) and chin (205 u) (Table II).

The thickest dermis in the general skin areas was on the croup (5.2 mm), back (4.4 mm), gluteal region (4.4 mm), flank (4.4 mm) brachium (4 mm), abdomen (3.8 mm) and in the thigh and thorax (3.6 mm). Of the special areas, the dermis was thickest on the dorsal surface of the tail (6.3 mm), ergot (6.1 mm), and at the attachment of the mane (5.6 mm) (Table III).

Components of Skin

Blood supply: The skin was highly vascular. The blood vessels were more numerous in the areas with a thick epidermis or dermis. Particularly the vascularity of the upper lips, lower lips, croup, coronary border and nostrils were very striking. There were three well formed vascular plexuses in the areas under investigation. First the branches of the large vessels of the subcutis formed a plexus at the lower part of the reticular layer. A second very prominant plexus was formed in the region of the cutaneous glands and hair roots. Branches from this plexus supplied the hair papillae, sweat glands and part of the sebaceous glands. A third prominant plexus was formed at the upper part of the papillary corium. Numerous vessels from this plexus entered the dermal papillae. Similar arrangements were reported for cattle by

Goodall and Young (1955) and in the horse by Smith (1888).

Arterio-venous anastomoses: These were observed in the papillary corium of all areas having a thick epidermis or dermis. These vessels were thick walled arterial vessels with several layers of epitheloid cells on the wall (Plates XXXIV, XXXV and XXXVI). Thus the lumen of the vessels was narrow. They formed coils or convolutions and gave an appearance of a glomus. These vessels were usually cut in several sites in a cross section (Plate XXXVI). They were observed mainly in the upper lip, lower lip, nostrils, upper eyelid, croup, coronary border, external ear, brisket, circumanal region, and thigh. Their presence in the coronary border and papillae of horse's hoof was reported by Clara (1956), in the horse's ear by Danial and Marjorie (1956), and in human finger and toes by Montagna (1962), Odland (1966), and Copenhaver (1964). This type of modification of the arterial vessels in the skin provides a shunt to diminish flow through extensive areas of vascular beds to decrease loss of heat by convection and radiation from the extensive surface of the skin.

In addition to the arterio-venous anastomoses, a large number of intra-arterial cushions were present in the arteries, usually in the areas rich in anastomoses. These were composed of epitheloid cells pushed towards the lumen from the inner wall of the vessels. Due to this arrangement, the lumen became a crescent-like slit (Plate XXXVII).

Another type of intra-arterial cushion was observed in the papillary layer of the corium in the upper lips and thigh.

In this form arterial vessel left the parent artery through the summit of the cushion carrying blood from the center of the lumen (Plate XXXVIII). Burton (1966) mentioned this type of arterial modification in the uterus of the rat and other species. According to Burton (1966), this arrangement allows the distributing arteries to sample the blood from the center of the parent vessel. Such vessels receive blood which is rich in red blood cells. Since the red blood cells have the tendency to accumulate in the axis of the vessels, such an arrangement distributes blood rich in red blood cell to a part of the skin where local demand for oxygen becomes increased due to functional demand.

Hair

Classification, density and arrangement: The following classification of the hairs of the horse is based on Sisson and Grossman (1953). The hairs are divided into (1) general coat or cover hairs which cover the general body surface; (2) coarse hairs of great length located on the dorsal border of the neck and the adjacent part of the withers (mane), the forehead (foretop), the dorsal and lateral surfaces of the tail, and surrounding the horny ergot on the flexor surface of the fetlock; and (3) the special tactile hairs endowed with specific function located on the lips and nostrils; and (4) fine hairs located on the lips, nostrils, external ears and circumanal region (Plates XXVI and XXVIII). The coarse hairs were deeply rooted in the dermis but never crossed the whole width of the dermis.

The coat hairs on the general skin surface were usually medullated with a few large hairs set deeply into the dermis (Plate XVI). The hairs were closely distributed on the dorsal and lateral surfaces of the trunk and limbs. They were scarce on the posterior side of the abdomen and medial surface of the thigh (Plate XVII). An individual cover hair with its follicle, associated sebaceous glands and sweat gland or duct occurred as a unit in the dermis and was covered by organized collagenous fibers (Plates XVI and XVII). They were arranged in a distinct line towards the surface and finally erupted in the grooves of the surface epidermis to form rows with adjacent lines (Plate II). At the coronary border there were groups of hairs which were longer than the normal cover hairs bordering the dorsal border of the hoof (Plate XXXIII). All the hairs erupted on the surface at an acute angle.

Structures of hairs: The structures of the hairs and hair follicles conformed to the description of mammalian hair found in standard texts with the exception of the findings listed below.

1. The medulla of the hair of the horse contained rectangular cells lying side by side. The intercellular spaces were wide with desmosomes connecting the cells with each other (Plate XVIII). Trautmann and Fiebiger (1957) described these cells as rectangular, separated by wide space with rough borders.

2. The connective tissue part of the follicle was very thick at its middle third and was strongly acidophilic.

3. The roots of the hairs were branched and the end of each branch was bulbous. The bulbs fitted into the pits of the inner wall of the external root sheath. This was revealed by the Bielschowsky-Gros method.

Follicular folds: These folds were present only in large hair follicles just below the opening of the sebaceous glands. These appeared as a modification of the inner epithelial sheath of the follicles. The external sheath at this point thinned out and formed a pocket. The folds in the form of flaps extended obliquely upwards on the inner surface of the pocket (Plate XIX). The folds were directedly proportional in size with the sizes of the follicles. As a result of this anatomical feature of the follicular folds in the horse they might function to prevent inward movement of any substances whether sebum or debris from the outside. This might afford protection to the soft structures of the follicles. This seems reasonable due to the fact that the large follicles had larger folds with 8-10 flaps, the medium sized follicle contained 2-5 flaps and the smaller follicles lacked folds. However since large sebaceous glands were associated with small follicles, the function of the follicular folds in the horse could not be confined solely to the accumulation or expulsion of sebum as proposed by Strickland and Calhoun (1960) in the cat and Sinha (1964) in cattle.

Tactile hairs: These were found on the upper lip, lower lip, and nostrils. They were very strong, long, and deeply

set into the dermis. The follicles were very large and contained the hair at the center. It was 1.7 mm in cross section. The connective tissue sheath was very thick and divided into inner and outer layers with sinus spaces in between. The sinuses were filled with blood and traversed by connective tissue trabeculae. There were usually two small sebaceous glands at the neck. No arrector pili muscle or sweat gland was associated with tactile hairs. The "ringwulst" and annular sinus (Strickland and Calhoun, 1963 and Trautmann and Fiebiger 1957) which are the characteristic feature of the tactile hairs of carnivores and rodents were absent. Skeletal muscle fibers were seen in the near vicinity of the follicle. This was also reported by Sinha (1964) in cattle and by Strickland and Calhoun (1960) in cat.

Arrector pili muscles: They were observed throughout the whole skin. They were usually placed on the side of the hair follicle forming an obtuse angle with the dermis (Plate XLVIII). The muscle arched on the free side of the sebaceous gland. The ends in some cases were divided into 2-6 branches (Plate XV). Both ends terminated in elastic fibers. In the general skin, in many cases, a branch was detached from the main muscle and passed to the duct of sweat gland where the duct perforated it and passed vertically for a considerable distance along the arrector pili muscle. They were very long with the follicles of the coarse hairs and were strong and wide on the back, croup and gluteal region (Plate XV).

Histochemistry of hair follicles: The follicles were tested for PAS positive substances and glycogen. The cells of the epithelial root sheath were highly reactive to PAS. The connective tissue sheath was mildly PAS positive and the basement membrane was strongly reactive. The cuticle of the hair showed a mild reaction (Plate XXI). The cortex was PAS negative. The medullary cells contained strongly PAS positive granules scattered within the cells. The border of these cells, along with the intercellular spaces, were also strongly PAS positive.

Glycogen was present in the cytoplasm of the external root sheath in diffused form. The quantity varied greatly from the upper to the lower end of the follicles. The glycogen rich cells were present in the middle third of the follicle. The glycogen diminished gradually towards the root as well as toward the epidermal end, until the cells were completely free of glycogen at both ends (Plate XX). On a regional basis, most of the follicles of the upper and lower lips and nostrils were rich in glycogen. The follicles of the general body areas though containing glycogen were usually poor. According to Montagna (1962), the active follicles were always rich in glycogen.

On comparing the quantity of glycogen and PAS positive substances in the follicles and hair, it was found that the cells of the outer root sheath contained, in addition to glycogen, other non-glycogenic PAS positive substances. The inner root sheath of the follicles and the cuticle and

medulla of the hair contained only non-glycogenic substances.

Epidermis

The free surface of the skin contained ridges, grooves (plate II), opening of sweat ducts and hair follicles (plate XXVII). The skin was distinctly wavy on the lateral and ventral side of the neck, thorax, abdomen and tail. In these areas, the epidermis was thickened at the summit of the ridges, perhaps due to adhesion of the two slopes at the summit. The slope of the ridges were usually composed of thin epidermis. The hair erupted in the grooves (plate II) and the epidermis on both sides of the hair contained a thickened area at the opening of the hair follicle. The skin on the forehead was almost smooth and on the back, croup, legs, arms, lips, nostrils and eyelids was moderately wavy.

In the areas with thick epidermis, as in lips, nostrils, eyelids, and posterior abdomen, the epidermal pegs were both simple and branched. The core of the ridges was filled with dermis and the spaces between the epidermal pegs were filled by the dermal papillae. The vertical extension of the dermal papillae varied directly with the thickness of the epidermis.

The epidermis was composed of stratified squamous epithelium that covered the entire body surface. The shapes and sizes of the cells differed, depending upon their position in the epidermis. The functionally active or viable cells were of cuboidal, columnar, polyhedral, and fusiform shape. Usually, the cells at the lower layer were columnar in the

thick epidermis and high cuboidal to cuboidal in moderate to thin epidermis. The cells from the suprabasal layer to the surface layer became gradually fusiform and flattened. The surface layer were composed of dead, flattened, scaly or horny cells.

The epidermis was mainly composed of three layers--the stratum corneum, stratum granulosum and stratum germinativum. A stratum lucidum, characteristic of certain areas of the skin of man (Montagna, 1962) and carnivores (Strickland and Calhoun, 1963, Webb and Calhoun, 1954), was not found in any part of the skin of the horse.

Stratum corneum: This layer was composed of dead, flattened, non-nucleated, keratinized, closely packed squamous cells. Occasional dissociated cells resembling scales were also observed. The cell boundaries were not distinct in the superficial layer but were distinct near the stratum granulosum. The cells of the corneal layer retained some cellular integrity in areas of pressure and where horny structures were formed. This observation is in agreement with Montagna (1962). They remained cemented together and did not exfoliate (Plate VIII, XXVII). The cells of the stratum corneum in thin epidermis, as on the general body surface, were somewhat loose and their cellular boundaries were obscured (Plates I and III). This layer was extremely thick and formed thick horny tissue in the chestnut (Plates VIII and XXXII), coronary border and ergot. The layer also was very thick in upper lip, lower lip, nostril (Plate XXVII), circumanal region, ventral abdomen and tip of the tail. The cells of this layer were

very closely adherred in less hairy skin as in lips, nostrils, and circumanal region, but formed distinct threads in the general hairy skin. The arrangement of these threads gave a net-like appearance, particularly on the dorsal surface of the tail. Fine filamentous structures were observed in the cells of some thick cornified areas. This observation agrees with Sinha (1964). Intercellular spaces were very distinct in thick cornified layer (Plate VIII) but no desmosomes were observed in any areas under investigation. The surface was usually smooth in areas of thick epidermis but uneven in areas with thin epidermis.

Stratum granulosum: Large fusiform cells, heavily packed with highly basophilic granules were present here (Plate VIII). The cells were arranged in rows and there were many layers which formed a thick stratum corneum. In areas with a thin epidermis and a thin cornified layer, they were usually well apart in a single row just below the stratum corneum. In general, the thickness of this layer directly varied with the thickness of the superficial cornified layer. At the coronary border, chestnut and ergot up to 12-20 layers of cells were observed (Plate VIII). Two to four cells occurred in the lips, nostrils, and circumanal region (Plate VI). Prominent intercellular spaces existed with indistinct desmosomes (Plates VI, VIII). The cytoplasmic organelles, particularly tonofilaments, were not recognized, perhaps due to heavy accumulation of keratohyalin granules. The nuclei were shrunken, and in the upper layer of thick epidermis they were pycnotic.

Stratum germinativum: This layer may be subdivided into (1) stratum cylindricum or basal cell layer, composed of a single layer of columnar or high cuboidal epithelium. The cells of this layer were directly in contact with the dermis. The cytoplasmic basal processes, which were often branched, penetrated the underlying basement membrane (Plates V and VII) and anchored the epidermis with the dermis. The desmosomes and tonofibrils within the cytoplasm of the cells were distinctly observed down in this layer (Plates V and VII). Favre (1950) stated that the process of keratinization actually began, although imperfectly, in the basal layer of the stratum germinativum. The nuclei were elongated and paralleled the long axis of the cells. Mitotic figures generally were observed in thick epidermis but were seen less frequently in the thin epidermis. The cells were laden with melanin pigments in the epidermis of the eyelids, lips, nostrils, and prepuce. In the general skin, the cells contained appreciable quantities of pigments. The pigments usually were diffused in the cytoplasm of the cells of this layer.

In addition to normal basal cells, dendritic melanocytes were observed intermittently with the cells of the basal layer. In ordinary preparation these cells did not take the hematoxylin and eosin stain. On the basis of this characteristic they are also termed clear cells. The melanocytes were usually located horizontally. The basal portion of many of these cells extended into the basement membrane (Plate XV). The vertical processes projected into about half of the stratum germinativum. The processes contained melanin

pigments which formed a bead-like configuration. At the end of the dendritic processes the pigments tended to form a drop (Plate VI). The cytoplasm of the melanocytes lacked tonofibrils and the desmosomes were absent.

(2) Stratum spinosum, spinous layer, or prickle cell layer: This layer extends from the top of stratum cylindricum to the bottom of the stratum granulosum. The cells were polygonal in shape with centrally placed, spherical or oval nuclei. In thick epidermis this layer was composed of as many as 27 cells in the lips and nostrils, and in thin epidermis like the pinna as low as three cells. On the general body surface the thickness varied from 3-9 cells. The cells adherred to each other by distinct desmosomes and the cytoplasm was traversed by numerous tonofibrils (Plates V and VII). Characteristic supranuclear caps were formed by the melanin pigments in this layer (Plate VI). The caps were more distinct in the heavily pigmented epidermis and in the cells of the upper part of this layer. The significance of such cap formation is not known. Their presence in such a position in the cells might protect the nucleus and other vital cytoplasmic organelles from injurious effects of the ultraviolet ray of the sun.

Pigmentation: Pigmentation was observed in all skin areas under investigation. The pigment granules were brown and occurred within the cells of all layers of epidermis. They occurred in abundance in the cells of the basal layers and gradually decreased from the basal layer to the stratum corneum. Within the cell cytoplasm, they assumed a

characteristic supranuclear position from the stratum spinosum up to stratum granulosum (Plate VI and XV). They were observed in the stratum corneum in more pigmented skin such as lips, eyelids, and nostrils and were absent in general skin areas. These findings agree with Sinha (1964) and Goldsberry and Calhoun (1959). Continuing from the basal epidermal cells pigment was abundant in the cells of the basal layer of the external root sheath of the hair follciles down to the opening of the duct of the sebaceous glands. The wall of the ducts of the sebaceous and sweat glands also contained some pigments. The skin of the upper lip, lower lip, nostrils, upper eyelid, lower eyelid, prepuce and circumanal region were heavily pigmented. The skin of the general body surface was moderately pigmented. No difference was observed in pigmentation of the skin between the dorsal, lateral and ventral surfaces as was reported in cattle by Goldsberry and Calhoun (1959) and Sinha (1964). A few cells contained pigment granules in the dermis of heavily pigmented areas.

Keratinization (cornification): The epidermis of all the skin areas investigated showed keratinization. The process is thought to occur due to transformation of tonofibrils and the gradual formation of keratohyalin granules in the cytoplasm of the cells of the stratum germinativum and stratum granulosum (Montagna 1962). The keratohyalin granules of the stratum germinativum and stratum granulosum finally changed to keratin at the junction between the stratum granulosum and corneum. The process of keratinization was

more vigorous in areas where the thick cornified layer was formed, such as the chestnut, ergot and coronary border. This was evident by the presence of a thick layer of stratum granulosum, the cells of which were laden with well formed keratohyalin granules. The cornification process was also quite active in all areas with thick epidermis, such as lips and nostrils.

The formation of keratohyalin granules was tested by Gomori's aldehyde fuchsin and the keratohylin granules were stained with this method. This was confirmed by staining the chicken gizard, which contains known keratohyalin granules. With the help of this stain the keratohyalin granules were observed in the cells of the suprabasal layer of the epidermis. The numbers increased rapidly from this layer and filled the cells completely at the upper germinal layer. These granules packed the stratum granulosum so completely that the intercellular spaces barely could be seen. The stratum corneum did not take the stain as it was free from keratohyalin granules (Plate VII). This finding revealed that the keratohyalin granules start forming in the cells of the suprabasal layer. This is in disagreement with the statement of Sinha (1964) that keratohyalin granules occur only in stratum granulosum.

Dermis (Corium)

The dermis contains three types of connective tissue fibers. The arrangement and population of the fiberous components were different in the different parts. According

to the thickness and arrangement of the connective tissue fibers, the dermis is divided into two layers--Stratum papillare and Stratum reticulare. The junction between these two layers was very distinct in the general body skin (Plate IX). Usually, the layers were widely separated when the skin was fixed in Petrunkevitch's cupric paranitro-phenol fixative (Gurr, 1962) or when the sections were allowed to float longer than normal on warm water and stained as usual. Under these treatments, the fiberous components of the stratum papillare in general were disorganized and loose, while the stratum reticulare remained absolutely compact. This condition of disorganization and looseness of fibers in the stratum papillare and compactness in stratum reticulare was due to the different organization of fibers in the respective layers.

Stratum papillare: This layer extends from the dermo-epidermal junction to the subglandular region. This was the narrower of the two layers of dermis and consisted of fine collagenous fibers interwoven with elastic and reticular fibers (Plates XIV and XLVIII). As in cattle (Sinha 1964), where the skin was thick and the hairs were scanty, dermal papillae of various sizes and shapes were present. The papillae were generally long and sometimes bifurcated, as in the lips (Plate XXVI), abdomen (Plate IV), nostril (Plate VI), external ear (Plate XXIX), circumanal region (Plate XXX), eyelids and prepuce. The papillae contained loops of capillaries. The superficial surface was uneven and perfectly united with the epidermis, while the bottom surface was almost

even and imperfectly united with the reticular layer (Plate IX). This layer contained the hair follicles, sebaceous glands, sweat glands and arrector pili muscle. The arrector pili muscles were attached with the superficial papillary layer and the lower third of hair follicles by strong elastic tendons (Plates XLVIII and XV). Skeletal muscle fibers in bundles of 3-4 fibers or singly were present in this layer in the nostril (Plate XLVIII) and lips (Plate XXVI). They too were attached to the subepidermal part of the dermis by even stronger and thicker elastic bundles (Plate XII). The ducts of sweat glands which often opened directly on the epidermal surface bisected the layer at its upper half (Plate XXVII). Numerous blood vessels of different sizes formed vascular plexuses in the subepidermal region of this layer.

Stratum reticulare: This layer was composed of coarse collagenous fibers arranged in bundles. The bundles were organized both vertically and horizontally in a definite manner in the upper part and abruptly became disorganized at the reticulo-papillary interface (Plates IX, X and XI). They were very compact in the middle part and formed alternating bundles at angles to each other and paralleling the surface. This finding agrees with those of Montagna (1962) for man. In the general skin areas, a subreticular layer was organized horizontally with medium sized collagenous fibers interwoven with coarse elastic fibers. The reticular layer was comparatively poor in elastic fibers in its upper part, whereas the lower part was very rich in elastic fibers.

This finding slightly differs with Schönberg (1926), who stated that the reticular layer in the horse was poor in elastic fibers. Very large arteries and veins were present in this layer (Plate X). They formed large vascular plexuses at the lower part. Large bundles of nerve fiber were observed in all the layers of the dermis and pacinian corpuscles were seen in the reticular layer of the skin of the back.

Cellular Components:

Fibroblasts: The predominant cells of the dermis were the fibroblasts. They were most numerous and more basophilic in the papillary layer than in the reticular layer. The cytoplasm was homogenous and slightly acidophilic. The nuclei were mainly oval shaped and were strongly basophilic. Occasional cells were branched with fine fibers attached with the processes. The fibroblasts in the reticular layer were less numerous and were compressed between the coarse collagenous fibers. In the reticular layer the cells appeared more elongated than the cells of the papillary layer. Cell membranes were not seen clearly.

Mast Cells: They were observed in the whole dermis but were more numerous in the papillary layer. They were present in large numbers on the wall of the blood vessels in the papillary layer of the dermis. They were also present in the subepidermal region and around the sebaceous glands. The cells were irregular in outline, with a centrally placed round nucleus. The cytoplasmic granules were abundant and

uniformly distributed. No difference could be found in the cells of the reticular and the papillary layer as was observed by Sinha (1964) in cattle. Their distribution was almost uniform in the areas under study.

Macrophages: In addition to those two types of cells, the papillary layer contained macrophages with a round usually acentrically placed nucleus. In a few cases, the macrophages contained foreign particles in their cytoplasm.

Dermal Chromatophores: These cells were common in the areas adjacent to heavily pigmented epidermis. The cells contained granules in the cytoplasm. They were also observed on the walls of some blood vessels in the upper part of the papillary layer and on the duct of sebaceous glands.

Fibrous Components

The dermis was composed of collagenous elastic and reticular fibers. All three components were present in both stratum papillare and stratum reticulare. The sizes, orientation, and the population of the type of fibers were different in the different parts of the dermis.

Collagenous Fibers: These were the predominant type throughout the entire dermis. They were fine and irregularly arranged in the papillary layer. In the subepidermal region the fibers became very fine and were continuous with the reticular fibers, as if the reticular fibers branched off from the collagenous fibers (Plate XIV). This observation was in agreement with Robb Smith (1945). These fibers were interwoven with the elastic and reticular fibers and were distinct in the stratum papillare (Plates XII, XIV and XLVIII). In

the reticular layer the fibers were very coarse and formed prominent bundles. The fibers of the lower part of the reticular layer of general areas were oriented parallel to the surface (Plate X).

Elastic Fiber: The skin of the horse in general was very rich in elastic fibers. In the papillary layer they formed wide nets between the hair follicles, on the wall of the follicles (Plate XIII), in the subepidermal region, and between the sweat glands. The fibers in the interfollicular and interglandular net were medium sized and on the walls of the follicles and in the subepidermal nets were fine. Though characteristically the elastic fibers were not in bundles, their aggregations on the capsules of sebaceous glands (Plate XIII), at the point of attachment with the arrector pili muscle and skeletal muscles, presented a bundle like appearance (Plate XII, XIII and XV). Fine branches were given off from the medium fibered interfollicular network to the hair follicles where they were organized in both longitudinal and transverse patterns along the long axis of the hair follicles. At the middle third of the hair follicle the fibers formed a thick capsule-like sheath along with a few collagen fibers (Plates XII and XIII). The areector pili muscles were attached to the follicle as well as to the subepidermal region by means of elastic fibers. At both the ends of the muscle the elastic fibers branched in several subdivisions, covering a wide area (Plates XV and XLVIII). At the follicular end of the muscle (origin) the fine fibers joined the follicular capsules. At

the subepidermal end (insersion) the branching fibers continued subdividing until they penetrated the basement membrane (Plates XV and XXXI). Some of the very fine fibers came in actual contact with the basal epidermal cells. The elastic fibers encircled the ends of the skeletal muscle fibers in the lips and nostrils and branched off to form a brush-like tuft. These fibers extended vertically and joined the subepidermal nets (Plate XII). The fibers from the subepidermal nets also branched off and became finer and finer tojoin the basement membrane (Plate XXXI). Occasional thick elastic fibers were observed in the upper and middle parts of the reticular layer. At the lower part of the reticular layer of the general skin areas, elastic fibers were in abundance and paralleled the surface at an angle with each other. This finding agreed with those of Sinha (1964), who observed a similar arrangement in cattle.

Reticular Fibers: These fibers were observed mainly in the papillary layer. The fibers were frequently branched in an acute angle. They were closely associated with the basement membrane. Fine filamentous fibers branched off from the fibers of the basement membrane to come in close contact with the basal epidermal cells (Plate XIV). Some of them appeared to enter the intercellular spaces. They were present around the hair follicles in a similar pattern. Reticular fibers were also present on the wall of blood vessels and cutaneous glands. They did not occur freely in the reticular layer.

The Basement Membrane

The basement membranes of the dermo-epidermal interface and of the hair follicles were very distinctly PAS positive. The basement membrane, on which the epidermis rests, was present in all the skin areas under study. The membrane was thick where the epidermis was thick and thin with thin epidermis. The PAS positive basement membrane surrounding the hair follicles at their middle third was the thickest of any in the skin (Plate XXI). The basement membranes of the sweat and sebaceous glands were very thin. The area occupied by a basement membrane at the dermo-epidermal interface and that surrounding the hair follicles contained a thick network of reticular fiber. When cut obliquely those fibers remaining close to the basal layer of the epidermis gave an illusion of small button-like ends, projecting towards the epidermis or remaining in the intercellular spaces (Plate XIV). This was also the observation of Dick (1947) and Odland (1958). When the sections which were stained by the PAS method, periodic acid-silver-orcin-aniline blue, and by aldehyde fuchsin were compared, it was apparent that the basement membrane was composed of a network of reticular fibers, and the meshes were filled by PAS positive mucopolysaccharides.

Dermo-epidermal Junction

The basement membrane is one of the most important structures at the dermo-epidermal junction. The minute structural organization of which has just been described.

In the first place, delicate cytoplasmic processes of the cells of the basal layer entered into the basement membrane where the processes gave off short collateral branches or divided further to form fine rootlets (Plates V and VII). Probably the processes entered into the reticular meshwork of the basement membrane first and then gave off branches or divided to form a bunch of rootlets at the end of each process. Secondly, the elastic fibers from the dermis entered into the basement membrane where they further divided and their terminal branches arborized with the already rich reticular mesh and cytoplasmic processes (Plates XV and XXXI). Finally, the reticular fibers were also continuous with the fine collagen fibers of the dermis.

In summary, the penetration of the cytoplasmic processes into the basement membrane, the enmeshing of elastic and reticular fibers and the attachment of the reticular fibers to the dermal collagenous fibers, all combined to give strength to this attachment.

The Sebaceous Glands

Distribution and Morphology: The sebaceous glands were normally very large in the horse. With the exception of the large tarsal glands, they occurred in all areas under investigation and opened directly into the neck of the hair follicles by a short duct. Usually there were two glands with each follicle (Plate XVI) but as many as six in some follicles. This was in agreement with Trautmann and Fiebiger (1957), and Krolling and Grau (1960). Smith (1888)

observed two glands in association with one follicle. They both opened on the sides of the follicles, one on each side (Plates XVI and XLVIII). In case there were more than two, the glands opened in a series, one above the other, on both sides of the follicle (Plates XXII and III). They were very large at all the mucocutaneous junctions, prepuce, upper lips, external ear canal and at the margin of the hoofs. The glands of the external ear canal and circumanal region were lobulated and covered by a well developed capsule (Plates XXIX, XXX). At the margin of hoof and in the upper lip, they were highly branched and each branch was lobulated (Plates XXV, XXX). The glands with coarse hair were extremely long and paralleled the long axis of the hair follicle.

Histologic Structure: The sebaceous glands of general body areas were composed of 2-8 lobes and the special areas mentioned above were highly lobulated with as many as twenty lobes. All the lobes of a gland opened into a common short excretory duct, which in turn discharged the contents of the gland into the hair follicle. The wall of the ducts was continued with the external root sheath of the follicle and contained two to four layers of cells. In the body of the gland the cells varied in size. The cells in the periphery were strongly basophilic and were cuboidal shaped with a round nucleus. Gradually the cells became larger and polyhedral near the center of the gland. They appeared foamy towards the ducts, contained pycnotic nuclei and then ruptured and disintegrated. Cellular debris was present

in the duct.

The Sweat Glands

Distribution and Morphology: The sweat glands were present in the skin of the general areas of the entire body surface and were well developed. There was always one gland associated with each follicle and set deep into the dermis below the level of hair follicles. They formed a continuous layer just below the hair follicles in the flank and abdomen. Smith (1888) observed such a formation in the flank. The sweat glands on the posterior ventral side of the abdomen were comparatively large (Plate IV). In the skin below the mane, tail and fetlock they were long tubules with a very small coiled secretory portion. The glands were very large in the skin of the circumanal region (Plate XXV), external ear canal (Plate XXIX), prepuce, nostril and in the lower lip. A gland free zone in the lower lip was present for about 1 cm from the mucocutaneous junction. The sweat glands were also absent in the upper lip, around the margin of the hoof, (about 5.5 mm) and around the ergot (about 5.5 mm).

The sweat glands were normally simple tubular and the tubules formed sac-like diverticula in the large sweat glands of special areas (Plate XXX). In agreement with Trautmann and Fiebiger (1957), the sweat glands in the horse were glomiform. Thesecretory part of the tubule was never branched but the diverticula from two adjacent coils were often found united. This is in agreement with Montagna (1962). The coiled ducts were much narrower than the secretory tubules.

after leaving the secretory coils the ducts often pierced the arrector pili muscle in the general body skin. They opened either into the upper part of the follicle or on the surface just adjacent to the follicular opening (Plates XXX, XXVII, and XLVIII). About one half of the ducts opened directly on the surface.

Histologic Structure: The secretory cells were in a single layer, rested on a thin layer of myoepithelial cells which in turn were on a thick basement membrane. This was in agreement with Montagna (1962). A loosely arranged connective tissue capsule was present. The secretory epithelium was columnar or high cuboidal with a round nucleus placed at the base. The wall of the cell facing the intercellular surface was smooth and provided a somewhat wider intercellular space. Infoldings were present at the base of the cells and the folds interdigitated with the underlying myoepithelial cells (Plate XXIII). Intercellular canaliculi were present at the basal part of the cells but the intracellular canaliculi or secretory canal mentioned by Copenhaver (1964) in eccrine glands was not present (Plate XXIV). The lumen of the secretory tubules contained PAS positive secretory substances.

Four different modifications of the secretory cells were observed: 1. Some glands of the general and special areas contained an irregular luminal surface due to an uneven projection of the apical end of a few cells. These apical projections gave a pinched-off appearance. With the use of

frozen section and phase microscopy, these apical ends were found intact and were thought to be artifacts (Copenhaver, 1964). 2. In the general skin areas, the luminal border of the secretory cells contained a terminal web (Hay, 1966) with scattered microvilli (Plate XXIV). 3. The free edges of the secretory cells of some large glands were provided with terminal web (Hay 1966) and a brush border. The brush border was in such a form that the entire liminal surface formed a continuous brush border (Plate XXIII). Takagi and Tagawa (1959) reported the presence of a brush border in the sweat glands of the horse. According to Montagna (1962), the luminal surface which consisted of a brush border was composed of microvilli. 4. In tubules with wider lumens, the cells were low cuboidal to even squamous type.

The secretory ducts were lined by stratified cuboidal epithelium. There were no myoepithelial cells on the walls of the duct.

No glycogen was present in the cytoplasm of the secretory cells or the myoepithelial cells. According to Evans et al (1957) sweat glands of the horse as well as the eccrine glands contained glycogen. Takagi and Tagawa (1959) did not find any trace of glycogen in the sweat glands of horses except in the myoepithelial cells. The secretory cells contained fine PAS positive granules particularly accumulated at the luminal ends. The terminal web in the luminal border of the cells was also PAS positive. PAS positive granules were abundant in the lumen and had a tendency to adhere to the

terminal web of the cell border.

Functionally the sweat glands of the horse belonged to the apocrine group as revealed by histologic and histochemical studies, but differed from the apocrine glands of man and other domestic animals. The typical apocrine mode of secretion was present. In addition it is possible that some secretion occurred by the exudation of liquid materials through microvilli or pinching-off of the ends of microvilli. Furthermore for profuse sweating in the horse perhaps the basal canaliculi add the watery part of the sweat through intercellular spaces (Plate XXIV). These dual secretory activities of the sweat glands of the horse has made them so efficient that they function like both an apocrine and eccrine gland in one unit. This proposal of the secretory mode of the sweat glands of the horse is based on the findings of this investigation and the thoughtful suggestions of Montagna (1962) and Copenhaver (1964).

Croup and adjacent areas: This area of the dermis is modified in the horse and extends caudally from the middle of the back to the posterior end of the croup and laterally from the croup covering most of the gluteal region. This area according to Schönberg (1926) becomes shiny and reflects images on tanning and he termed the area "spiegel" (mirror). Odoni (1951) reported this area as extremely thick in the horse in comparison to donkey and mules.

A different histologic feature distinguished this area from other parts of the dermis. The dermis was very compact in all the animals and the collagenous fibers were oriented in three distinct patterns in the reticular layer (Plate X). Fibers in the upper part were arranged both vertically and horizontally, the the middle part in all directions and in the lower part parallel to the surface. Though this was the normal arrangement of the fibers in the dermis of all general areas the arrangement in this area was particularly striking. The thickness of the total dermis reached its peak in the skin of croup (5.5 mm) and gradually diminished anteriorly and laterally but increased towards the tail accompanied by diminished compactness of the dermis (Table IV). The thickness of the dermis of the croup compared favorably with the findings of Odoni (1951). The development of the papillary and reticular layers appeared proportionate with the other general skin areas. A separate measurement of the reticular

and the papillary layer showed that the reticular layer was the thicker part. This finding was in agreement with Odoni (1951). The hairs were mostly of uniform size and the sebaceous glands were well developed. The arrector pili muscles were well developed usually with branching ends. The individual muscle occupied a large area for its attachment at the dermo-epidermal junction (Plate XV). The sweat glands were also well developed. The elastic fibers were much more numerous than in any other part of the general body skin, probably for the diffuse attachment of the arrector pili muscles.

External Ear: Both the epidermis and dermis were very thin on both surfaces of the pinna. The thickness increased gradually towards the external ear canal and at the base of the ear the skin in general became thick. There were prominent epidermal pegs and dermal papillae. The hairs were very fine and scattered. The sebaceous glands were highly developed and lobulated. The whole unit of the gland surrounds the neck of the associated hair follicle in most cases. A compact, moderately thick connective tissue capsule covered the glands and thus the lobules were packed together. Delicate connective tissue septa extending from both the surrounding capsule and the connective tissue sheath of the follicles separated the sebaceous lobules. No sebaceous glands opened on the surface. The sweat glands were extremely large and were located deep in the dermis. The secretory tubules were highly tortuous and clustered around

the root of the hair follicles (Plate XXIX). The canalicular system and the brush borders were similar to those in the general body sweat glands. Prominent myoepithelial cells were present in the secretory tubules only. The ducts usually passed through the sebaceous glands and opened on the surface adjacent to the pore of the hair follicles. The epidermal cells were pigmented. The pigmentation extended over the neck of the follicle and on the wall of the ducts of sebaceous glands. Numerous arterio-venous anastomoses with a regular glomus formation were observed. This is in agreement with Danial et al. (1956).

Circumanal region: In this area the epidermis was very thick (260u) but the cornified layer was not as prominent as that of other thick epidermal areas. The epidermal pegs and the dermal papillae were well developed. The hairs were very fine whereas the associated sebaceous glands were large and lobulated. The lobules were well apart and converged to the neck of the follicle to join the common duct. The dermis was in direct contact with the adjacent skeletal muscle bundles. The sweat glands were mostly a large saccular type (Plate XXX). A few small sized tubular glands were also present. The secretory cells in the saccular type of glands were low cuboidal to squamous. Evidence of a canalicular system was not seen in these glands, whereas in the tubular glands the canalicular system and brush border were present. The lumen of the secretory tubules and saccules contained abundant secretory materials. The ducts

often opened directly on the surface (Plate XXX). Smooth muscle bundles were very prominent in the papillary layer. The epidermis was heavily pigmented and the hair follicles, sebaceous ducts and even the dermis contained pigment granules. Few pigments were found on the wall of the secretory tubules of the sweat glands.

The dorsal neck and the tail: The histologic feature of the areas under cover of the long, coarse hairs, was similar. In both areas the hairs penetrated deep into the dermis but never crossed the entire width. The skin surface was wavy and covered by a thick cornified layer. The cornified layer in both sites was formed of threadlike cornified cells and occurred in a pattern that gave the appearance of a net when loosened. Most of the long coarse hairs were of uniform size. In cases where the hairs were closely distributed, a very small space was left in between for the passage of the arrector pili muscle and the cutaneous glands. Two elongated sebaceous glands were associated with each follicle. The sweat glands were the smallest of the body. They were composed of a small secretory part with a long duct, tortuous below and straight towards the epidermis. Usually the ducts were associated with the arrector pili muscle and penetrated the muscle at several points giving the idea that the muscle supports the sweat ducts. The ducts opened in the upper part of the neck of the follicles or on the surface close to the follicular opening. The arrector pili muscles were long and slender. Usually there was one branched muscle associated with each follicle. In

some cases two muscles were also observed. The individual muscle was up to 2 mm in length. The reticular layer of the dermis of the root of the tail contained sheets of collagenous fibers oriented parallel to the surface while the other areas on the neck or tail did not have such a layer. The fibers of the reticular layer were very irregularly oriented. The skin in these areas was 6-6.3 mm in thickness and the epidermis was about 80 microns on an average.

Eyelids: The skin of the eyelids were moderately thick (about 3.00 mm) whereas the epidermis was thicker (about 100 microns in both the lids) with branched epidermal pegs. The epidermis was heavily pigmented with densely packed clear cells in the basal layer. The pigments were also present in the dermis. The skin was covered by fine hairs and provided with large branched sebaceous glands. Sinha (1964) also observed a similar condition in cattle. The sweat glands were both tubular and saccular types with secretory materials in the tubules. The eyelashes were coarse hairs rooted deep into the dermis. The accompanying secabeous glands were also large. The dermis was provided with bundles of smooth muscle fibers (Müllers muscles) scattered throughout. Scattered skeletal muscle fibers were observed deep in the dermis. Tarsal glands, the largest modified sebaceous glands in the body, occurred in rows in both lids. They were covered by a thick connective tissue capsule and the lobules were separated by distinct connective tissue septa derived from the capsule. The sebaceous lobules joined at the center of

the glands to open into a commun duct. The duct opened on the conjunctival surface near to the junction of epidermis with the conjunctiva.

Chestnut and ergot: The chestnut of both the fore and hind limbs and the ergot of the fetlock had similar histologic features. The epidermis was extremely thick with a very thick cornified layer (Plate XXXII) which formed the horny tissue of the organ. With the exception of the stratum lucidum, the other layers of the epidermis were present. The stratum cylindricum formed the basal layer and the border of the long dermal papillae. The often branched dermal papillae were highly vascular and the loops of the capillaries extended to the tip of the papillae. The cells of the interpapillary zone were polyhedral and contained large keratohyalin granules in the upper part. Horny tubules were formed regularly above the dermal papillae. The stratum granulosum was very thick (Plate VIII). The cornified cells near the stratum granulosum had distinct intercellular spaces without intercellular bridges. The dermis below the horny structure of the chestnut was one of the thinnest (2.5 mm) in the body while the dermis below the ergot was one of the thickest. The dermis usually contained a few arterio-venous anastomoses. Arterio-venous anastomoses were observed just below the dermal end of the papillae. Clara (1956) reported arterio-venous anastomoses in the papillae of the hoof. The sebaceous glands surrounding the ergot were highly developed and branched. A zone of about 5.5 mm which was free from sweat glands was

present around the ergot.

Coronary border: This is a well demarcated border between the hoof margin and the skin. It consisted of horny and hairy parts. The epidermis from the hairy part gradually thickened near the junction with the horny part. The cornified layer, epidermal pegs and the dermal papillae were also increased in thickness and length towards the border line. At the border line the cornified layer changed into a massive compact horny tissue; the epidermal pegs became the interpapillary epithelial tissue and the dermal papillae became the regular papillary body. Horny tubules appeared at this point. The border line was demarcated by coarse, long hairs. The follicles of these hairs were in groups of 3-5 (Plate XXXIII) but erupted on the surface singly. The sebaceous glands in the hairy part were normally large and lobulated. The sebaceous glands gradually became larger and larger towards the border line where the glands were extremely large and highly branched (Plate XXXIII). They were one or two glands thick and occurred on the horny side of the border line. Sweat glands were absent for about 6 mm dorsal to the border line and the coarse hairs of the border were without associated sweat glands. In agreement with Schummer (1951, cited by Clara, 1956) few arterio-venous anastomoses were present.

Prepuce: The thick epidermis was about 245 microns. The epidermal pegs were very deep and branched. The dermal papillae accordingly were tall with loops of blood vessels.

The basal cells were heavily pigmented (Plate XXXI) with a few clear cells in between. The dermo-epidermal junction was very rich in fine elastic fibers. These fibers were derived from the branching of vertically oriented sub-epidermal elastic fibers (Plate XXXI). The hairs were thinly distributed accompanied by a large sebaceous gland. The sweat glands were saccular and placed in a row. The arrector pili muscles were well developed. Prominent arterio-venous anastomoses were present in the dermis.

Nostrils: The epidermis of the nostrils was very thick (about 300 microns) and well developed epidermal pegs were present. The stratum granulosum and corneum were fairly thick. The basal layer of the stratum germinativum was heavily pigmented while the cells of the upper layer were moderately pigmented (Plate XXVII). The dermal papillae contained capillaries. The hairs were fine but were in large numbers with moderately large sebaceous glands. Very large tactile hairs were present throughout. The arrector pili muscle and sweat glands were medium sized. Most of the sweat glands were tubular and their ducts opened on the surface close to the pore of the hair follicles (Plates XXVII, XLVIII). A few saccular glands were also present deep in the dermis. The upper part of the dermis was very rich in elastic fibers and just below the dermo-epidermal junction formed a thick elastic net. The central core formed by the dermis of both sides contained large skeletal muscles, bundles of collagenous fibers as well as fat (Plates XXVIII).

Small bundles of skeletal fibers were detached from the central large bundles to insert in the sub-epidermal region by means of elastic tendons (Plates XXVIII, XLVIII). Arterio-venous anastomoses were present in the upper dermis with a regular glomus formation.

The Lips

Upper lip: The upper lip had the highest epidermal thickness in the body (750 microns) with a thick stratum corneum and stratum granulosum. Epidermal pegs were well developed and branched. Tall dermal papillae, sometimes branched, filled the space between the epidermal pegs. The basal cells were moderately pigmented and pigments were also present in the cells of the upper layer.

The hairs were fine to medium sized and were distributed fairly close to each other. Large numbers of tactile hairs were present and scattered among the common hairs. They were somewhat smaller than the tactile hairs of the nostrils. Each follicle received at least two sebaceous glands. The sebaceous glands were usually branched and very large near the mucocutaneous junction(Plate XXV). There were no sweat glands in the upper lip. The dermis merged with the underlying thick layer of skeletal muscle. Small bundles or single skeletal muscle fibers detached from the underlying muscle and inserted in the upper part of the dermis in both the lips by an extremely thick elastic tendon (Plate XII). The upper lip was perhaps the richest in elastic fibers of all the areas studied. Probably this rich elastic component

in the upper lip aids the animal in using it as the organ of prehension. The upper lip was rich in arterio-venous anastomoses. A few arterial cushions were evenly distributed in the upper part of the dermis. The arrector pili muscles were rudimentary.

Lower lip: In general, the histology of the lower lip was similar to that of the upper lip and nostrils except for the few differences noted below.

1. The average thickness of the epidermis was only 278 microns.
2. The skeletal muscle fibers extended in all directions in the upper part of the dermis (Plate XXVI).
3. There were saccular type sweat glands which often were very large in the region about 1 cm posterior to the mucocutaneous junction.

The presence of a large number of arterial cushions in both the upper and lower lip aids in distribution of red cell-rich blood to the local tissue. With the higher concentration of red blood cells the blood naturally becomes oxygen rich. This ccupled with the rich deposits of glycogen in the follicular cells of the lip might enable the horse to meet the excess energy requirement for active use of the lips as the organ of prehension.

Nerve supply of the lips: Innervation of the lips was demonstrated by the Bielschowski Gross method, a modification by Devenford (Lillie 1965). Three plexuses of nerve trunks were recognized in the lip. That first plexus was observed

below the dermal end of the hair follicles. The nerve trunks in this plexus were very thick with medulated fibers. Medium-sized nerve trunks leaving this plexus reached the space formed between the lower part of the sebaceous glands and hair follicles. At this point the trunks divided in most cases and gave off 2-3 branches (Plate XLIV). One of these branches entered between the gland and follicle and the other two passed over the capsule of the sebaceous glands. The interfolliculo-glandular branch in many cases gave off many branches and some of them ended in round or slightly elongated formed organs in close approximation to the follicle (Plate XLIV). The others innervated the hair follicles. The second plexus was formed in the subepidermal corium, about the level of the neck of the hair follicles (Plate XXXIX). A few branches from this plexus innervated the neck of the hair follicles. Numerous organized and free endings were observed in this part of the dermis. Fine non-medullated fibers formed networks just below the dermo-epidermal junction. Many of the fibers extended horizontally along the junction and others entered into the epidermis. Their course could not be followed above 5-6 cell layers. The third plexus was in the dermal papillae. Smith (1888) also observed a similar plexus in the dermal papillae of horse's lip. Fibers, both in bundles and free, occurred in the papillae (Plate XXXIX). Many fine fibers extended vertically on the edge of the dermal papillae, reached the tip of the papillae and entered the germinal cell layer of the epidermis,

where their course could not be followed further. Nerve fibers on the wall of blood vessels were also observed in large number.

Innervation of hair follicles: The hairs of the mammalian skin are important organs of sensory perception. As an organ of tactile perception, their pattern of innervation suited them very well. According to Winkelmann (1959), nerve fibers supplying the hair follicles varied from 5-12. The larger follicles had large numbers of fibers and the smaller ones less.

The follicles were reached by fibers from the part of the dermis below the loweat part of the sebaceous glands. Thick myelinated fibers reaching the follicles divided and formed a very distinct network. In this network one set of fibers extended longitudinally along the axis of the follicle and another set encircled the follicles. The fibers were in very close touch with the cells of the external root sheath. According to Winkelmann (1959), the fibers of this network were non-myelinated and the inner set was arranged longitudinally and the outer circular. Some of these fibers appeared to terminate in the follicles and others branched repeatedly along the hair axis. The fibers of the latter group further subdivided and formed bushy terminal ends in close contact with the walls of the cells of outer root sheath (Plate XLVII). This observation is in agreement with Weddell and Palli (1954), Singer and Salpeter (1966), Copenhaver (1964), Dixon (1964), and Winkelmann (1959). Some of the fibers from the subdermal plexus also innervated

the hair follicles.

Innervation of tactile hair follicles was similar to that of the general hairs. Three to seven large nerve trunk from the lower part of the dermis supplied the hair (Plate XLIII). They crossed the sinus of the follicle through the trabeculae to the inner connective tissue sheath of the follicle. They extended vertically over the sheath until they reached the neck where they innervated the external root sheath of the follicle.

Organized Nerve Endings

A large variety of nerve endings was observed in the lips of the horse. It was very difficult to assign each of them morphologically to specific modalities. Smith (1888) observed small pacinian-like corpoacles in the lip of the horse and a similar observation was confirmed by Sinha (1964) in cattle. It is the belief of many authors, including Montagna (1962), that the morphological differences in nerve endings depends on their location in the skin. According to Montagna (1962), the number of follicles and the number of organized end organs were in inverse ratio. They were more in the skin with less hairs or without hair. As cited by Montagna (1962), Winkelmann observed that the nerve nets in the skin without hair may give rise to a spherical mass simulating mucocutaneous end organs.

The nerve endings that were observed in the lips of the horse may be classified into four main groups: (1) Lamellated endings (Plate XLVI), (2) Capsulated endings (Plates XLV,

XLII, XLI, XL), (3) Non-capsulated end balls (Plate XLIV), and (4) Fine free nerve endings of the upper dermal papillae and epidermis.

Lamellated endings: These endings were not very common. They occurred in the upper dermis. The endings were pumpkin shaped. They were covered by a thin capsule of one cell thick. Within the capsule there was a lamella of one cell thick consisting of epitheloid cells. The nerve fibers were at the central axis (Plate XLVI). Only one nerve fiber entered the narrow end of the organ. No filamentous breakup was observed.

Capsulated end organs: They were the most numerous in the dermis. They were usually large below the level of sebaceous glands and became smaller towards the surface. At least four different forms were observed. (a) Well formed oval shaped organs (Plate XLV). This type was covered by a one cell thick capsule. One thick myelinated nerve fiber entered the organ and divided rapidly to form fine networks. The networks, at points within the organ condensed to form numerous round or oval shaped bulbs. The bulbs and the networks contained a central core. (b) Small oval shaped organs (Plate XLI) were the most numerous. They were smaller near the epidermis. The distribution of fibers within the organ was the same as described under (a). The capsule was very thin. (c) Capsulated disk (XLII). These were few and usually occurred just below the epidermis. The fiber entering the organ broke up into filaments which formed a disk.

(d) Paired capsulated ending--only one of the organs of this type was noticed below the level of sebaceous glands. An outer capsule more than one cell thick was continuous around the neural elements. The capsule thickened at the dorsal and ventral sides to give connection with a centrally placed septum 2-3 cells thick (Plate XL). The neural elements were like the capsulated organs discussed under Capsulated End Organs.

Free nerve endings: These were present in the dermis close to the epidermis. Fine fibers penetrated the basal 5 or 6 cells layers of the stratum germinativum. In the dermal papillae they were present along the border. They extended little further from the tip of the papillae to the to the surface.

Non-capsulated Ball: This type was seen along the hair follicles and in the upper part of the dermis. One to three fibers branched and formed a glomus-like ball. The branched fibers formed a ball at the end (Plate XLIV).

TABLE I

AVERAGE MEASUREMENT OF TOTAL SKIN THICKNESS IN MM

Skin Regions	GA 2*	SB 12*	SC 9*	GD 17*	ME 17*	MF 15*	Average
Upper lip	3.7	2.7	3.8	4.6	3.2	4.0	3.6
Nostril	3.7	3.7	4.7	3.8	3.8	2.6	3.7
Upper lid	2.3	2.7	3.6	3.5	4.2	4.1	3.4
Lower lid	2.1	1.9	3.2	2.9	2.1	3.3	2.6
Forehead	3.3	3.9	2.3	3.1	3.0	2.3	3.0
External ear	3.6	2.9	2.3	3.6	2.3	2.9	2.9
Pinna (B)	2.1	2.8	2.3	2.9	2.8	2.7	2.6
Dorsal neck (mane)	7.1	5.9	4.1	7.6	7.1	6.1	6.3
Dorsal neck (mane)	4.5	7.5	6.6	6.1	4.6	4.3	5.6
Back	4.6	4.6	4.1	5.8	3.7	4.5	4.6
Croup	5.7	6.2	4.7	5.1	5.3	5.1	5.5
Root of tail - D	6.9	10.7	5.8	5.8	5.1	3.8	6.3
Tip of tail - D	6.3	10.2	6.6	5.1	5.2	5.6	6.5
Lower lip	3.8	2.7	2.5	2.9	3.3	3.3	3.1
Chin	4.8	4.6	5.0	5.4	5.5	---	5.3
Submandibular region	2.2	3.6	---	3.5	1.8	1.7	2.5
Lateral neck - C	3.7	---	2.6	4.4	3.0	3.6	3.4
Ventral neck - C	3.6	4.8	3.5	4.1	---	3.3	3.7
Brisket	3.2	3.8	3.2	4.6	---	3.3	3.6
Lateral neck - B	2.9	5.0	3.6	3.6	3.3	2.6	3.5

(continued on next page)

TABLE I (continued)

Skin Regions	GA 2*	SB 12*	SC 9*	GD 17*	ME 17*	MF 15*	Average
Chest wall	3.0	4.5	3.2	4.4	3.4	4.0	3.7
Flank	3.7	5.1	3.8	5.2	4.7	4.1	4.4
Gluteal region	4.6	5.6	4.7	4.6	4.2	3.4	4.5
Circumanal region	4.0	3.4	2.1	3.5	2.5	2.0	2.9
Thigh (lateral)	3.8	4.4	2.9	3.4	4.0	3.7	3.7
Thigh (medial)	3.6	4.1	3.7	---	2.9	3.4	3.5
Abdomen	4.0	4.6	3.5	4.6	3.6	3.2	3.9
Thorax (ventral-posterior)	4.5	4.6	5.0	4.2	3.7	3.7	4.3
Thorax (ventral-anterior)	3.5	4.1	2.8	2.9	3.5	3.7	3.4
Brachium	3.3	6.3	3.9	4.0	4.0	3.1	4.1
Axilla	3.2	4.1	---	---	---	2.0	3.1
Prepuce	---	6.2	4.0	---	---	---	5.1
Average of general skin areas	3.6	4.6	3.5	4.1	3.5	3.3	3.8

Letter Code:

G = Gelding
S = Stallion
M = More
A to F = Animal designated
* = Age in years

D = Dorsal
C = Central
B = Base
P = Posterior
A = Anterior

TABLE II

AVERAGE MEASUREMENT OF EPIDERMIS IN MICRONS

SKIN AREA	GA 2*	SB 12*	SC 9*	GD 17*	ME 17*	MF 15*	Average
Upper lip	500	650	750	1000	850	800	757
Nostril	230	200	200	260	270	235	298
Upper lid	70	140	100	110	110	90	103
Lower lid	65	125	130	90	70	100	97
Forehead	50	50	60	50	---	40	50
External ear	50	40	50	60	50	80	55
Pinna (base)	90	50	65	100	75	100	80
Dorsal neck - C	100	80	90	85	110	90	93
Dorsal neck - P	40	40	50	60	60	80	55
Back	50	60	70	60	80	40	60
Croup	50	50	70	70	90	60	65
Root of tail - D	70	150	140	80	50	50	90
Tip of tail	80	200	80	120	150	120	125
Lower lip	250	200	280	310	280	320	278
Chin	280	120	215	225	190	---	205
Submandibular region	60	55	---	50	50	52	53
Lateral neck - C	40	---	60	70	50	50	55
Ventral neck - B	35	60	45	60	55	50	50
Brisket	35	40	60	50	40	45	46
Lateral neck - B	40	45	40	60	40	50	46

(continued on next page)

TABLE II (continued)

Skin Area	GA 2*	SB 12*	SC 9*	GD 17*	ME 17*	MF 15*	Average
Chest wall	35	40	50	50	55	45	46
Flank	45	50	50	55	60	50	52
Gluteal region	50	70	40	53	50	50	52
Circumanal region	250	240	250	300	390	240	262
Thigh (lateral)	50	52	50	60	50	50	52
Thigh (medial)	50	55	50	---	50	75	56
Abdomen	60	55	60	95	70	60	67
Thorax (ventral-posterior)	45	40	50	50	50	40	44
Thorax (ventral-anterior)	40	70	50	70	45	60	57
Axilla	30	70				45	48
Prepuce		250	240				245

Letter Code:

G = Gelding
S = Stallion
M = Mare
A to F = Animal designated
* = Age in years

C = Central
B = Base
P = Posterior
A = Anterior

TABLE III

AVERAGE MEASUREMENT OF DERMIS IN MM

Skin Area	GA 2*	SB 12*	SC 9*	GD 17*	ME 17*	MF 15*	Average
Upper lip	3.2	2.0	3.0	3.5	2.3	3.2	2.9
Nostril	3.5	3.5	4.5	3.5	3.5	2.3	3.5
Upper lid	2.2	2.6	3.5	3.4	4.1	4.0	3.3
Lower lid	2.0	1.8	3.1	2.8	2.0	3.2	2.5
Forehead	3.2	3.8	2.2	3.1	3.0	2.3	2.9
External ear	3.5	2.9	2.2	3.5	2.2	2.8	2.8
Pinna (base)	2.0	2.7	2.2	2.8	2.7	2.6	2.3
Dorsal neck - C	7.0	5.8	4.0	7.5	7.0	6.0	6.2
Dorsal neck - P	4.5	7.5	6.5	6.0	4.5	4.2	5.6
Back	4.9	4.6	4.2	5.7	4.0	4.5	4.6
Croup	5.6	6.1	4.8	5.8	5.6	5.0	5.5
Root of tail - D	6.8	10.5	5.7	5.7	5.0	3.7	6.2
Tip of tail	6.2	10.0	6.5	5.0	5.0	5.5	6.3
Lower lip	3.5	2.5	2.2	2.6	3.0	3.0	4.9
Chin	4.5	4.5	4.8	5.2	5.3	---	4.9
Submandibular region	2.1	3.5	---	3.4	1.7	1.6	2.4
Lateral neck - C	3.7	---	2.5	4.3	2.9	3.5	3.3
Ventral neck - B	3.6	4.7	3.5	4.0	---	3.2	3.8
Brisket	3.2	3.8	3.1	4.5	---	3.3	3.6
Lateral neck - B	2.9	5.0	3.6	3.5	3.3	2.5	3.5

(continued on next page)

TABLE III (continued)

Skin Area	GA 2*	SB 12*	SC 9*	GD 17*	ME 17*	MF 15*	Average
Chest wall	3.0	4.5	3.1	4.3	3.3	4.0	3.7
Flank	3.7	5.0	3.7	5.1	4.6	4.0	4.4
Gluteal region	4.5	5.5	4.7	4.5	4.2	3.3	4.5
Circumanal region	3.7	3.2	1.8	3.2	3.6	1.8	2.7
Thigh (lateral)	3.7	4.4	2.9	3.3	3.6	3.9	3.6
Thigh (medial)	3.5	4.0	3.6	---	2.8	3.3	3.4
Chestnut (hind limb)	1.8	3.6	2.0	1.5	2.1	1.9	2.0
Ergot	6.5	12.0	4.2	4.5	6.0	3.5	6.1
Coronary border	6.3	6.0	4.3	4.8	4.5	4.0	5.0
Abdomen	3.9	4.5	3.4	4.5	3.5	3.1	3.9
Thorax (ventral-posterior)	4.5	4.6	4.9	4.1	3.6	3.7	4.2
Thorax (ventral-anterior)	3.5	4.0	2.7	2.8	3.5	3.6	3.4
Chestnut (fore limb)	2.1	---	2.2	2.1	2.2	1.8	2.1
Brachium	3.0	6.0	3.5	4.0	4.2	3.5	4.0
Axilla	3.2	4.0				2.0	3.1
Prepuce		5.5	3.8				4.7

Letter Code:

G = Gelding
S = Stallion
M = Mare
A to F = Animal designated
* = Age in years

C = Central
B = Base
P = Posterior
A = Anterior

TABLE IV

DERMAL THICKNESS OF CROUP IN MM AND ITS COMPARISON WITH ADJACENT SKIN AREAS

	Back (Post. Thoracic)	Croup	Gluteal Region
Stallion			
Pap. Layer	2.0	2.5	2.2
Ret. Layer	2.3	2.9	2.9
Total	4.3	5.4	5.1
Geldings			
Pap. Layer	2.2	2.4	2.1
Ret. Layer	3.0	3.5	2.5
Total	5.2	5.9	4.6
Mares			
Pap. Layer	2.0	2.5	1.8
Ret. Layer	2.1	2.6	1.9
Total	4.1	5.1	3.7
Av. of all animals	4.6	5.5	4.5

TABLE V

SEX DIFFERENCES IN SKIN THICKNESS IN MM

	Stallion*	Gelding*	Mare*
Upper lip	3.2	4.1	3.8
Nostril	4.2	3.7	3.1
Upper eyelid	3.2	2.9	4.2
Lower eyelid	2.6	2.5	2.7
Forehead	3.1	3.2	2.7
External ear	2.6	3.6	2.6
Base of the ear	2.5	2.5	2.7
Dorsal neck mane	5.0	7.3	6.6
Dorsal neck mane	7.0	5.3	4.4
Back	4.3	5.2	4.1
Croup	5.4	5.4	5.2
Root of tail - D	8.2	6.3	4.4
Tip of tail	8.4	5.7	5.4
Lower lip	2.6	3.3	3.3
Chin	4.8	5.1	
Submaxillary region		2.8	1.7
Lateral neck - C		4.1	3.3
Ventral neck - C	4.3	3.8	3.3
Brisket	3.5	3.9	3.3
Lateral neck - B	4.3	3.8	2.9
Chest wall	3.8	3.7	3.7
Flank	5.2	4.5	4.4
Gluteal region	5.2	4.6	3.8
Circumanal region	2.8	3.7	2.2
Thigh (lateral)	3.7	3.6	3.8
Thigh (medial)	3.9	---	3.1
Abdomen (posterior)	4.0	4.3	3.4
Thorax (posterior-ventral)	4.8	4.3	3.7
Thorax (ventral-anterior)	3.4	3.2	3.6
Brachium	5.1	3.6	3.6
Average	4.1	3.7	3.3

* Two animals

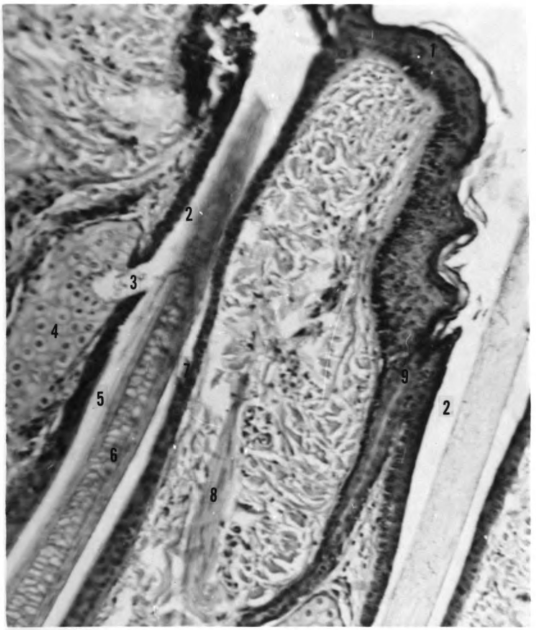


Plate I

General skin area.
1. Epidermis. 2. Pilo-sebaceous canal. 3. Opening of sebaceous duct. 4. Sebaceous gland. 5. Hair follicle. 6. Hair showing cortex and medulla. 7. Follicular fold. 8. Arrector pili muscle. 9. Opening of sweat duct at the neck of the follicle.

Vertical section, H & E Stain. X240

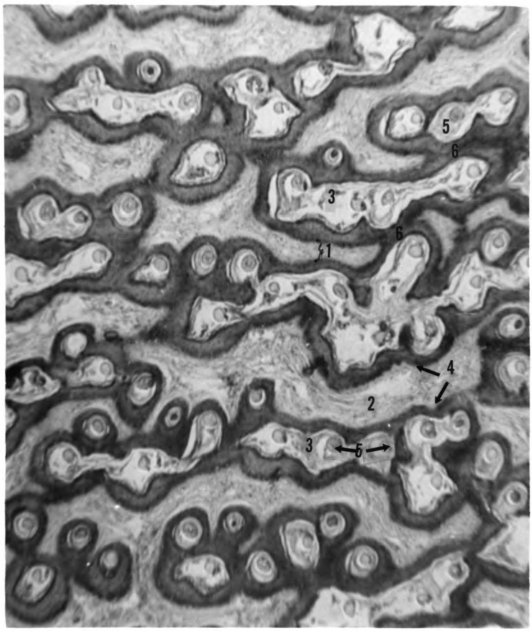


Plate II

Lateral surface of the thigh.
1. Surface integumentary ridges. 2. Core of integumentary ridges filled by dermis. 3. Integumentary valleys or grooves. 4. Two edges of the epidermis on the side of integumentary ridges. 5. Hairs erupt in the valleys in rows. 6. Summit of the ridges.

Horizontal section, H & E Stain. X60

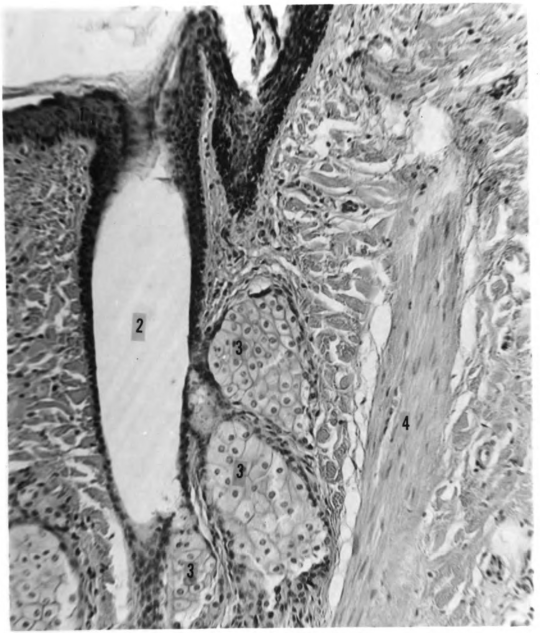


Plate III

Skin of the abdomen.
1. Epidermis. 2. Pilo-sebaceous canal. 3. Three sebaceous glands open in one follicle. 4. Thick arrector pili muscle.

Vertical section, H & E Stain. X250

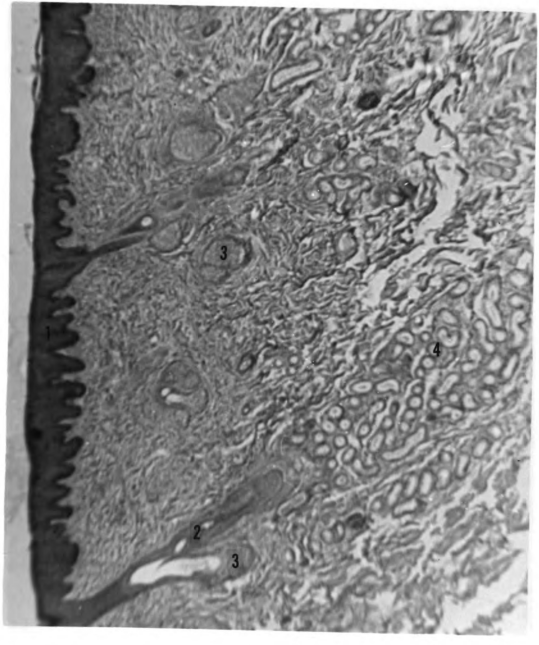


Plate IV

Skin of the abdomen.
1. Epidermis. 2. Hair follicle. 3. Sebaceous gland.
4. Large sweat gland deep in the dermis.
Note: Very few hair follicles.

Vertical section, H & E Stain. X60

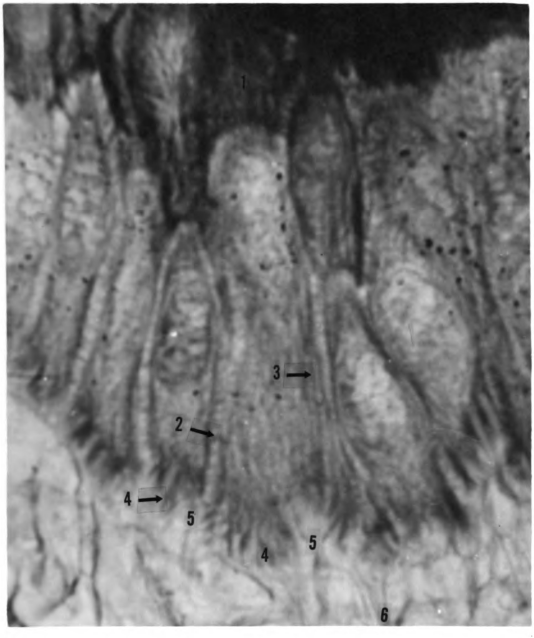


Plate V

Dermo-epidermal junction, nostril.
1. Suprabasal region of epidermis with greatly increased keratohyalin granules. 2. Desmosomes. 3. Tonofibrils. 4. Epidermal basal processes with collateral branches. 5. Basement membrane. 6. Elastic fibers.

Vertical section, Gomor's aldehyde fuchsin stain. X2450

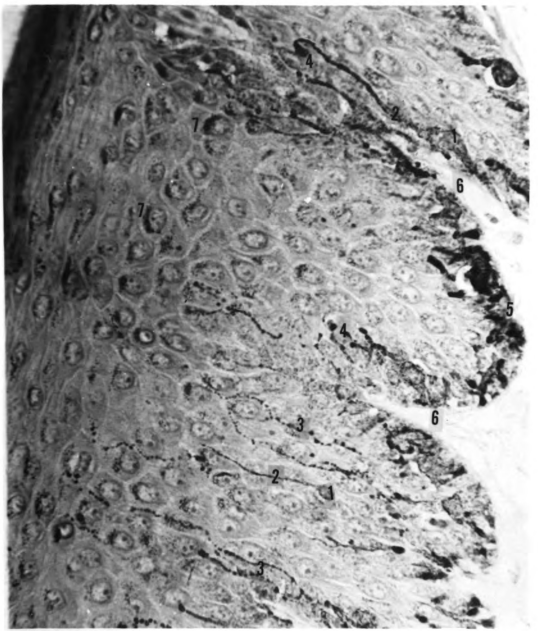


Plate VI

Skin of the nostril showing melanocytes and their processes.
1. Melanocyte. 2. Dendritic processes of melanocyte. 3. Beaded appearance of melanin pigments in the processes. 4. Melanin pigments forming a drop at the end of the processes. 5. Melanin pigments in the basal cells. 6. Dermal papillae. 7. Supranuclear cap.

Vertical section, H & E Stain. X610

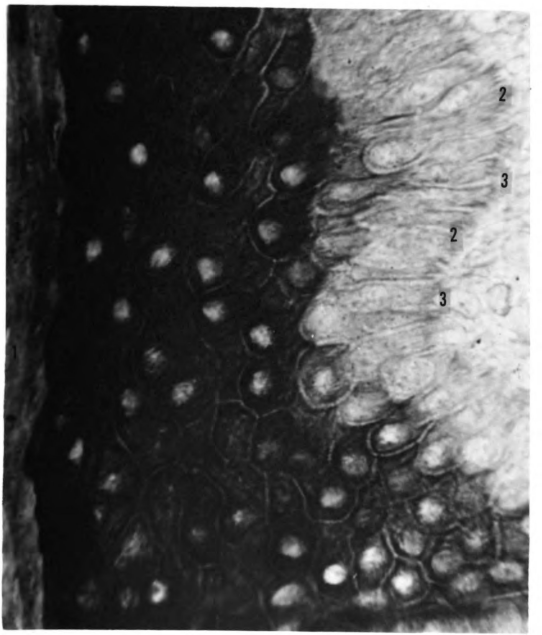


Plate VII

The skin of the nostril.
1. Stratum corneum. 2. The epidermal basal processes.
3. Basement membrane.
(Note the gradual increase of keratohyalin granules from the basal layer to the stratum granulosum).

Vertical section, Gomori's aldehyde fuchsin stain. X1000

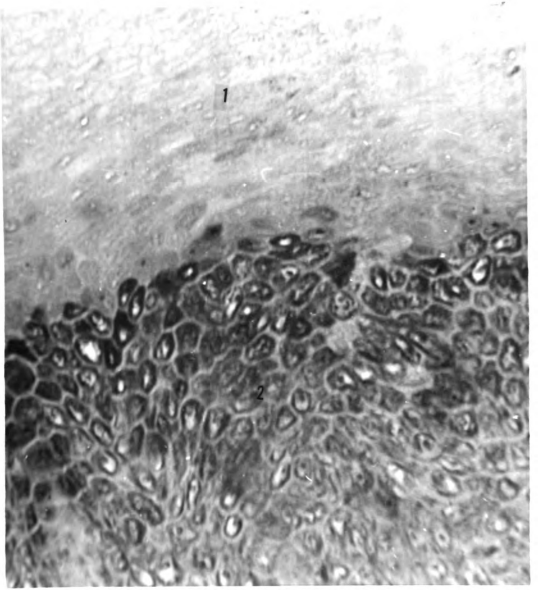


Plate VIII

The chestnut, showing the junction of stratum corneum and stratum granulosum.
1. Stratum corneum. 2. Stratum granulosum.

Vertical section, H & E Stain. X250

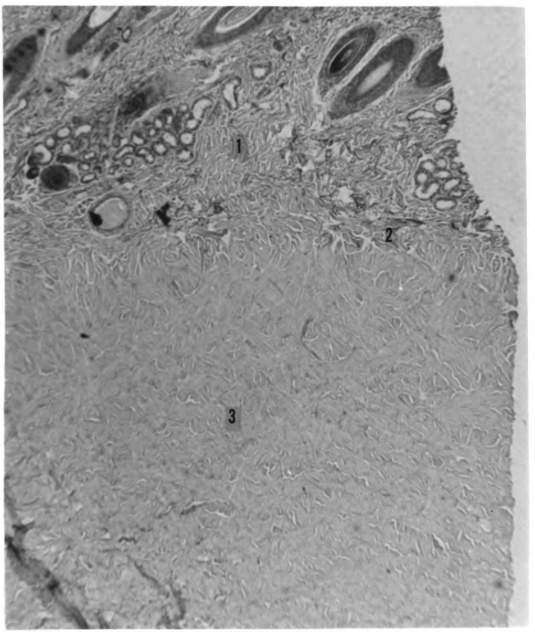


Plate IX

The skin of the region of the croup.
1. Papillary layer. 2. Reticulo-papillary junction.
3. Reticular layer.

Vertical section, H & E Stain. X50

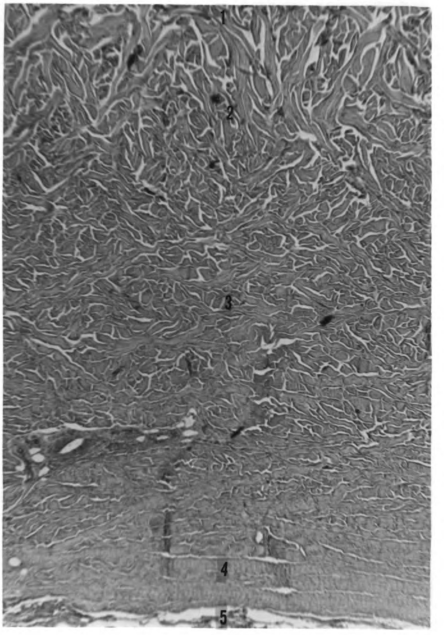


Plate X

Reticular layer of the croup, showing the three different arrangements of the collagen fibers.
1. Junction between reticular and papillary layer.
2. Vertically and horizontally arranged bundles of collagenous fibers. 3. Thick irregularly arranged fibers in the middle layer. 4. Fibers arranged parallel to the surface. 5. Subcutis.

Vertical section, H & E Stain. X200

Plate XI

Upper reticular layer of the croup, showing the collagen bundle arrangement and the detail of the individual fiber. 1. Vertical fibers. 2. Horizontal fibers. 3. Longitudinally arranged fibrils within the fibers.

Vertical section, H & E Stain. X620

Plate XII

The chin (level 15), showing the attachment of individual skeletal muscle fibers with the superficial dermis by a strong bundle of elastic fibers.
1. Hair follicle. 2. Sweat duct. 3. Sebaceous gland. 4. Cross and longitudinal elastic fiber network on the follicular wall. 5. Arrector pili muscle. 6. Sweat gland. 7. Skeletal muscle fiber. 8. Elastic fiber bundle.

Vertical section, Gomori's aldehyde fuchsin stain. X250

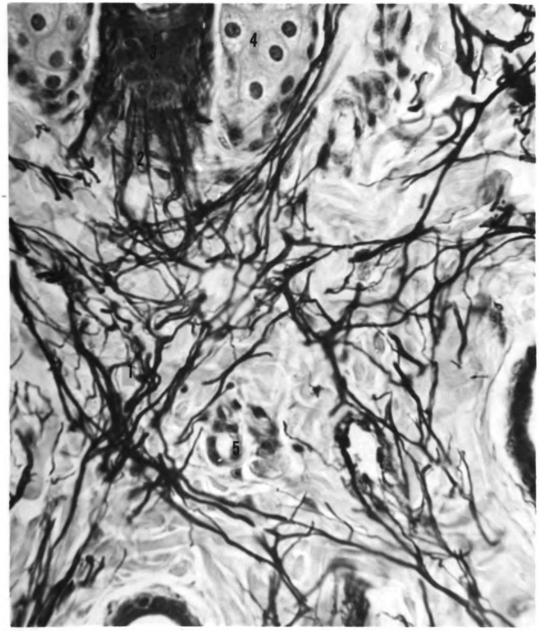


Plate XIII

General skin, showing the arrangement of the elastic fibers in the papillary layer and the attachment with hair follicle.
1. Network of elastic fibers. 2. Attachment of elastic fibers with hair follicle. 3. Hair follicle. 4. Sebaceous glands. 5. Capillaries.

Horizontal section, Gomori's aldehyde fuchsin stain. X310

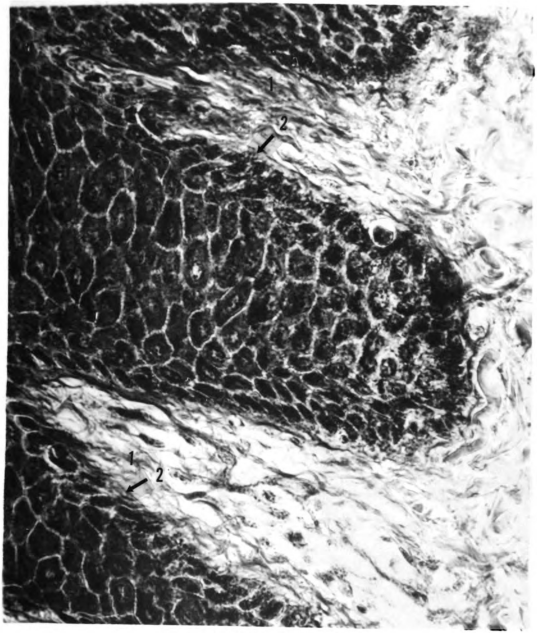


Plate XIV

Upper lip, showing the reticular fibers.
Fine reticular fibers which have broken up and formed a network at the dermo-epidermal interface. Fine fibers are seen in close contact with the cells of the basal layer.
1. Reticular fibers. 2. Region of basement membrane with reticular mesh.

Vertical section, periodic acid, orcein, silver and aniline blue. X700

Plate XV

The skin of the croup, showing the branched arrector pili muscle and its attachment with the epidermis by elastic fibers.
1. Epidermis. 2. Region of basement membrane. 3. Branching elastic fibers 4. Arrector pili muscle. 5. A clear cell.

Vertical section, H & E Stain. X510

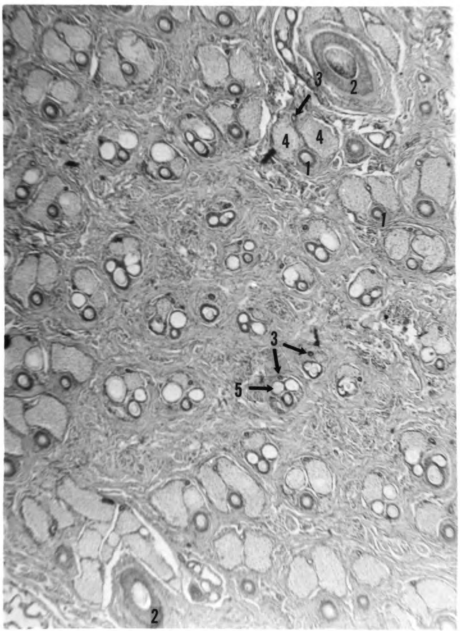


Plate XVI

Skin of the back showing different sizes of hair follicles. Large hair follicles scattered among the small hair follicles.
1. Small hair follicles with at least two sebaceous glands. 2. Large hair follicles. 3. Duct of sweat gland (cross section). 4. Sebaceous glands. 5. Duct of sebaceous glands.

Horizontal section, H & E Stain. X50

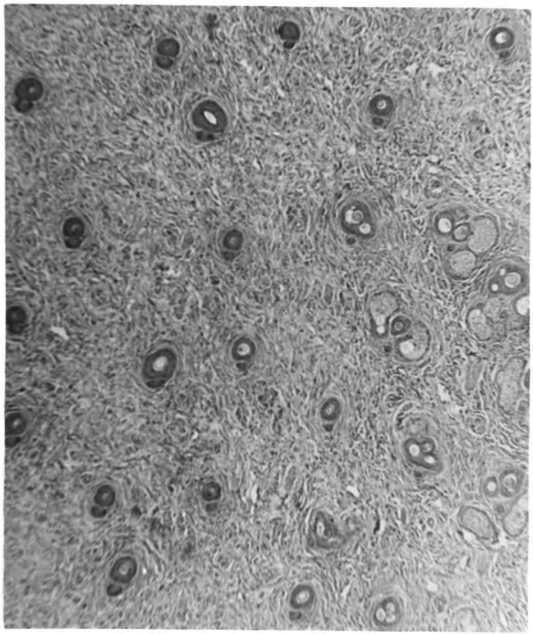


Plate XVII

Skin of the abdomen, showing a thin hair distribution.
Horizontal section, H & E Stain. X65

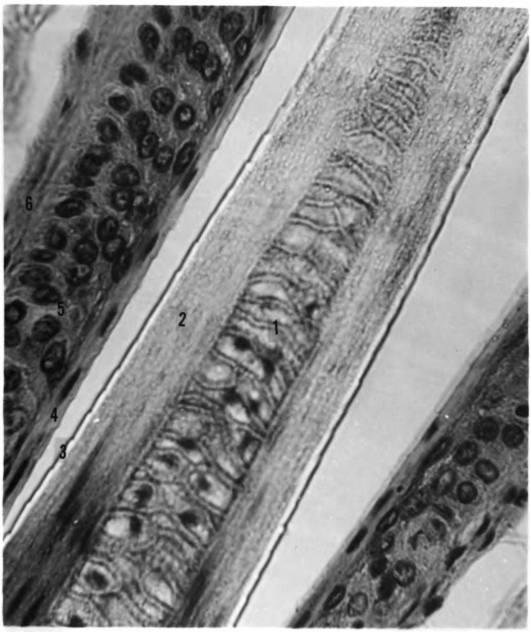


Plate XVIII

Hair and hair follicle.

1. Medulla. 2. Cortex. 3. Hair cuticle with serrations directed upward. 4. Inner root sheath. 5. External root sheath. 6. Connective tissue sheath.
Note the desmosomes in the medullary cells.

Vertical section, H & E Stain. X950

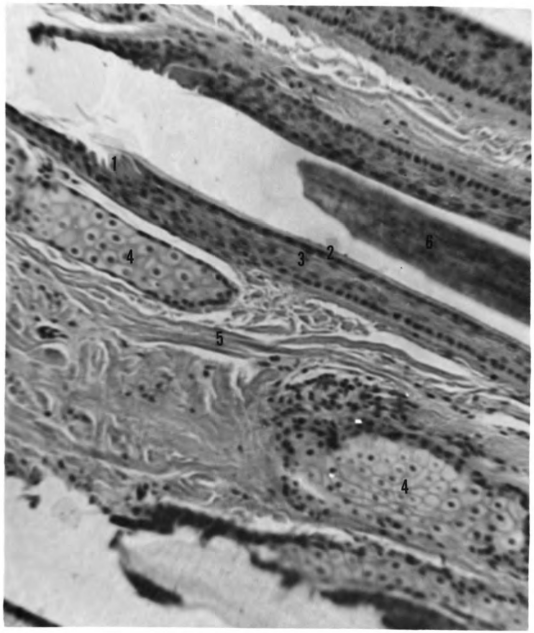


Plate XIX

Hair follicle, showing follicular folds.
1. Follicular folds. 2. Inner root sheath. 3. External root sheath. 4. Sebaceous gland. 5. Arrector pili muscle. 6. Hair.

Vertical section, H & E Stain. X250

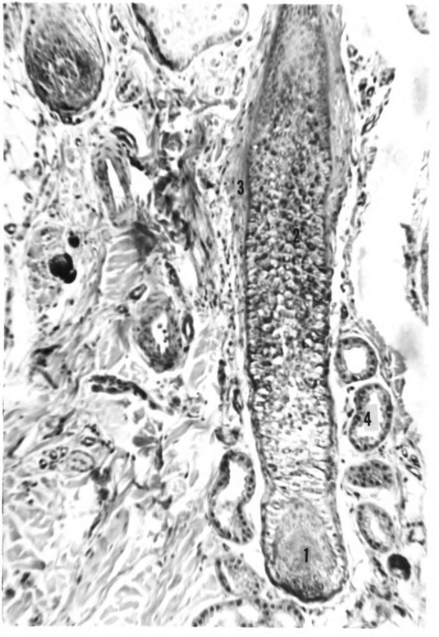


Plate XX

Hair follicle, showing the strong reaction for glycogen in the cytoplasm of the cells of external root sheath. No cytoplasmic glycogen in upper or lower part of the follicle.
1. Hair bulb. 2. Cells of external root sheath. 3. Connective tissue sheath. 4. Sweat gland.

Vertical section, Bauer-Feulgen reaction for glycogen. X170

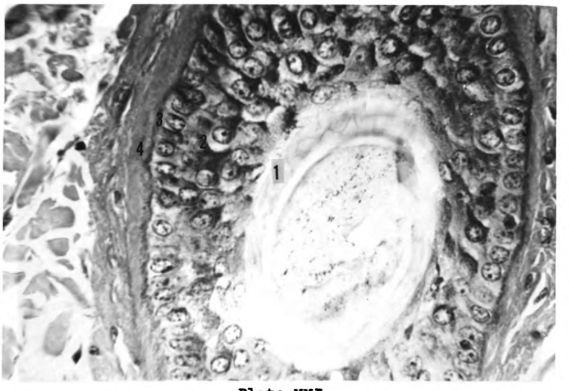
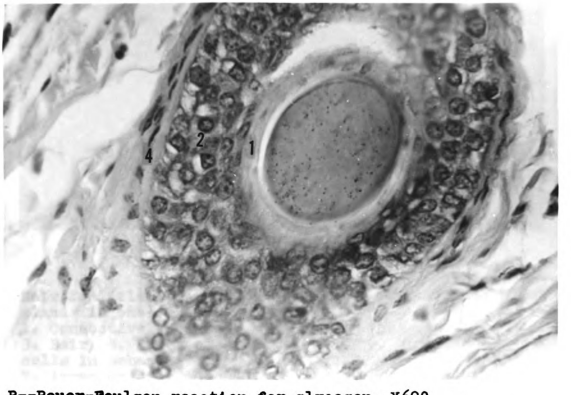


Plate XXI

A--PAS Reaction. X690



B--Bauer-Feulgen reaction for glycogen. X690
1. Inner root sheath. 2. External root sheath. 3. Basement membrane. 4. Connective tissue sheath.

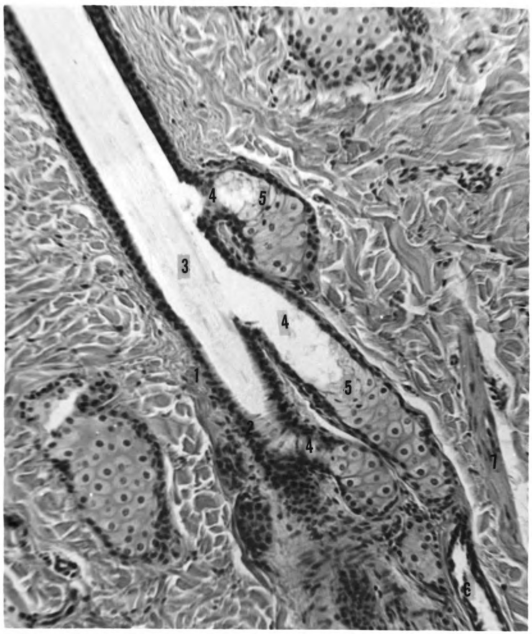


Plate XXII

Hair follicle (submandibular region). Opening of 3 sweat glands in one follicle.
1. Connective tissue sheath. 2. External root sheath.
3. Hair. 4. Ducts of sebaceous glands. 5. Disintegrating cells in sebaceous glands. 6. Duct of sweat gland.
7. Arrector pili muscle.

Vertical section, H & E Stain. X220

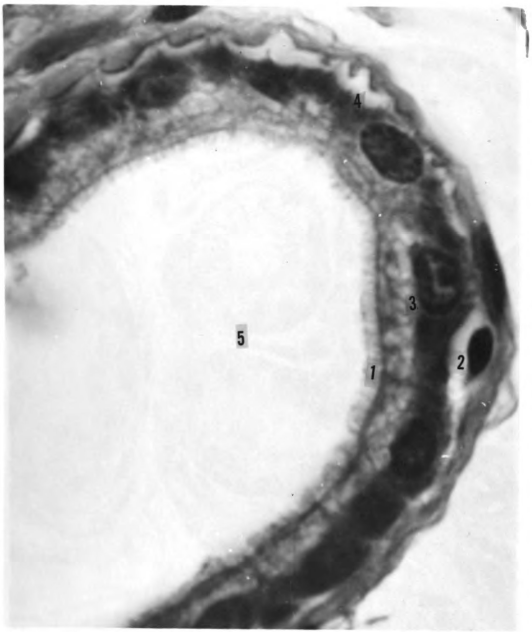


Plate XXIII

Apocrine sweat gland (circumanal region).
1. Microvilli. 2. Myoepithelial cell. 3. Secretory cells.
4. Basal epithelial folds. 5. Lumen.

Cross section, H & E Stain. X2500

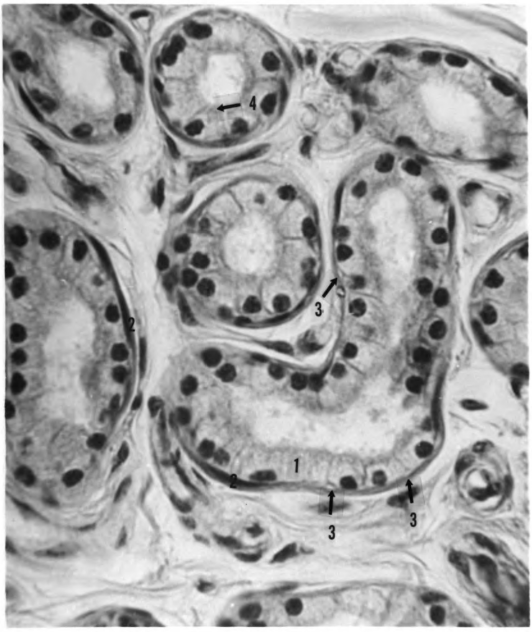


Plate XXIV

Sweat gland (general body region).
1. Secretory cells. 2. Myoepithelial cells. 3. Basal intercellular canaliculi. 4. Microvilli.

H & E Stain. X900

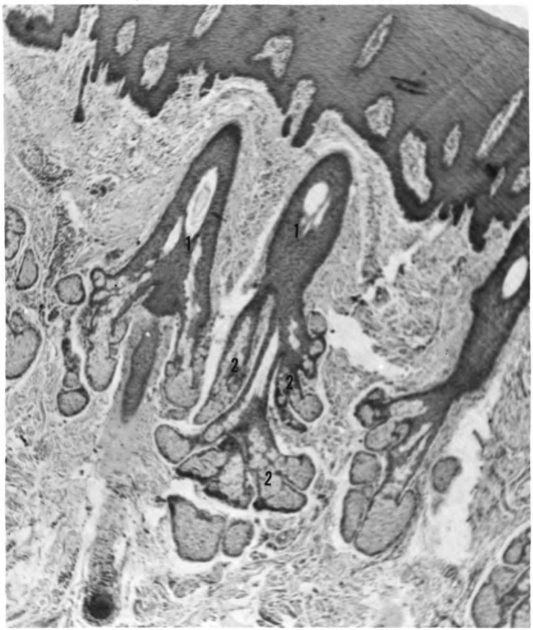


Plate XXV

Skin of the upper lip.
1. Hair follicle with fine hair. 2. Number of branched sebaceous glands open into the follicle.
Note. Absence of sweat gland.

Vertical section, H & E Stain. X50

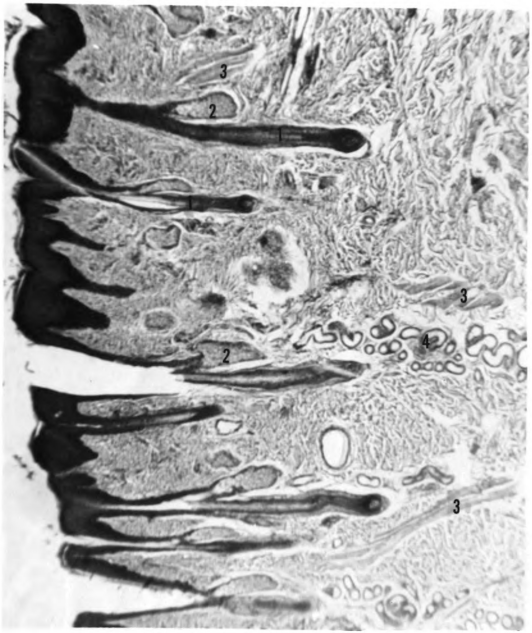


Plate XXVI

Skin of the lower lip.
1. Hair follicle with fine hair. 2. Sebaceous gland.
3. Skeletal muscle fibers. 4. Sweat gland.

Vertical section, H & E Stain. X65

Plate XXVII

Skin of the nostril.
1. Stratum corneum. 2. Stratum granulosum. 3. Stratum germinativum. 4. Basal layer of cells with melanin pigment. 5. Sweat duct opening on the surface of epidermis. 6. Epidermal pegs. 7. Dermal papillae. 8. Sebaceous glands.

Vertical section, H & E Stain. X270

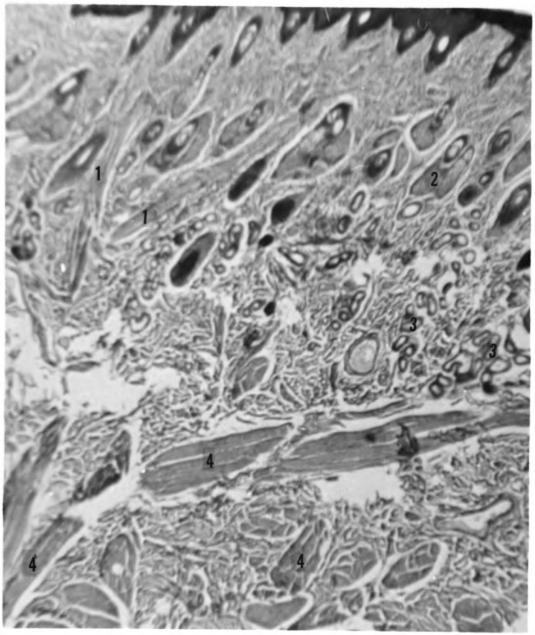


Plate XXVIII

Skin of the nostril, showing the arrangement of the skeletal muscle in the upper dermis.
1. Skeletal muscle fibers attached at the upper dermis.
2. Sebaceous gland. 3. Sweat gland. 4. Thick bundle of skeletal muscle in the deep dermis extending in 3 planes.

Vertical section, H & E Stain. X70

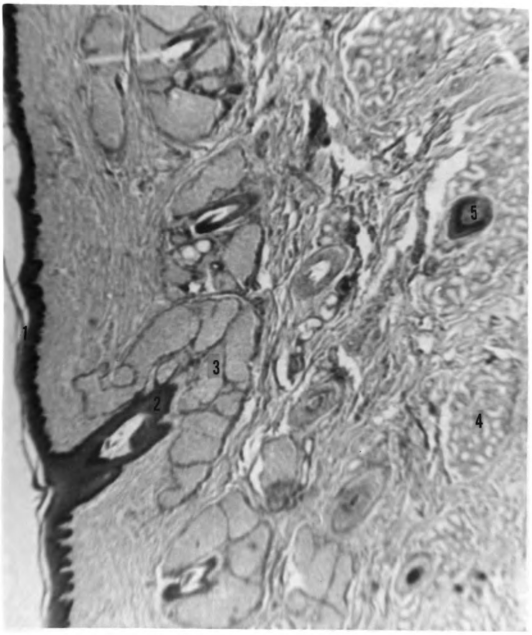


Plate XXIX

Skin of the external ear.
1. Epidermis. 2. Hair follicle. 3. Large sebaceous gland.
4. Very large saccular sweat glands deep in the dermis.
5. Hair bulb with dermal papilla.

Vertical section, H & E Stain. X60

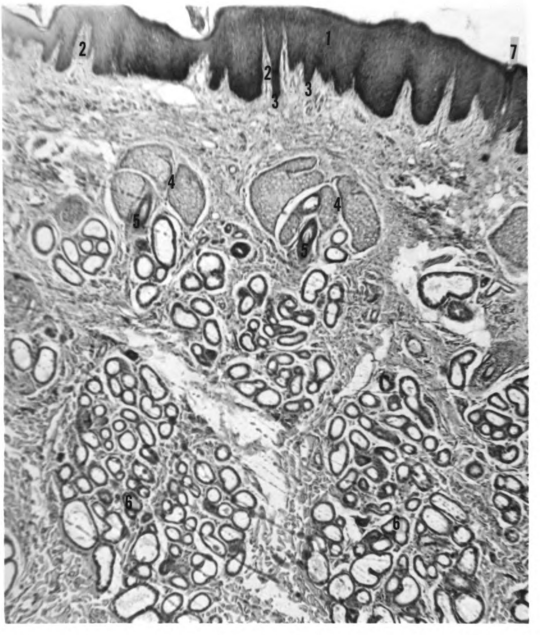


Plate XXX

Skin of the circumanal region.
1. Epidermis. 2. Dermal papillae. 3. Epidermal pegs. 4. Lobulated sebaceous gland. 5. Hair follicle. 6. Large saccular sweat gland. 7. Opening of the duct of sweat gland.

Vertical section, H & E Stain. X60

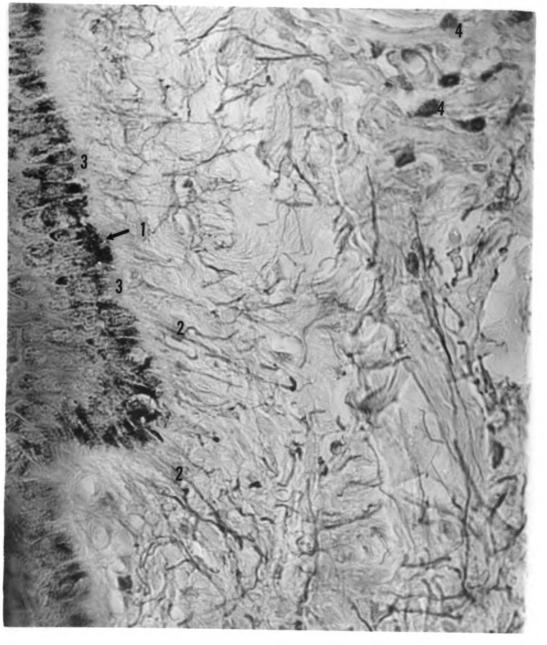


Plate XXXI

Skin of the prepuce, showing branched elastic fibers attached to the basement membrane.

1. Basal cells containing melanin granules. 2. Elastic fibers at dermo-epidermal junction. 3. Area occupied by basement membrane. 4. Mast cells.

Vertical section, Gomori's aldehyde fuchsin stain. X620

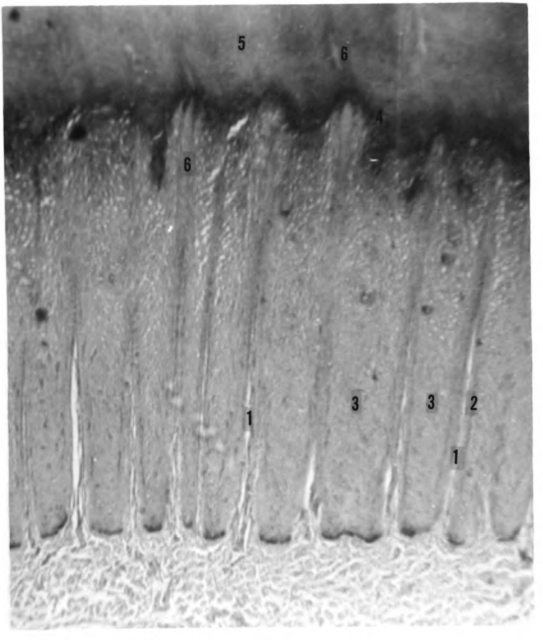


Plate XXXII

Chestnut (hind limb).
1. Dermal papillae. 2. Peripapillary epithelium. 3. Interpapillary epithelium. 4. Stratum granulosum. 5. Stratum corneum. 6. Horn tubule.

Vertical section, H & E Stain. X75

Plate XXXIII

Coronary border.
1. Duct of highly branched sebaceous glands. 2. Very large branched sebaceous glands. 3. A row of hairs in the border. 4. Arrow points towards the hoof.

Vertical section, H & E Stain. X60

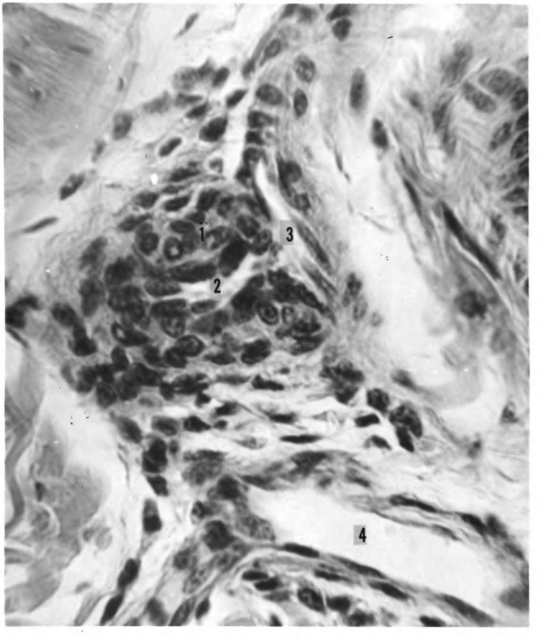


Plate XXXIV

Arterio-venous anastomoses (upper lip).
1. Epitheloid cells. 2. Central lumen. 3. Arteraole at opening of the connecting channel. 4. Venule.

Cross section, H & E Stain. X960

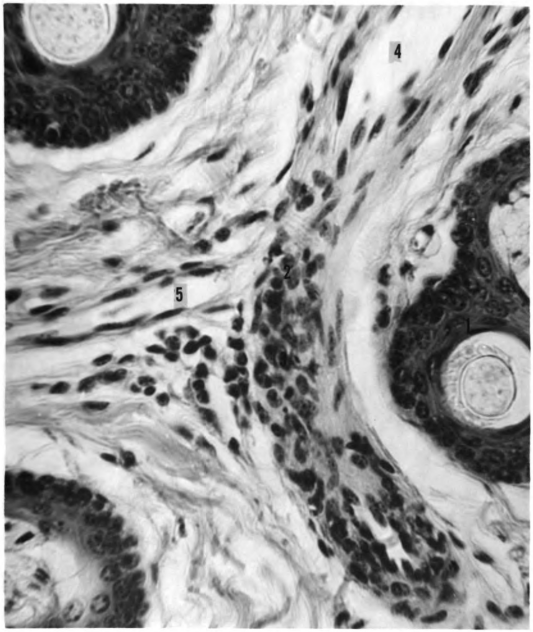


Plate XXXV

Longitudinal section of an arterio-venous anastomoses in the skin of the croup.
1. Hair follicle with hair. 2. Arterio-venous anastomosis. 3. Epitheloid cells on the wall. 4. Arteriole. 5. Venule.

H & E Stain. X660

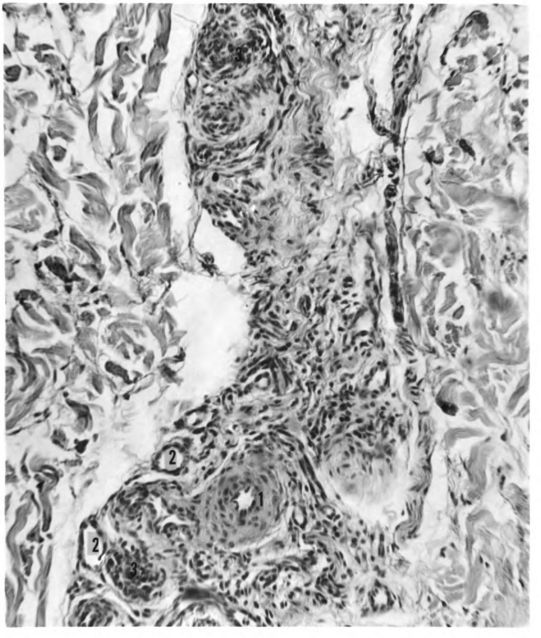


Plate XXXVI

Glomus formation (lower lip).
1. Artery. 2. Venule. 3. Modified wall of coiled arteriole in the glomus cut in several cross sections.

H & E Stain. X260

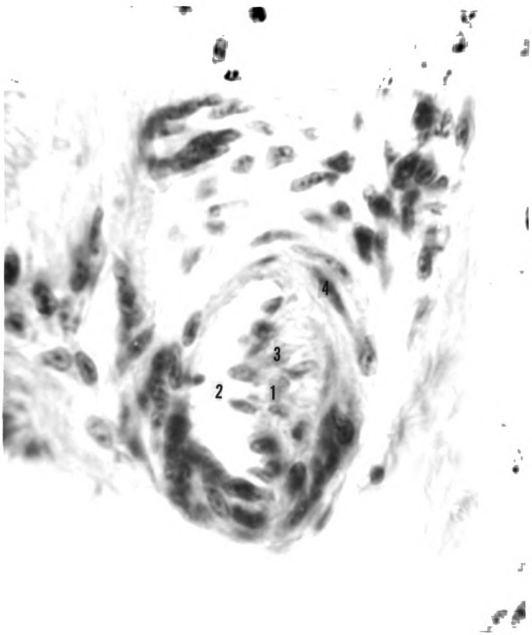


Plate XXXVII

Cross section of an artery containing arterial cushion (upper lip).
1. Cushion. 2. Lumen of the vessel. 3. Epitheloid cells.
4. Smooth muscle cells in the wall of the vessel.

H & E Stain. X1060

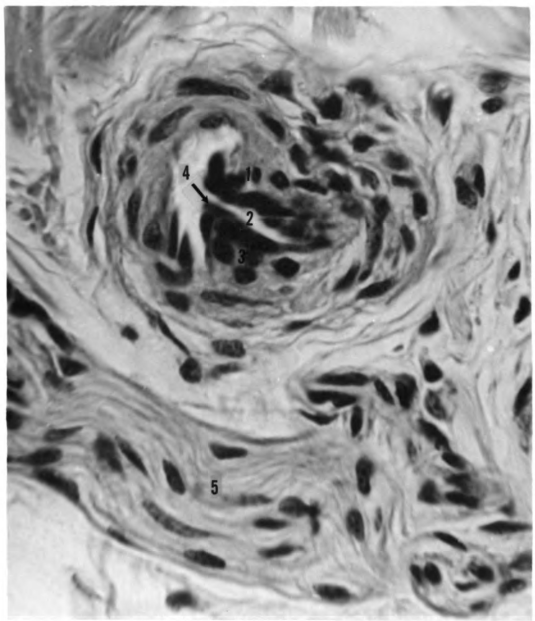


Plate XXXVIII

Arterial cushion cut in cross section, showing arteriole leaving the main artery from the raised central part of cushion (thigh, lateral surface).
1. Cushion. 2. Arteriole leaving the main lumen through the cushion. 3. Epitheloid cushion cells. 4. Endothelium of the arteriole. 5. Nerve.

H & E Stain. X1350

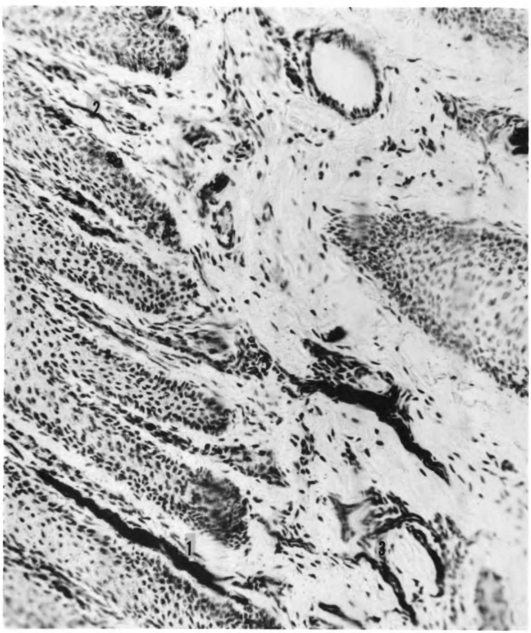


Plate XXXIX

Skin of the upper lip.
Plexus of nerve fibers in the superficial dermis and the innervation of dermal papillae.
1. Thick nerve fiber bundle in the papillae. 2. Fine nerve fibers in the papillae. 3. Nerve plexus in the upper part of papillary layer of the dermis.

Vertical section, Bielschowski-Gros. X240

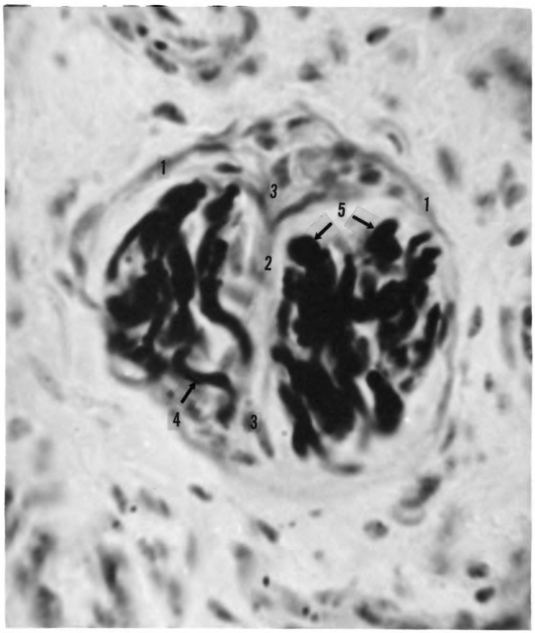


Plate XL

Paired encapsulated nerve endings (upper lip).
1. Capsule one to three cells thick. 2. Connective tissue septum separating the two end organs. 3. Septum joining the capsule at a thicker area. 4. Branched nerve fibers within the organ. 5. Round or elliptical shaped endings forming buttons.

Bielschowski-Gros. X1750

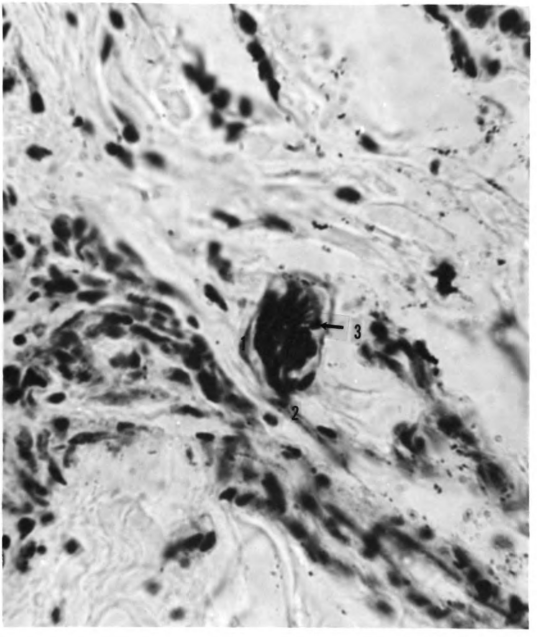


Plate XLI

Thin capsulated nerve ending (upper lip).
1. Capsule. 2. Nerve fibers. 3. Knob-like endings.

Bielschowski-Gros. X1000

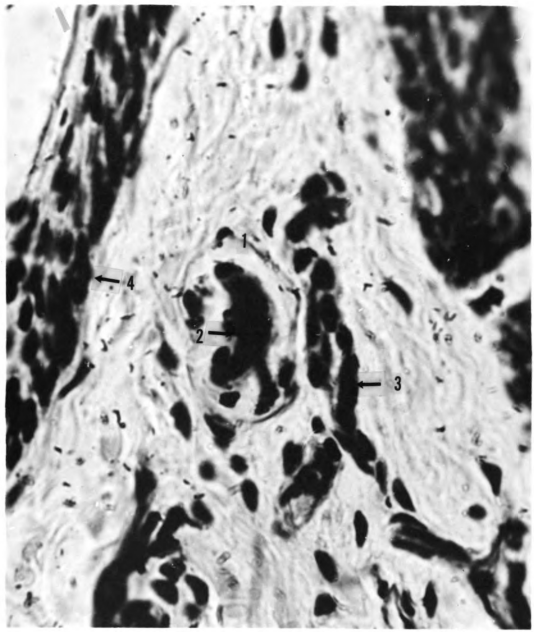


Plate XLII

Disk-like capsulated nerve ending (upper lip).
1. Capsule. 2. Condensed neural elements forming disk.
3. Nerve fiber. 4. Hair follicle.

Bielschowski-Gros. X1150

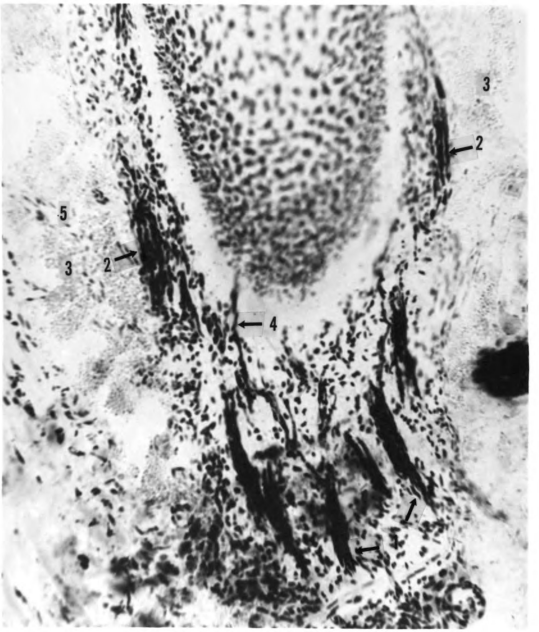


Plate XLIII

Innervation of the sinus hair (upper lip).
1. Nerve fibers entering the follicle. 2. Nerve fibers in the inner connective tissue sheath. 3. Sinus containing blood. 4. Nerve fibers entering outer root sheath. 5. Connective tissue trabeculi.

Vertical section, Bielschowski-Gros. X250

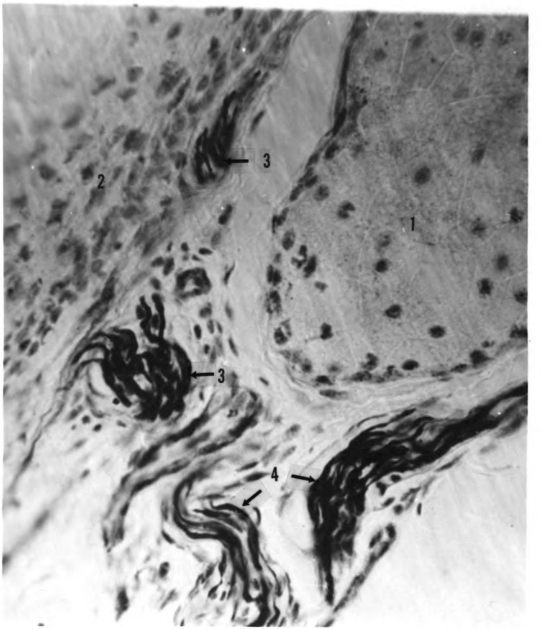


Plate XLIV

Nerve endings along hair follicle (upper lip). 1. Sebaceous gland. 2. Hair follicle. 3. Glomus-like nerve endings along the hair follicle. 4. Nerve fibers bundle.

Bielschowski-Gros. X730

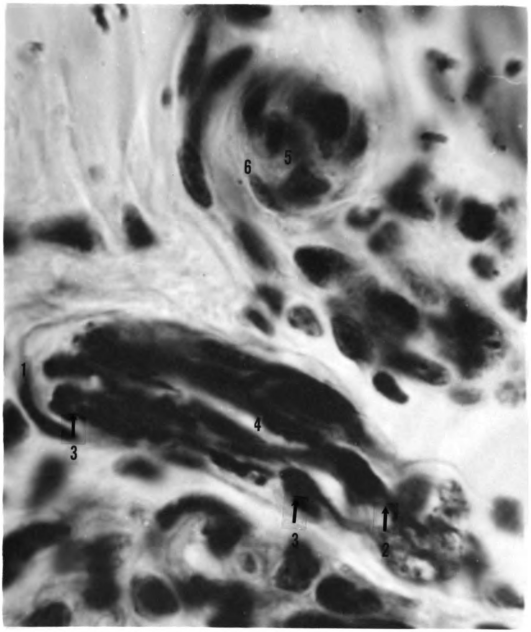


Plate XLV

Highly organized encapsulated nerve ending (upper lip). 1. Capsule. 2. Nerve fiber entering the organ. 3. End buttons within capsule. 4. Central space. 5. Cross section of a pacinian-like small ending. 6. Epitheloid cell.

Cross and longitudinal section, Bielschowski-Gros. X2400

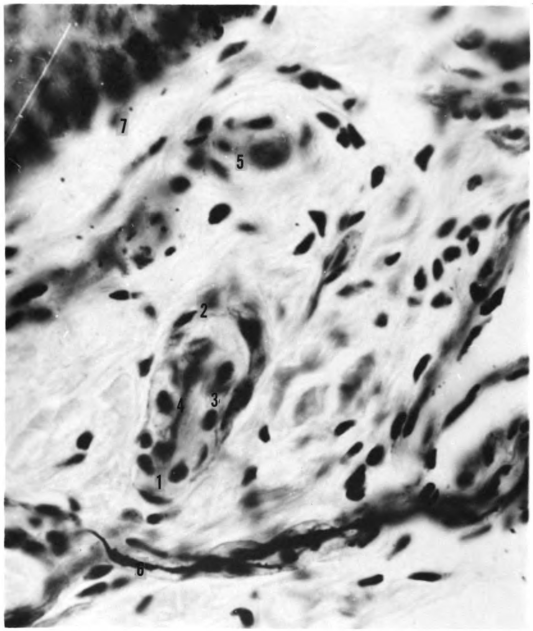


Plate XLVI

Lamellated nerve endings (upper lip).
1. Longitudinal section of a small pacinian-like ending. 2. One cell thick capsule. 3. Epitheloid cells within capsule forming lamella. 4. Central axis containing nerve fiber. 5. Cross section of similar nerve ending. 6. Myelinated nerve fiber. 7. Hair follicle.

Cross and longitudinal sections, Bielschowski-Gros. X1000

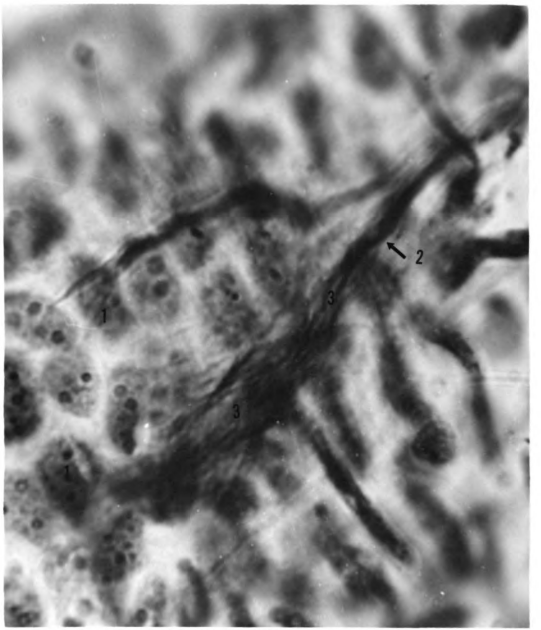


Plate XLVII

Innervation of a part of hair follicle (upper lip).
1. Nucleus of follicular cell. 2. Bundle of nerve fibers.
3. Nerve fibers break up into a network.

Bielschowski-Gros. X2600

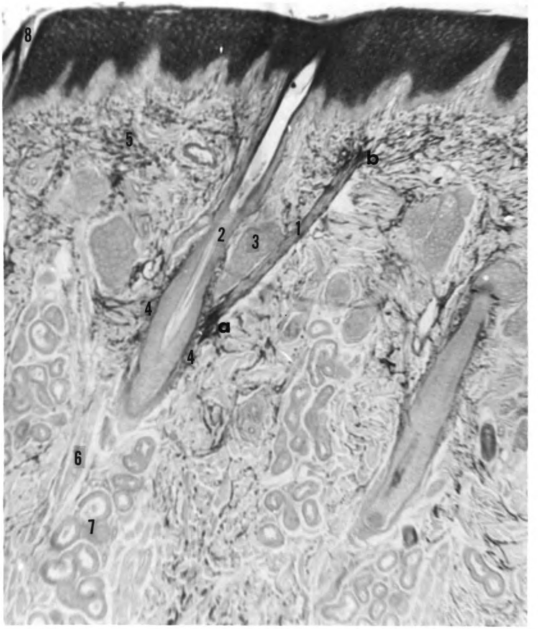


Plate XLVIII

Skin of the nostril.
1. Arrector pili muscle--(a) Origin (b) Insertion.
2. Hair follicle. 3. Sebaceous gland. 4. Elastic network around the hair follicle. 5. Elastic network in the upper papillary layer. 6. Skeletal muscle fiber in the papillary layer. 7. Sweat gland. 8. Opening of the sweat duct.

Vertical section, Gomori's aldehyde fuchsin. X75

SUMMARY AND CONCLUSIONS

Six adult horses, including 2 stallions, 2 geldings and 2 mares were used for this investigation. The animals were from 2 to 17 years old. The average skin thickness of general body skin was 3.8 mm, ranging from 2.5 mm in the submandibular region to 6.4 mm on the dorsal surface of the tail. Variations in skin thickness were determined in relation to age and sex.

The epidermis consisted of 3 layers: stratum germinativum, stratum granulosum and stratum corneum; the stratum lucidum was absent. The outer surface of the epidermis formed ridges and grooves. The hair erupted on these grooves and formed rows on the epidermal surface. Keratohyalin granules in the stage of formation were observed in the cells of the supra-basal layer of the epidermis and increased gradually until the cytoplasm of the cells of the stratum granulosum was completely filled. Basal epithelial processes anchored the epidermis with the underlying tissue. In addition to the cells of the germinal layer the basal layer contained melanocytes with long beaded dendritic processes filled with melanin pigments.

The dermis consisted of two layers: the stratum papillare and the stratum reticulare with well recognized demarcation. A modified dermal region extended from the posterior part of the dorsum to the end of the croup with lateral extentions over the gluteal region. The maximum thickness of this part of the dermis occurred on the croup (5.5 mm). The collagenous fibers in the papillary layer were fine and loosely arranged

but in the reticular layer were compact and formed a third layer in the lower part. The papillary layer contained an extensive elastic network. Elastic fibers from this network established connection with dermo-epidermal junction. Where the epidermis was thick and had epidermal pegs the dermis formed papillary bodies, rich in blood vessels.

The medulla of the hair contained two layers of rectangular cells and were attached to adjacent cells by desmosome. The hairs were not in groups and the larger follicles contained follicular folds. Tactile hairs of the ungulate type were present in the upper lip, lower lip and in the nostrils. Usually two sebaceous glands were associated with each follicle. They were large in regions with fine hairs, elongated with coarse, long hairs and smaller near normal body haris. They were very large in the external ear canal, circumanal region, prepuce, lower lip and extremely large and branched in the hoof margin. The arrector pili muscles were well developed on the dorsal and lateral sides. Those associated with the coarse hairs of the mane and tail were particularly long and slender.

Sweat glands were apocrine type and tubular on the general body surface. Large saccular sweat glands occurred in the external ear, circumanal region, prepuce and lower lip. On the general body surface they were large on the flank and abdomen. The secretory cells contained a brush border at the luminal side and canaliculi at the basal side near the base of the intercellular spaces. Both a submicroscopic apocrine

and canalicular secretory mode has been proposed.

Numerous arterio-venous anastomoses were present in the upper and lower lips, nostrils, coronary border, external ear, and the dorso-lateral side of the hind quarter. Arterial cushions were present in the lips, and in the skin of the thigh.

Four types of morphologically different nerve endings were recognized in the lip: lamellated endings, capsulated end organs, free nerve endings, and non-capsulated balls. In addition, nerve nets were demonstrated on the hair follicle.

BIBLIOGRAPHY

Adachi, B. 1903. Haut pigment beim Menschen und bei den Affen. Zeitschr. f. Morph. u. Anthrop. 6:1-131.

Aeby, C. 1835. Die Herkuft des pigments im Epithel. Zentralkl. f. med. wiss. 23:273-275.

Ahmed, N. N. 1965. Histochemical study of lipids in human sebaceous glands. J. Histochem. Cytochem. 13:6.

Aoki, T., S. Kimura and M. Wada. 1959. On the responsiveness of the sweat glands in the horse. J. Invest. Dermatol. 33:441-443.

Baird, P. C., W. F. Lever and T. D. Spices. 1942. The physiology of skin. Ann. Rev. Physiol. 4:171-186.

Baker, J. R. 1946. Histochemical recognition of lipine. Quart. J. Microscop. Sci. 87:441-470.

Bates, E. P. 1934. A quantitative study and interpretation of the occurrence of basophile (mast) cells in the subcutaneous tissue of the albino rat. Anat. Rec. 61:231-239.

Bear, R. S. and R. S. Morgan. 1957. Composition of bands and inter bands of collagen fibrils. Connective Tissue Symposium. pp. 321-333. Charles C. Thomas, Springfield.

Berlin, L. B. and I. G. Pridvizhkin. 1965. Histochemical study of glycogen in the skin of human embryo. Dolk. Akad. Naud. SSSR. 160:213-215.

Bern, H. A. 1954. Histology and chemistry of keratin formation. Nature 174:509-511.

Berry, J. 1953. Recherches sur l'origine des cellules de Langerhans de l'epiderme. Biol. Med. 42:293-315.

Bertalanffy, F. D., V. Pusey and M. O. Abbott. 1965. Mitotic rates of rat epidermis during growth, maturity, senility, and regeneration. Arch. Dermatol. 92:91-102.

Billingham, R. E. and P. B. Medawar. 1953. A study of the branched cells of the mammalian epidermis with special reference to the fate of their divisions products. Phil. Trans. of Royal Soc. B237:151-171.

Billingham, R. E. and W. K. Silvers. 1960. The melanocytes of mammals. Quart. Rev. Biol. 35:1-14.

Bloch, B. 1921. Über die Entwicklung des Haut und Haar pigments beim menchlichen Embryo und über das Erloeschen der pigmentbildung im ergraunden Haar. Arch. f. Dermat. u. Syph. 135:77-108.

_____. 1927. Das pigment in Jadassohn's Handbuck, der Haut und geschlechtskrankheilen. Part 1:434, Berlin, Springer.

Bloom, W. and D. W. Fawcett. 1962. The Textbook of Histology. pp. 379-380. W. B. Saunders Co., Philadelphia.

Bodian, D. 1936. A new method for staining nerve fibers and nerve endings in mounted paraffin section. Anat. Rec. 65:89-98.

Bollinger, A. and N. D. McDonalds. 1949. Histological investigation of glycogen in skin and hair. Aust. J. Exp. Biol. 2:233-238.

Bornstein, P. and A. B. A. Karl. 1965. Collagen structural studies based on the cleavage of methionyl bonds. Science 148:1353-1355.

Bradfield, J. R. G. 1951. Glycogen of vertebrate epidermis. Nature 167:40-41.

Breathnach, A. S. 1963. A new concept of the relationship between the Langerhans cells and the melanocytes. J. Invest. Dermatol. 40:279-281.

Breathnach, A. S., M. S. C. Birbeck, and J. D. Everall. 1963. Observations bearing on the relationship between Langerhans cells and melanocytes. Ann. N. Y. Acad. Sci. 100:223-237.

Bucher, C. J. and K. D. Blackley. 1936. The use of Dioxane in the preparation of histological section by the paraffin method. Arch. Pathol. 22:225.

Burton, A. C. 1966. Physiology and Biophysics of Circulation. Yearbook Medical Publishers Inc., Chicago.

Calvery, H. O., J. H. Draize and E. P. Lang. 1946. Permeability of skin. Phys. Rev. 26:502-514.

Cauna, N. 1959. The mode of termination of sensory nerve and its significance. J. Comp. Neur. 113:169-210.

Chambers, R. and G. S. Renji. 1925. The physical relationship of the cells in epithelial layer. Am. J. Anat. 35:385-402.

Charles, A. and F. G. Smiddy. 1957. The tonofilaments of human epidermis. J. Invest. Dermatol. 29:327-337.

Chase, H. B., H. Rauch and V. W. Smith. 1951. Critical stages of hair development and pigmentation in the mouse. Physiol. Zool. 24:1-8.

Chauveau, A. 1873. Comparative Anatomy of Domestic Animals. pp.793. W. R. Jenkin, New York.

Clara, M. 1956. Die arterio-venäsen Anastomosen. 2. Aufl. Wein, Springer, verlag in Vienna.

Colin, E. C. 1943. Hair direction in mammals; Embryogenesis of hair follicles in the guinea pig. J. Morph. 72:191-223.

Copenhaver, W. M. 1964. Bailey's Textbook of Histology. William's and Wilkin's Co., Baltimore.

Danial, P. M. and M. L. P. Marjorie. 1956. Arteriovenous anastomosis in external ear. Quart. J. Exp. Physiol. 41:107-123.

Danneel, R. and G. Cleffmann. 1954. Die Einwanderung der pigmentzellen in die Haut and die Haar bei Nagatieren. Biol. Zentral. 72:414-428.

Dick, J. C. 1947. Observation on the elastic tissue of the skin with a note on the reticular layer at the junction of the dermis and epidermis. J. Anat. 81:201-211.

Dixon, A. D. 1961. The innervation of hair follicles in the mammalian lip. Anat. Rec. 140:147-158.

Dozza, G. and L. Rampichini. 1963. Histological characteristics of the mast cells for mm^2 in various cutaneous regions of "Equus Asinus" and pamphoid reactivity of the same regions to intracutaneous inoculation of 48/80 (histamin releaser). Arch. vet. Ital. 14:555-566.

Dry, F. W. 1926. The coat of the mouse. J. of Genetics 16:287-340.

Edwards, E. A. and S. Q. Duntley. 1939. The pigments and color of living human skin. Am. J. Anat. 65:1-33.

Ehrlich, P. 1879. Beitrage zur kenntnis der granulierten. Bend-geweleszellen und der eosinophilen leukocyten. Arch. f. Anat. u. Physiol. (phys. abt.) p. 166.

Ehrmann, S. 1885. Untersuchungen über die Physiologie und Pathologie des haut Pigments. Arch. f. Dermat. u. Syph. 17:507-532.

El-Bahrawy, A. A. 1922. Über den Mongolen fleck bei Enropäern. Arch. f. Dermat. u. Syph. 141:171-192.

Elias, H. 1948. On the phylogeny of the mammalian hair. (abstract) Anat. Rec. 101:675.

Ellenberger, W. 1906. Handbuch der vergleichenden mikroskopischen Anatomie der Haustiere. Paul Parey, Berlin. 1:161.

Ellis, R. A., W. Montagna and H. Fauger. 1958. Histology and cytochemistry of human skin. XIV. The blood supply of cutaneous gland. J. Invest. Dermatol. 30:137-145.

Evans, C. L. and D. F. G. Smith. 1956. Sweating response in the horse. Proc. Roy. Soc. 145:61-83.

Evans, C. L., A. M. Nisbat and K. A. Ross. 1957. A histological study of the sweat glands of normal and dry coated horses. J. Comp. Path. Therap. 67:397-405.

Favre, M. 1950. Le chondriome de l'epiderme normal et des epidermes pathologiques. Ortho et parakeratinizasions. Ann. derm. Syphilig. 10:241-262.

Fazzari, I. 1951. Problema dello-strama. Rass Clin. Sci. Int. Biochem. Ital. 27:355-361.

Felsher, Z. 1966. Studies of the rings of Henle associated with collagenous bundles in human and calf skin. Anat. Rec. 154:513-525.

Fowler, E. H. and M. L. Calhoun. 1964. The microscopic anatomy of developing fetal pig skin. Am. J. Vet. Res. 25:156-164.

Frey, M. 1896. Untersuchungen über die Sinnesfunktioner der menschlichen Haut. Abh. Sach's Ges (Akad) wiss. 40:175-266.

Glaister, J. 1931. A study of Hairs and Wools belonging to the Mammals. pp. 91-92. MISR Press, Cairo.

Goldberry, S. and M. L. Calhoun. 1959. The comparative histology of the skin of Hereford and Aberdeen Angus cattle. Am. J. Vet. Res. 20:61-68.

Gomori, G. 1950. Aldehyde-fuchsin--A new stain for elastic tissue. Am. J. Clin. Path. 20:665-666.

Goodall, A. and S. Young. 1955. The vascular supply of the skin of Ayrshire calves and embryos. J. Agri. Sci. 44:1-4. (Abstract in Vet. Bull. 1955).

Grassmann, W. 1955. Unsere heutige kenntnis des collagen. Leder. 6:241.

Gridley, M. F. 1960. Dominici's mast cell stain. Manual of Histologic and Special Staining Technics. pp. 108-109. McGraw-Hill Book Co., Inc., New York.

_____. 1960. Bauer-Feulgen reaction for glycogen. Manual of Histologic and Special Staining Technics. pp. 129-130. McGraw-Hill Book Co., Inc., New York.

Gurr, E. 1962. Periodic acid-silver-orcein-analine blue (for selective demonstration of connective tissue fibers). Staining Animal Tissue. pp. 359-361. Leonard Hill (Books) Limited, London, N. W.

_____. 1962. Petrunkevitch's cupric paranitrophenol fixative. Staining Animal Tissue. pp. 483. Leonard Hill (Books) Limited, London, N. W.

Guyer, M. F. 1949. Animal Micrology. University of Chicago Press, Chicago.

Hadwen, S. 1931. The melanotoma of gray and white horses. Can. Med. Assoc. J. 25:519-530.

Hall, D. A., R. Reed and R. E. Tumbridge. 1955. Structure of elastic tissue. Nature 170:264-266.

Hall, D. A. 1957. Chemical and enzymatic reaction on elastin. Connective Tissue Symposium. pp. 238-253 Charles C. Thomas, Springfield.

Ham, A. W. 1961. Histology. Lippincott Co., Philadelphia.

Hansen, G. A. 1957. On the structure and function of mast cells. Connective Tissue Symposium. pp. 12-36. Charles C. Thomas, Springfield.

Hardy, M. 1952. Histochemistry of hair follicles in mouse. Am. J. Anat. 90:285-338.

Hay, E. D. 1966. Epithelium. Histology. R.O. Greep, Editor, 2nd ed., p. 74. McGraw-Hill Book Co., Inc., New York.

Hibbs, R. G. 1958. The fine structure of human eccrine sweat glands. Am. J. Anat. 103:201-218.

_____. 1962. Electron microscopy of human apocrine sweat glands. J. Invest. Dermatol. 38:77-84.

Holmes, R. A. 1960. The Microscopic Anatomy of the Skin of Mus norvegicus albinus. M. S. Thesis, Michigan State University.

Holmgren, H. and O. Wilander. 1937. Beitrag zur kenntnis der Chemie und Funktion der Ehrlichschen Mastzellen. Z. Microskop. Anat. Forsch. 42:242-278.

Hopkins, F. M. 1949. Analysis of some phases of melanoblast migration in the barred Plymouth Rock embryos. Physiol. Zool. 22:1-22.

Hu, F., R. J. Sterieo, H. Pinkus and R. P. Fasnaugh. 1957. Human melanocytes in tissue culture. J. Invest. Dermatol. 28:15-32.

Hu, F. and R. Cardell. 1962. Observations on the ultrastructure of human skin. Henry Ford Hosp. Med. Bull. 10:63-87.

Hurley, H. J. and W. B. Shelby. 1954. The role of myoepithelial cell of the human apocrine sweat gland. J. Invest. Dermatol. 22:143-156.

Jarrett, A. 1958. Structure du collagene et du tissue de la peau non-fixee. Bull. Soc. Franc. Dermatol. et Syph. 65:376-380.

Jirka, M. and J. Katas. 1959. Some observation of the chemical composition of horse sweat. J. Physiol. 147: 74-77.

Johnson, P. L. and G. Bevelander. 1946. Glycogen and phosphatase in the developing hair follicle. Anat. Rec. 95:193-200.

Kawata, S. 1943. Über die Nervenversorgung im Pferdehufe, insbesondere seiner Endapparate. Jap. J. Vet. Sci. 5:479-497.

Keddie, F. and D. Sakai. 1965. Morphology of the horny cells of the superficial stratum-corneum, cell membrane and melanin granules. J. Invest. Dermatol. 44:135-138.

Kozlowski, G. P. 1966. The Microscopic Anatomy of the Integument of Sheep. M. S. Thesis, Michigan State University.

Krölling, O. and H. Grau. 1960. Lehrbuch der Histologie und vergleichenden Microskopichen Anatomy der Haustiere. p. 453.

Kuntz, A. and J. Hamilton. 1938. Afferent innervation of the skin. Anat. Rec. 71:387-400.

Kurusumi, K. 1959. E. M. studies on the human axillary apocrine sweat glands. Arch. Histol. Japan. 16:523-566.

Lee, M. M. C. 1960. Histology and histochemistry of human apocrine sweat glands with special reference to their defense mechanism. Anat. Rec. 136:97-105.

Leydig, F. 1876. Über die allgemeinen Bedeckungen der Amphibian. Arch. f. Mikr. Anat. 12:119-241.

Lillie, R. D. 1952. Histochemistry of connective tissue. Lab. Invest. 1:30.

_____. 1965. Bielschowski-Gros Method Histopathologic Technic and Practical Histochemistry. 3rd. ed. pp. 612-613. McGraw-Hill Book Co., Inc., New York.

Lovell, J. E. and R. Getty. 1957. The follicle, epidermis, dermis and skin glands of dog. Am. J. Vet. Res. 18: 873-885.

Ludford, R. J. 1924. Cell organization during keratinization in normal and malignant growth. Quart. J. Micro. Sci. 69:29-58.

Malewitz, T. D. and E. M. Smith. 1955. A nuclear stain employing dilute Harris hematoxylin. Stain Tech. 30: 311-312.

Mallory, F. B. and F. Porter, Jr. 1927. Reticulin. Am. J. Path. 3:595-525.

Marcarian, H. Q. and M. L. Calhoun. 1966. Microscopic anatomy of the integument of adult swine. Am. J. Vet. Res. 27:765-772.

Marshall, P. H. A. 1902. On hairs in the equidae. Vet. J. 57:34-42.

Masson, P. 1948. Pigment cells in man; Biology of melanomas. Spec. Publ. N. Y. Acad. Sci. 6:15-51.

Matoltsy, A. G. and M. Matoltsy. 1962. A study of morphology and chemical properties of keratohyaline granules. J. Invest. Dermatol. 38:237-247.

McGuire, J. S. and A. B. Lerner. 1963. Effect of tricosopeptide "ACTH" and alpha melanocyte stimulating hormone on the skin color of man. Ann. N. Y. Acad. Sci. 100:622-625.

Medawar, P. B. 1941. Sheets of pure epidermal epithelium from human skin. Nature 148:783.

Meirowski, E. and G. Behr. 1948. Some aspects of the physiology and pathology of cornification. J. Invest. Dermatol. 10:343-378.

Melaragno, H. P. and W. Montagna. 1953. The tactile hair follicles in the mouse. Anat. Rec. 115:129-142.

Menefee, M. G. 1955. The differentiation of keratin containing cells in the epidermis of embryo mice. Anat. Rec. 122:181-192.

Mercer, E. H. 1961. Keratin and keratinization. Pergamon Press, New York.

Messenger, J. H. 1890. The vibrissae of certain mammals. J. Comp. Neur. 10:399-402.

Meyer, K., P. Hoffman and A. Linker. 1957. The acid mucopolysaccharides of connective tissue. Connective Tissue Symposium. pp. 86-96. Charles C. Thomas, Springfield.

Mikhail, G. R. and A. M. Milinska. 1965. Mast cell population in human skin. J. Invest. Dermatol. 43:249-254.

Montagna, W. 1950. Perinuclear sudanophil bodies in mammalian epidermis. Quart. J. Micro. Sci. 91:205-208.

_____. 1962. The Structure and Function of Skin. Academic Press, New York.

Montagna, W., H. B. Chase, and H. P. Melaragno. 1951. Histology and cytochemistry of human skin. I. Metachromasis in the mons pubis. J. Nat. Cancer Inst. 12: 591-597.

Montagna, W., H. B. Chase, J. D. Malone and H. P. Melaragno. 1952. Histology and cytochemistry of human skin. II. The distribution of glycogen in the epidermis, hair follicles, sebaceous glands and eccrine sweat glands. Anat. Rec. 114:231-248.

Montagna, W. and R. A. Ellis. 1957. Histology and cytochemistry of human skin. XII. Cholinesterases in the hair follicles of the scalp. J. Invest. Dermatol. 29: 151-157.

_____. 1959. Cholinergic innervation of the meibomian gland. Anat. Rec. 135:121-127.

Montagna, W. and C. R. Nobeck. 1947. Histochemistry of sebaceous glands of rat. Am. J. Anat. 81:39-58.

Montagna, W. and J. S. Yun. 1964. The skin of the domestic pig. J. Invest. Dermatol. 42:11-21.

Munger, B. L. 1960. An electron microscope study of the sweat glands of cat foot pad. Anat. Rec. 136:248-253.

Nicholas, A. M. 1963. The mast cells. Ann. N. Y. Acad. Sci. 103:246-252.

Nielson, S. W. 1953. Glands of the canine skin. Am. J. Vet. Res. 14:448-454.

Odland, G. F. 1950. The morphology of the attachment between the dermis and the epidermis. Anat. Rec. 108:399-407.

_____. 1958. The fine structure and interrelationship of cells in the human epidermis. J. Biophy. Biochem. Cytol. 4:529-538.

_____. 1966. Skin. Histology. R. O. Greep, Editor. 2nd ed., pp. 420-445. McGraw-Hill Book Co., Inc., New York.

Odoni, E. 1951. Der Spiegel des Pferdes, eine modifizierte Hautpartie in der Kruppen und oberschenkelgegend. Buchdrudkerei AG. Baden. Zürich.

Okun, M. R. 1965. Histogenesis of melanocytes. J. Invest. Dermatol. 44:285-299.

Orekhovitch, V. N. and V. O. Sphikiter. 1957. Procollagen as biological precursors of collagen and the physico-chemical nature of this protein. Connective Tissue Symposium. pp. 281-293. Charles C. Thomas, Springfield.

Parakkal, P., W. Montagna, and R. A. Ellis. 1962. The skin of primates. XI. The skin of white browed gibbon. Anat. Rec. 143:171-179.

Pease, D. C. 1958. The basement membrane. The structure of histological order and complexity. Fourth Internation conference on Electron Microscopy. Springer - Berlin, Germany.

Porter, K. R. 1966. Mesenchyma and connective tissue. Histology. R.O. Greep, Editor. 2nd. ed. p. 99. Mc-Graw-Hill Book Co., Inc., New York.

Pullar, P. 1964. Keratin formation in tissue culture. In: Progress in the Biological Science in Relation to Dermatology. Cambridge University Press, New York. 2:213-224.

Rabl, H. 1896. Pigment und pigmentzellen der Haut der Wirbeltiere. Ergebn. d. Anat. u. Entwickl. 6:439-470.

Reed, R. 1957. The architecture of the collagen fibrils. Connective Tissue Symposium. pp. 299-307. Charles C. Thomas, Springfield.

Reneto, G. S. 1963. Mechanism of migration of the melanocytes from the hair follicle. Ann. N. Y. Acad. Sci. 100: 249-253.

Riley, J. F. 1959. The Mast Cells. E. and S. Livingston Ltd., Edinburgh, England.

Robb-Smith, A. H. T. 1945. Histology of the reticular tissue in the skin. Brit. Med. Bull. 3:172-175.

_____. 1957. What is reticulin? Connective Tissue Symposium. pp. 177-184. Charles C. Thomas, Springfield.

Rook, A. J. and G. S. Walton. 1965. Comparative Physiology and Pathology of Skin. Blackwell Scientific Publishers, Oxford.

Ross, J. B. 1965. The dermo-epidermal interface in health and disease. Brit. J. Dermatol. 77:77-79.

Rothman, S. 1954. Physiology and Biochemistry of the Skin. University of Chicago Press, Chicago.

Rowles, M. E. 1940. The development of melanophore from embryonic mouse tissues grown in the coelom of chicken embryos. Proc. Nat. Acad. Sci. U. S. 26:673-680.

_____. 1947. Origin of pigment cell from the neural crest in the mouse embryo. Physiol. Zool. 20:248-266.

_____. 1953. Origin of mammalian pigment cell and its role in the pigmentation of hair. In: Pigment Cell Growth. pp. 1-12. Academic Press, New York.

Sandifer, T. N. 1966. Equine Infectious Anemia. Washington Notebook. Veterinary Economics. June, p. 20.

Sar, M. and M. L. Calhoun. 1966. Microscopic anatomy of the integument of the common American goat. Am. J. Vet. Res. 27:444-456.

Schönberg, F. 1926. "Der Ross Spiegel." Eine Eigentumlichkeit des integumentum Pelvis beim Pferde. Berliner Tierarztliche wochenschrift. Vol. 42.

Selby, C. C. 1957. An electron microscopic study of the epidermis of mammalian skin. J. Invest. Dermatol. 29: 131-135.

Shane, G. P. 1939. The role of embryonic ectoderm and mesoderm in pigment production in amphibians. J. Exp. Zool. 8:193-215.

_____. 1944. The embryology - "Vertebrate pigment cells" Part II (Bird). Quart. Rev. Biol. 19:98-117.

Singer, M. and M. M. Salpeter. 1966. "Nervous Tissue." Histology. R.O. Greep, editor. 2nd ed. McGraw-Hill Book Co., Inc. New York

Sinha, R. D. 1964. Microscopic Anatomy of the Integument of Holstein Cattle. M. S. Thesis, Michigan State University.

_____. 1965. Eye Adnexa of Sheep and Goat. Ph. D. Thesis, Michigan State University.

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

Smith, F. 1888. The histology of the skin of horse. Vet. J. 26: 333-340.

Smith, J. L. and M. L. Calhoun. 1964. The microscopic anatomy of the integument of newborn swine. Am. J. Vet. Res. 25:165-173.

Straile, W. E. 1960. Sensory hair follicles in mammalian skin. "The Tylotrich follicles." Am. J. Anat. 106: 133-141.

_____. 1961. The morphology of Tylotrich follicles in the skin of the rabbit. Am. J. Anat. 109:1-13.

Strickland, J. H. and M. L. Calhoun. 1960. The microscopic anatomy of the skin and external ear of Felis domesticus. Am. J. Vet. Res. 21:845-850.

_____. 1963. The integumentary system of cat. Am. J. Vet. Res. 24:1018-1029.

Szelingrowski, E. 1962. Contribution to the histology of the skin of horse. (Collection of vet. med. Warsaw, Poland). Folia Morphol. (Warsaw) 13:531-535. (English Summary).

Takagi, S. and M. Tagawa. 1959. A cytological and cytochemical study of the sweat gland of the horse. Jap. J. Physiol. 9:153-159.

_____. 1961. Nerve fibers supplying the horse sweat gland. Jap. J. Physiol. 11:158-161.

Thuringer, J. 1928. Studies on cell division in the human epidermis. Anat. Rec. 40:1-13.

Trautmann, A. and J. Fiebiger. 1957. Fundamentals of Histology of Domestic Animals. (Translated and revised by R. E. Habel and E. L. Biberstein). Comstock Publishing Associates, Ithaca, New York.

Vincent, S. B. 1913. The tactile hair of the white rat. J. Comp. Neur. 23:1-38.

Waddington, C. H. 1956. Principals of Embryology, "Origin of Melanocytes." Allen and Unwin, London. p. 256.

Waldeyer, W. 1875. Über Bindgewebezellen. Arch. f. Mikr. Anat. 11:176-178.

Wall, P. D. 1964. Two transmission systems for the skin sensation. In: Sensory Communication. Massachusetts Inst. Tech. Press, Cambridge, Mass. pp. 475-496.

Waterston, D. 1933. Observations on sensation. The sensory function of the skin for touch and pain. J. Physiol. 77:251-257.

Webb, A. J. and M. L. Calhoun. 1954. The microscopic anatomy of mongrel dogs. Am. J. Vet. Res. 15:274-280.

Weddell, G. 1941. The pattern of cutaneous innervation in relation to cutaneous sensibility. J. Anat. 75:444-453.

Weddell, G. and D. C. Sinclair. 1952. The anatomy of organized nerve endings in human skin. J. Anat. 86: 496-503.

Weddell, G. and W. Pallie. 1954. The value of spreading factors in the demonstration of tissue neural elements. Quart. J. Micro. Sci. 95:389-397.

Weddell, G., E. Palmer and W. Pallie. 1955. Nerve endings in mammalian skin. Biol. Rev. 30:159-195.

Weissenfels, N. 1956. Licht phasenkontrast und elektronenmikroskopische untersuchungen uber die enstellung der propigment granule in Melanoblastenkulturen. Zeitschr. f. Zellforsch. 45:60-73.

Wellier, B. H. 1953. Basic mechanism in the differentiation of pigment cells. J. Embryol. Exper. Morphol. 1:297-299.

Winkelmann, R. K. 1957. The sensory end organ of the hairless skin of the cat. J. Invest. Dermatol. 29:374-354.

_____. 1959. The innervation of a hair follicle. Ann. N. Y. Acad. Sci. 83:400-497.

_____. 1960a. Nerve endings in the Normal and Pathological Skin. Charles C. Thomas, Springfield.

Winkelmann, R. K. 1960b. Similarities in cutaneous nerve end organs. "Advances in Biology of Skin." Vol. 1. Cutaneous Innervation. Pergamon Press, New York.

Winkelmann, R. K. and R. W. Schmidt. 1959. Cholinesterase in the skin of the rat, dog, cat, guinea pig and rabbit. J. Invest. Dermatol. 33:185-190.

Yamada, H. 1960. Electron microscopic observations of the secretory processes of the axillary apocrine glands. Acta Pathol. Jap. 10:173-187.

Yoichiro, S. 1965. Histochemical demonstration of phosphorylase a, b and phosphorylase kinase in normal human skin. Johuko J. Exp. Med. 85:160-170.

Zelickson, A. S. 1965. The Langerhans cells. J. Invest. Dermatol. 44:203-205.

Zimmermann, A. A. and S. W. Becker. 1955. Further studies on melanocytes and melanogenesis in the human fetuses and newborn. J. Invest. Dermatol. 25:103-112.

_____. 1959. Melanoblasts and Melanocytes in Fetal Negro Skin. University of Illinois Press, Urbana, Ill.

Zweifach, B. W. 1959. The structural aspects and hemodynamics of microcirculation in the skin. In "The Human Integument". Am. Assoc. Advance. Sci., Washington D. C.