II Epithelial Tissue
Surface epithelia are closed, avascular, but innervated cell unions that cover and protect the underlying connective tissue. The various types of surface epithelium are depicted in this plate.

One criterion in differentiating pseudostratified from stratified epithelium is the relationship between the cells and the basal lamina (arrows). In the case of pseudostratified epithelium, all cells are in contact with the basal lamina though they do not necessarily extend to the epithelial surface. In stratified epithelia, on the other hand, only the basal cells are in contact with the basal lamina.

Stratified epithelia are named according to the shape of the cells that form the surface. Thus, the surface cells are prismatic in stratified columnar epithelia and plate-like in stratified squamous epithelia.

REFERENCE
Plate 8. Localization of Various Surface Epithelia

This plate indicates, though without aiming to be complete, the distribution of surface epithelia in an organism. Simple squamous epithelia (Fig. A) primarily line heart and body cavities (endocardium, pleura, peritoneum), all vessels, etc. Simple cuboidal epithelium (Fig. B) is not so widely distributed; it occurs in various parts of the renal tubules, choroid plexus, pigment epithelium of the retina, etc. Simple columnar epithelium (Fig. C) is found in the oviducts and uterus (Fig. C1), from the cardiac orifice to the anus as a lining of the intestinal tract (Fig. C2), in the large collecting tubules, in the papillary ducts of the kidney (Fig. C3), etc. Pseudostratified columnar epithelium with and without stereocilia (Fig. D1, 2) is found in the ductus epididymidis and ductus deferens; a pseudostratified epithelium with cilia (Fig. E) is present in the respiratory tract (nasal cavities, trachea, bronchial tree).

Transitional epithelium (Fig. F) is found specifically in the urinary tract (renal pelvis, ureter, bladder, initial section of the urethra). Stratified columnar epithelium (Fig. G) is uncommon: It is largely found in transitional areas between stratified squamous and pseudostratified columnar epithelia ( palate, epiglottis, fornix conjunctivae) and in part of the urethra. Nonkeratinized stratified squamous epithelium (Fig. H) occurs in areas subject to greater mechanical stress, such as the oral cavity, esophagus, anus, vagina, and anterior epithelium of the cornea. This type of epithelium has to be constantly moistened by glandular secretion. Keratinized stratified squamous epithelium (Fig. I) as the epidermis forms part of the skin. This epithelium protects the organism from physical and chemical noxae and hinders desiccation (perspiration in sensibilis).

This type of epithelium forms an inner coating of the heart and blood and lymph vessels.

On the inner surface of a vein (Fig. A), longitudinal, spindle-shaped, flattened epithelial cells are evident. Some of these cells (inset) are depicted three-dimensionally in Fig. B.

The cytoplasm of the endothelial cells is flattened; the nucleus-containing portion (Fig. B 1) of the cell body bulges into the vascular lumen. The cells display elongated interdigitations (Fig. B 2); the cell boundaries can be visualized with silver staining of the intercellular matrix substance (Fig. C). The junctions between the cells are strengthened by zonulae occludentes (Fig. B 3) and are frequently covered by short marginal folds (Fig. B 4).

Fairly numerous microvilli (Fig. B 5) are found on the free cell surface, especially in the vicinity of the nucleus. They are particularly numerous on resorptive squamous epithelial cells of mesodermal origin (mesothelium), which line the pleural and peritoneal cavities. Mesothelial cells (see Plates 56, 57) have a similar appearance to endothelial cells. The spherical structures on the cell surface (Fig. B 6) possibly originate as a result of exocytosis (expulsion) of cell products. The minute invaginations on the free cell surface (Fig. B 7) are micropinocytotic vesicles.

The cytoplasm of endothelial cells contains a few mitochondria (Fig. B 8), some cisternae of rough endoplasmic reticulum (Fig. B 9), and the Golgi apparatus (Fig. B 10). Simple squamous epithelium lies, like all other epithelia, upon a basal lamina (Fig. B 11). Collagen microfibrils (Fig. B 12) separate this basal lamina from the basal lamina (Fig. B 13) surrounding smooth muscle cells (Fig. B 14).

Within the blood vessel, the endothelial cells provide a smooth surface so as to hinder blood coagulation.

Magnifications: Fig. A, × 220; Fig. B, × 14,000; Fig. C, × 700

REFERENCES
Simple squamous epithelium, the so-called corneal endothelium, lines the posterior surface of the cornea (Fig. A). The cell boundaries can be visualized distinctly with silver staining, just as in vascular endothelium. The forms of the cells and their interdigitations can be easily seen with increased magnification. The nuclei (Fig. B1) are flattened; unlike vascular endothelial cells, few microvilli (Fig. B2) are evident on the cell surface. The corneal endothelial cells lie on a thick Descemet's membrane (Fig. B3), which also constitutes their basal lamina. Two sets of collagen microfibrils (Fig. B4), perpendicular to one another, with interjacent processes of corneal fibroblasts or keratocytes (Fig. B5), can be seen.

Pulmonary alveoli are also lined with simple squamous epithelium, which predominantly consists of type I alveolar cells. Their extremely thin cytoplasm permits gas exchange and the passage of soluble substances between blood and alveolar air (see Plate 31).

Magnifications: Fig. A, x 65; Fig. B, x 8,000

REFERENCES
Example: Distal Tubule of the Nephron

Simple cuboidal epithelium occurs in many glands and glandular ducts (see Plates 37–39), various sections of the renal tubules, choroid plexus (see Plate 12), and as germinal epithelium of the ovary (see Plate 76). Viewed in profile, the cells of this epithelium have a cuboidal form; the cells are, however, small prisms (hence the alternative name “isoprismatic epithelium”).

A section from the distal tubule of the nephron (Fig. A) is presented three-dimensionally in Fig. B. The cells of the distal tubule are approximately as wide as they are high. In plan view, they largely appear as hexagons. The round or oval nuclei (Fig. B1) of this epithelium are predominantly located in the apical pole of the cell; invaginations of the plasma-lemma penetrate deep into the basal cell pole. The whole of these invaginations form a basal labyrinth (Fig. B2), which permits intensive transport of substances. Part of the basal lamina (Fig. B3) has been folded back so that the polygonal pattern of the basal infoldings may be seen. (See Plate 90 in Krstić 1979.)

Magnification: Fig. B, × 2,000

REFERENCES
Plate 12. Surface Epithelia. Simple Cuboidal Epithelium from the Rat Choroid Plexus

The villous processes (1) of the choroid plexus, which coats the roof of the third and fourth ventricles as well as parts of both lateral ventricles, are lined with cuboidal cells. Their free convex surface is covered with numerous, long microvilli. The round nuclei are primarily located in the middle of the cell body. A basal labyrinth (2) is important in the transport of metabolites.

Two blood capillaries (3) of the fenestrated type can be observed in the interior of the villous process. The basal laminae between the epithelium and capillaries are not depicted for the sake of clarity.

The epithelium of the choroid plexus is involved in active secretion (production of cerebrospinal fluid).

Magnification: \( \times 3,300 \)

REFERENCES
EPITHELIAL TISSUE

Example: Pigment Epithelium of Human and Mouse Retina

A further type of simple cuboidal epithelium is the pigment epithelium of the retina. It can be easily lifted from the connective tissue membranes of the eyeball, mounted onto a microscope slide, and observed unstained from above (Fig. A). In this way, the polygonal forms of the cells (Fig. A1) and the large numbers of spindle-shaped melanin granules can be seen.

In vertical section (Fig. B), the brownish pigment epithelial cells (Fig. B1) are seen to be quadrilateral. With their basal poles they lie on a basal lamina; the apical portions, in which are located many melanin granules (Fig. B2), come into contact with the tips of the rods and cones (Fig. B3). Light travels in the direction of the arrow.

Figure C depicts pigment epithelial cells of the house mouse; this section roughly corresponds to the inset in Fig. B. The cells lie on a basal lamina (Fig. C1), contain a spherical or ellipsoidal nucleus, a moderately developed basal labyrinth (Fig. C2), and more smooth (Fig. C3) than rough (Fig. C4) endoplasmic reticulum. Above the nucleus are located numerous 2- to 4-μm-long spindle-shaped melanin granules (Fig. C5), which continue into the long apical cell processes (Fig. C6). The latter are inserted between the outer segments (Fig. C7) of the rod cells, the membranous disc (Fig. C8) of which can be recognised.

Upon exposure to light, the apical processes, containing the pigment granules, increase in length so that they surround every outer segment. In this way, minute camerae obscurae are formed around every photoreceptor, and this considerably improves the resolving power of the eye. In darkness the processes shorten, the pigment granules stream back into the cells, and sensitivity increases at the expense of resolving power. These so-called retinomotor movements are much better developed in lower animals than in mammals.

Magnification: Figs. A, B, ×350;
Fig. C, ×5,600

REFERENCES
Novikoff AB, Leunberger PM, Novikoff PM, Quintana N (1979) Retinal pigment epithelium: interrelations of endoplasmic reticulum and melanosomes in black mouse and its beige mutant. Lab Invest 40:155-165
Plate 14. Surface Epithelia. Simple Columnar Epithelium from the Rat Jejunum

This simple epithelium has a large distribution: It occurs in the gastrointestinal tract from the cardiac orifice to the anus. Figure A depicts part of an intestinal villus with columnar epithelium. The inset corresponds to the area in Fig. B.

The cells of simple columnar epithelium (absorptive cells or enterocytes) are slender; in cross section they have a polygonal form. Neighboring cells are connected by means of terminal bars (Fig. B1) and fairly complicated interdigitations. The intercellular spaces can be widened, especially in the lower half of the cell, according to the functional condition of the epithelium. Lateral microvilli (Fig. B2) then project into these spaces. The nuclei of columnar cells are ellipsoidal as a consequence of the shape of the cell. In the cytoplasm are scattered numerous mitochondria, a well-developed Golgi apparatus, and cisternae of smooth and rough endoplasmic reticulum. The microvilli (Fig. B3) of the apical pole are very characteristic of these cells and constitute an enormous increase in cell surface area. The microvilli form the striated border, which is also visible under the light microscope.

Goblet cells (Fig. B4), which synthesize and secrete mucous granules (Fig. B5), are located between the columnar cells. In common with other epithelial cells, absorptive cells lie upon a basal lamina (Fig. B6), which separates them from the fenestrated capillaries (Fig. B7) and subepithelial loose connective tissue (Fig. B8). The kind of epithelium described here is involved in absorption (see Plate 31).

Magnifications: Fig. A, x 80; Fig. B, x 4,000

REFERENCES
Taylor AB, Auberson JM (1972) Scanning electron microscope observations of mammalian intestinal villi, intervillous floor and crypt tubules. Micron 3:430-453
Example: Collecting Tubule of the Rat Kidney

In the upper part of the plate, an interlobular artery (1) is depicted with an afferent (2) and efferent (3) arteriole. A nephron, the parts of which are - renal corpuscle (4), proximal tubule (5), thin segment (6), distal tubule (7), and connecting portion (8) - is joined to a collecting tubule (9), which is lined with simple columnar epithelium (10). Part of the basal lamina (11) is folded back, revealing the polyhedral basal surfaces of the epithelial cells. A similar pattern can be recognized in the lumen of the collecting tubule, corresponding to the pattern on the cell surface. The enlarged intercellular spaces (12) between the prismatic cells probably assist in reabsorption of water from urine.

Magnification of the sectioned collecting tubule cells: \( \times 900 \)

REFERENCES
Andrews PM (1975) Scanning electron microscopy of human and rhesus monkey kidneys. Lab Invest 32:610-618
EPITHELIAL TISSUE

Plate 16. Surface Epithelia. Simple Columnar Epithelium with Cilia from the Human Oviduct

Simple cuboidal epithelium from the mucous coat of the oviduct consists of two morphologically distinct types of cell. One type comprises the ciliated cells (1), which contain a large nucleus and relatively well-developed organelles. Numerous long cilia (2) project from the apical surface; their rootlets (3) extend to the nucleus. Secretory or nonciliated cells (4) constitute the second type of cell. They are also columnar, rather more slender than the ciliated cells, and have a protruding apical surface, upon which only a small number of microvilli are located. Their internal structure corresponds to that of secretory cells; in addition to the well-developed rough endoplasmic reticulum and Golgi apparatus, they contain mitochondria and secretory granules (5). During the menstrual cycle, the number and structure of both kinds of cell are altered: In the first half (proliferative or follicular phase) of the cycle, the ciliated cells predominate; in the second half (secretory or luteal phase), the number of ciliated cells decreases and the secretory cells are dominant. In this phase, the latter secrete a hyaluronidase-resistant substance, which moistens the mucosa of the oviduct and promotes the development of the ovum on its way to the uterus. After the secretory cells have yielded their product, they become narrow and the cytoplasm becomes dense.

The movement of the cilia is directed toward the uterus, however in humans this has little to do with transport of the ovum. The current produced by the cilia largely aids the orientation of spermatozoa, which move upstream as a result of their positive rheotaxis. It is possible that the two kinds of cell may transform into one another. (See Plates 170, 171 in Krstić 1979.)

Magnification: × 4,000

REFERENCES
Without exception, all cells that constitute pseudostratified epithelia lie on a basal lamina, though they do not necessarily extend to the epithelial surface. Their nuclei occur at different levels within the epithelial layer. According to the length of the cells that comprise such an epithelium, it is possible to distinguish two, three, or more rows of nuclei, and this at first sight can resemble stratified epithelium. Pseudostratified columnar epithelium is present in many excretory ducts and in the ductus epididymidis.

Figure A shows a transverse section through the ductus epididymidis. Large numbers of spermatozoa (Fig. A.1) are located in the lumen of the ductus. The inset corresponds to Fig. B.

The cells lying on the basal lamina (Fig. B.1) are of two different sizes. The lower, incomplete row consists of basal cells (Fig. B.2), whereas the second, uninterrupted row is made up of columnar cells with stereocilia (Fig. B.3). The basal cells contain a spherical or ellipsoidal nucleus and poorly developed organelles. Since basal cells are able to differentiate into columnar cells they are seen as "replacement cells." The ellipsoidal, often deeply indented nuclei of the columnar cells (Fig. B.4) compose the second row of nuclei in this epithelium. A highly developed Golgi apparatus (Fig. B.5) from which arise many secretory granules (Fig. B.6) is characteristic of these cells. Rough endoplasmic reticulum (Fig. B.7) is usually located near the nucleus, whereas the cisternae of smooth endoplasmic reticulum, lysosomes, and lipofuscin granules are distributed in varying amounts throughout the cytoplasm.

The columnar cells are distinguished by the numerous stereocilia (Fig. B.8) on the apical cell surface. These immobile structures, which are probably involved in secretion, increase the free cell surface area by a significant degree. The secretory product of the columnar cells contains substances that are important in the metabolism of the as yet non-motile spermatozoa in the ductus epididymidis. (See Plate 105 in Kršteč 1979.)

Magnifications: Fig. A, ×150;
Fig. B, ×5,000

REFERENCES
Pseudostratified ciliated epithelium lines the nasal cavities, trachea, and bronchi. It contains several types of cell. The basal cells (1), the nuclei of which form a basal row, are poor in internal structures. They serve to replace dead ciliated cells. The basal cells daily renew about 2% of the cell population of the epithelium.

The cuneate cells (2) are slender and are located between the ciliated cells; they do not extend to the surface and contain more cytoplasmic structures. These "supporting cells" constitute an intermediate stage between the basal and ciliated cells, i.e., cells in the process of differentiation. The characteristic ciliated cells (3) of pseudostratified columnar epithelium are rich in organelles and bear numerous cilia (4) on their free surface, corresponding to the kinocilia (5) in the cell interior. Owing to their high degree of specialization, these cells have lost the capacity to divide and tend to be replaced by differentiation of the deeper-lying cells.

The mucus-producing goblet cells (6) are situated between the ciliated cells. The number of mucin granules (7) they contain varies according to functional circumstances. Following secretion from the goblet cells, these granules, together with the product of the seromucous glands of the respiratory tract, form a fine mucus film (not shown), which moistens the free surface of the epithelium. Most particles of dust that are present in the inspired air become attached to this mucus layer. These particles are then transported toward the larynx and pharynx by continuous ciliary motion and eliminated by coughing or swallowing.

In this epithelium are scattered endocrine cells (8), which, like the adjacent epithelial cells, lie on the basal lamina (9).

Magnification: × 2,900

REFERENCES

Plate 18. Surface Epithelium. Pseudostratified Columnar Epithelium with Cilia (Ciliated Epithelium) from the Rat Trachea
EPITHELIAL TISSUE

Plate 19. Surface Epithelia. Transitional Epithelium from the Empty Bladder of a Monkey

Transitional epithelium is classed as a pseudostratified epithelium since all the cells are most probably in contact with the basal lamina (1) by means of, in parts very slender, cytoplasmic feet. The epithelium comprises small basal cells (2), then intermediate cells (3) in the shape of a tennis racket, and finally the very voluminous facet or superficial cells (4). The polyploid superficial cells contain one large or two smaller nuclei. In the cytoplasm of the apical pole of the cell are found the Golgi apparatus, numerous microfilaments, and discoid vesicles (5). This dense cellular zone appears dark under the light microscope and is termed the crista.

The highly folded apical cell membrane of superficial cells is asymmetrical. The layer of the unit membrane in contact with urine is, in areas called plaques, thicker (~4.5 nm) than the cytoplasmic layer (~2.5 nm). It is believed that these circumscribed reinforcements of the membrane protect the epithelium against the effects of urine. (See Plate 92 in Krstič 1979.)

Magnification: ×2,900

REFERENCES
Plate 20. Surface Epithelia. Transitional Epithelium of an Empty and a Filled Rat Bladder

In the empty efferent urinary tract (renal pelvis, ureter, bladder, and initial section of the urethra), the epithelial cells have a columnar form (Fig. A). In this state, it is possible to count eight to ten rows of nuclei. The basal epithelial surface is infolded and the apical surfaces of superficial cells are convex. When the urinary tract is filled, the epithelium becomes thinner. In this state, only two to three rows of nuclei are evident (Fig. B). The coherence of the surface is maintained by the reserve folds of the plasmalemma and the discoid vesicles, which fuse with the apical cell membrane upon distension.

The name of this type of epithelium derives from these changes that take place in its structure.

Magnifications: Figs. A, B, × 1,900

REFERENCES


EPITHELIAL TISSUE

Plate 21. Surface Epithelia. Stratified Columnar Epithelium from the Rat Urethra

Stratified columnar epithelium, which has a limited distribution, is found between zones of pseudostratified columnar and nonkeratinized stratified squamous epithelium. As previously mentioned, it occurs in fornix conjunctivae, on the palate, epiglottis, and part of the urethra. It consists of several layers of cells, of which only the lowermost are in contact with the basal lamina (1). This cell layer comprises polygonal or cuboidal cells (2); the overlying cells are largely spindle-shaped (3); those forming the free epithelial surface are columnar (4). These columnar cells contain a notable amount of glycogen (5) and bear microvilli.

All the epithelial cells interdigitate to a high degree, which increases the elasticity of the epithelium. The functional properties of this type of epithelium are as yet poorly understood.

Magnification: × 2,900

REFERENCES
A transverse section through the cornea (Fig. A) reveals its epithelium (Fig. A1) and endothelium (Fig. A2; see Plate 10), between which lies the corneal stroma (Fig. A3). Figure B shows a section from the epithelium. The following layers can be distinguished in nonkeratinized stratified epithelium:

C. The stratum basale (basal cell layer) consists of relatively large and prismatic cells, which are attached to Bowman's membrane (Fig. B1) by numerous hemidesmosomes.

D. The stratum spinosum (spinous or prickle-cell layer) is made up of large polygonal cells that are joined by extensive interdigitations, studded with desmosomes. Their cytoplasm, like that of the basal cells, contains a significant number of tonofibrils (Fig. B2). The cells of layers C and D replace, by mitotic division, those that detach from the epithelial surface (stratum germinativum or germinal layer).

E. The stratum pavementosum, which lies above the spinous layer, consists of cells that adopt an increasingly flattened form; some cells lose their nuclei, though the desmosomes are retained. The cells eventually transform into thin anuclear plates (hence the name, stratum pavementosum). The free surface of some of these cells is covered with large numbers of microvilli and low ridgelike folds, so-called, microridges or microplicae (arrow).

Like all other nonkeratinized stratified epithelia of similar structure (oral cavity, esophagus, vagina, etc.), the cornea is moistened; in this case, the moisturizing is performed by the lacrimal glands. The anterior epithelium of the cornea comprises only five to nine cell layers and lies on the avascular corneal stroma; it receives nutrients solely by diffusion.

The diagnostically important corneal reflex is due to the highly developed ramifications of the sensitive nerve endings among epithelial cells.

Magnifications: Fig. A, x80; Fig. B, x2,600

REFERENCES
EPITHELIAL TISSUE

Plate 23. Surface Epithelia. Keratinized Stratified Squamous Epithelium or Epidermis of Human Hairy Skin

Among other functions, keratinized squamous epithelium provides protection for the organism from slight mechanical and chemical damage. The structure of the epithelium and its cells are adapted to this role.

The epidermis consists of the following layers:

E. Stratum corneum
D. Stratum lucidum (only in the glabrous skin of the inner surface of the hand and sole)
C. Stratum granulosum
B. Stratum spinosum
A. Stratum basale (germinative layer)

A. The small cuboidal basal cells (1) are attached by means of basal processes (2) — surrounded by the basal lamina — to the feltwork of reticular and collagen microfibrils (3) of the subepidermal connective tissue. The supranuclear cytoplasm of the basal cells contains some melanin granules (4).

B. One or more layers of large polygonal cells overlie the basal layer. The cells are joined by processes bearing hemidesmosomes (5). Numerous tonofibrils (6) run through the cytoplasm. After mechanical separation, the cells of this layer appear spinous (hence, prickle cells, stratum spinosum, or spinous layer). The basal and spinous layer together form the stratum germinativum, the germinal layer, in which (largely at night) mitoses take place.

C. In the stratum granulosum or granular layer, where the cells are already flattened, the highly refractile keratohyaline granules (7) appear as precursors of keratin. The cells gradually die as a result of an increase in this substance. One or two layers of granular cells are sufficient for light keratinization (as depicted in this plate), whereas three to five layers are required for heavy keratinization. The origin of keratohyalin is as yet unknown.

D. The stratum lucidum or clear layer is very refractile; it only occurs in glabrous, highly keratinized skin of the palms and soles. For didactic reasons, the stratum lucidum, composed of flattened cells, is also presented on this plate. Its cells contain keratin, and it is possible that the clear layer permits movement between the softer germinal and the harder corny layers.

E. The stratum corneum or horny layer can vary in thickness according to mechanical strain. Its cells are dead and their bodies are transformed into keratin scales (8). Since horny cells are constantly desquamating, they have to be continually replaced by cells from the germinal layer.

In a thick avascular tissue like the epidermis, supplied by unmyelinated nerve fibers (9), the broad intercellular spaces (10) act as a channel system and are involved in transporting substances. The intercellular spaces in the stratum granulosum and stratum corneum are significantly narrower (occasionally 20 nm) and are interrupted by desmosomes.

Melanocytes (11) occur in the epidermis and are illustrated in Plate 24. (See Plate 109, 110, 115, 116, 118, 158, 159 in KRSTIC 1979.)

Magnification: × 2,800

REFERENCES

The cells that synthesize the pigment melanin are termed melanocytes (1) and are located between the basal cells of the epidermis and in the hair bulb. Melanocytes stem from the neuroectoderm of the neural crest (see Plate 144); during embryonic development, they migrate into the epidermis and contact the basal lamina (2).

Melanocytes are very difficult to distinguish in normally stained sections. Following the dopa reaction (in which an enzyme responsible for melanin synthesis is stained) they appear black. Melanocytes are pale, highly branched cells. The cytoplasma contains a round nucleus, well-developed organelles, some free ribosomes, few microfilaments, and a varying number of melanosomes (3), precursors of mature melanin granules (4).

The melanin granules are about 0.7 x 0.3 μm in size and are invested with a unit membrane. These granules also occur in the cell processes (arrow), from which many are able to penetrate deep into the intercellular spaces and into the bodies of neighboring cells of the stratum germinativum. It is assumed that melanin granules can be transferred to neighboring germ cells by means of the melanocyte processes. It is also possible that the pigment particles are phagocytized by basal and prickle cells. Melanocytes are not connected to neighboring cells by desmosomes. In white race, only the basal cells contain melanin.

The existence of processes (5) oriented toward the subepidermal connective tissue suggests that melanocytes may even be able to migrate out of the corium after embryogenesis has been completed. Melanocytes retain the ability to divide for the duration of their lives. It has been estimated that there are about 1,200–1,500 melanocytes/mm² of skin. Pigment synthesis is stimulated by ultraviolet light (increased coloration of the skin following exposure to the sun). Albinos possess melanocytes in their skin, however the melanosomes are unable to turn black and transform into mature melanin granules, owing to the absence of the enzyme tyrosinase.

At the bottom of the plate, the basal processes (6) of the basal cells can be seen. Reticular (7) and collagen microfibrils (8) are connected to the basal lamina (2). (See Plates 75, 76 in KERTZ 1979).

Magnification: x8,000

REFERENCES


50 51
EPITHELIAL TISSUE

Plate 25. Secretory Surface Epithelia.
Example: Amniotic Epithelium of a Human Fetus

Certain epithelial cells have secretory activities: the surface epithelium of the stomach synthesizes mucus, which serves as a protection against the corrosive effects of HCl and pepsin, and the product of the surface epithelium of the gallbladder protects it against bile acids. The function of the simple cuboidal epithelium of the choroid plexus was mentioned in Plate 12.

Amniotic epithelium develops in the embryoblast from the extraembryonic cells opposite the embryonic ectoderm (Plate 1, Fig. G5). The amniotic cavity becomes wider and provides the necessary conditions for undisturbed development of the embryo.

Figure A depicts a 4-month-old human fetus with the amnion (Fig. A1). The chorionic vili (Fig. A2) and umbilical cord (Fig. A3) can be distinguished. The segment in the inset is enlarged in Fig. B.

In this region, the amniotic epithelium is simple and cuboidal; it lies upon a basal lamina (Fig. B1). The epithelial cells have a well-developed basal labyrinth, spherical nuclei, well-developed organelles, and numerous microvilli on the apical surface. As inclusions in the cytoplasm occur lipid droplets, glycogen (Fig. B2), and so-called amniotic vacuoles (Fig. B3). The latter are mainly located near the broad intercellular spaces (Fig. B4), which are penetrated by numerous microvillous processes. Amniotic epithelium produces about 1–2 l amniotic fluid (liquor amnii), in which the fetus floats freely. This fluid does not only serve to protect the fetus from mechanical damage or desiccation; the turnover of 0.5 l/h at the end of gravidity indicates that amniotic fluid is also of great physiological importance for the development of the fetus, providing it with a uniform hydrostatic support.

Magnification: Fig. B, × 4,500

REFERENCES

Sole Example: Epithelium of Stria Vascularis of Inner Ear

The surface epithelium hitherto described are all avascular; the stria vascularis of the inner ear is thus an exception. A section from the cochlea (Fig. A) is provided for purposes of orientation. On the outer surface is the spiral ligament (Fig. A 1), which is lined with the epithelium of the stria vascularis (inset). The cochlear duct (Fig. A 2) contains the organ of Corti (Fig. A 3). The processes (Fig. A 4) of the bipolar cells of the spiral ganglion can also be observed.

The epithelium of the stria vascularis comprises one to three layers and lies on a basal lamina (Fig. B 1). In addition to the basal cells (Fig. B 2), this epithelium is made up of marginal cells (Fig. B 3), which form the surface. These cells contain a large number of mitochondria in small labyrinthine compartments (Fig. B 4) and a few microvilli at the hexagonal apical cell pole. A type of intermediate cell (Fig. B 5) also occurs in the stria vascularis.

Percytes (Fig. B 6) and a basal lamina (not shown) surround the capillaries (Fig. B 7), which run between the epithelial cells. The stria vascularis is the only vascularized epithelium in the body.

The close contact between the capillaries and mitochondria-rich marginal cells is in accordance with the supposition that endolymph, important for the function of the organ of hearing, is produced in the stria vascularis.

Magnifications: Fig. A, × 70; Fig. B, × 1,500

REFERENCES
Plate 27. Atypical Epithelia. Examples: Enamel Organ of the Mouse and Thymus of a Human Adolescent

According to definition, epithelia are closed cell unions; the enamel organ and the stroma of the thymus, however, do not conform to this pattern.

On a frontal section through the head of a 21-day-old mouse fetus (Fig. A), it is possible to distinguish parts of the rhinencephalon (Fig. A1), the eye anlagen with the lenses (Fig. A2), the nasal cavity (Fig. A3), the canalis nasopharyngeus (Fig. A; arrow), and the oral cavity (Fig. A4) with the tongue (Fig. A5). The epithelium (Fig. A6) of the oral cavity forms the dental lamina (Fig. A7), from which the bell-shaped enamel organs (Fig. A8) develop. In the interior of each enamel organ, an increase in intercellular fluid forces apart the initially closely apposed cells, giving rise to the enamel pulp (Fig. A9). The mesenchyme condenses in the cup of the enamel organ and forms the dental papilla (Fig. A10). The area within the inset is illustrated in Plate 28.

The epithelium of the thymus originates from the endoderm of the third pharyngeal pouch; during embryonic development, the cells of this epithelium become infiltrated and separated by migrating lymphocytes. Under the light microscope at low magnification, the capsule (Fig. B1) and lobules of the thymus are quite distinct. Each lobule is divided into a cortex (Fig. B2) and medulla (Fig. B3). Figure C corresponds to the section of medulla in the inset where the Hassall's corpuscles (Fig. B4) are located.

Reticular-epithelial cells (Fig. C1) form the epithelial framework of the parenchyma of the thymus. These stellate cells of epithelial origin are connected by cell processes and build up a vascular, sponge-like network. These cells should not be confused with reticular cells of the reticular connective tissue (see Plate 55), which are of mesodermal origin. Many small lymphocytes (Fig. C2) are located in the interstices of the epithelial network. In Hassall's corpuscles (Fig. C3), the lamellar, epitheliogenic, reticular-epithelial cells are closely packed in the form of concentric arrays.

The area within the inset in Fig. C is enlarged in Plate 29.

Magnifications: Figs. A, B, ×30; Fig. C, ×750

REFERENCES
Continuation of Plate 27

At the beginning of odontogenesis, a dental lamina (1) grows from the stratified squamous epithelium of the oral cavity (2) into the subepithelial connective tissue, where it gradually forms the bell-like enamel organs. Every enamel organ (3) is seen to be comprised of an outer (4) and inner (5) epithelium. Between the two epithelia, the stellate epithelial cells (6) form a wide-meshed avascular network, the enamel pulp (asterisk), which is atypical for an epithelial tissue.

The outer layer of the enamel organ (4) is in contact with cells of the connective tissue of the dental sac (7) and numerous blood vessels (8).

The cells of the simple columnar, inner epithelium differentiate into ameloblasts (5), which synthesize the enamel (substantia adamantina) of the future crown.

As mentioned in Plate 27, mesenchyme enters the concavity of the enamel organ (dental papilla), where it forms the vascular dental pulp (9). The mesenchymal cells in contact with the ameloblasts arrange themselves into a vascularized epithelium-like layer and differentiate, under the inductive action of ameloblasts, into dentin-producing odontoblasts (10, Plate 113).

Magnification: × 500

REFERENCES

Plate 29. Atypical Epithelia: Thymus. Continuation of Plate 27

In a section from the medulla of the thymus, it is possible to see a broad three-dimensional framework of reticular-epithelial cells (1), which are separated from one another by lymphocytes (2). Granulocytes, mast cells (3), etc. also occur in the wide intercellular meshes. Some reticular-epithelial cells tend to arrange themselves into closed cell complexes. They move nearer to one another, like the concentric layers of an onion, and form an avascular Hassall's corpuscle (4). As in stratified squamous epithelium, the reticular-epithelial cells are connected to one another by numerous desmosomes. The cytoplasm contains granules (5), which morphologically resemble kerato-hyaline granules. Hassall's corpuscles enlarge by attaching new epithelial cells, which causes the innermost cells to become gradually sequestered from the capillaries (6) and degenerate. Thus, the centers of voluminous Hassall's corpuscles contain a large amount of cell debris (7). The Hassall's corpuscles most probably represent aggregations of exhausted reticular-epithelial cells. The corpuscles increase in number and diameter under conditions of stress (e.g., infections). The myoepithelial cells that originate from epithelial tissue are described in Plate 123.

Magnification: ×1,200

REFERENCES
Plate 30. Surface Epithelia. Atypical Epithelia. Change in Form of Epithelial Cells. Lens Fibers of the Rat

During embryonic development, the eye anlage, called the optic vesicle (Fig. A1), connected by the optic stalk (Fig. A2) with the brain wall (Fig. A3), grows toward the lateral side of the head. At the site where the optic vesicle comes into contact with the epidermis, formation of the lens ectoderm (Fig. A4) is induced. This epithelial structure gradually invaginates (Fig. B1) until it finally becomes separated from the surface and forms the lens vesicle (Fig. C1), which is surrounded by the optic cup (Fig. C2). The anterior wall of the lens vesicle (Fig. C3) consists of a low epithelium, whereas the cells of the posterior wall (Fig. C4) are columnar.

At a later stage of lens development, the anterior epithelium is still simple and cuboidal (Figs. D1, E1), whereas the posterior epithelium differentiates into lens fibers (Figs. D2, E2). A section from Fig. E is shown enlarged in Fig. F.

The lens is enveloped in a thick, elastic, cuticular capsule (Fig. F1), to which the zonular fibers (Fig. F2) are attached. At the equator of the lens, the mitotically active, simple cuboidal epithelium (Fig. F3) gradually differentiates (Fig. F4) into lens fibers. This involves the cells gradually losing their original form and nucleus; they become progressively longer, transform finally into lens fibers (Fig. F5), and arrange themselves in a complex series of layers. The innermost lens fibers that form the lens nucleus (Fig. F6) gradually shrink through loss of water. This decrease in volume is compensated by the addition of new lens fibers; thus, the lens practically does not increase in size after the 3rd year of life.

The cut surface of some fibers is shown so that their form and arrangement can be seen. The small inset in Fig. F corresponds to Fig. G.

The lens fibers are in fact very long hexagonal prisms (Fig. G1), and adjacent fibers interlock by means of processes (Fig. G2). The interior of the prisms contains moderately osmiophilic amorphous material. The strong connections between the lens fibers are necessitated by the constant lens movements associated with accommodation.

The lens contains neither vessels nor nerve endings. It is nourished solely by the aqueous humor and possesses no regenerative powers.

Magnification: Fig. G, × 3,000

REFERENCES
Surface epithelia carry out the following functions:

A. Protection
B. Absorption
C. Transport by means of cilia
D. Secretion
E. Excretion
F. Gliding between organs
G. Gas exchange

A. In principle, every type of surface epithelium performs a protective function, i.e., not just keratinized stratified squamous epithelium, which is particularly specialized for this purpose. Keratin scales confer resistance to mechanical and chemical damage and hinder desiccation of the organism.

Melanin granules, which develop in the melanocytes (Fig. A1; Plate 24) and are distributed in the epidermis, absorb ultraviolet rays and thus protect the organism from the injurious effects of this kind of radiation.

B. Absorption is the major function of simple columnar epithelium of the small intestine. In Fig. B, only the absorption of emulsified fats is depicted, since this process can be observed relatively easily with the transmission electron microscope. A pancreatic enzyme (lipase) breaks down the fats in the duodenum into monoglycerides and fatty acids. The short-chain fatty acids pass directly into the blood of the portal veins. The long-chain fatty acids and monoglycerides first of all reach the smooth endoplasmic reticulum, where they become esterified to triglycerides. The first fat droplets appear (Fig. B1) and become widespread in the rough endoplasmic reticulum (Fig. B2), where a protein component is probably attached. From the endoplasmic reticulum, the lipid droplets reach the Golgi apparatus (Fig. B3) and some sugar components are incorporated. From the Golgi apparatus, the fat droplets enter the broad intercellular spaces and penetrate the subepithelial connective tissue by crossing the basal lamina (Fig. B4). Eventually, these particles, termed chylomicrons (Fig. B5), accumulate in the lymph capillaries (Fig. B6).

C, D. Ciliary transport and the secretory activities of epithelia have already been discussed in Plates 18 and 25.

E. The epithelial cells of the renal tubules have both resorptive and excretory functions (arrows).

F. Under certain conditions, mesothelium (Plate 57) has a definite absorptive role. Its usual function is to ensure smooth movement between the surfaces of the inner organs.

G. The simple squamous epithelium of the pulmonary alveoli assists in the exchange of gases between blood and alveolar air. Carbon dioxide leaves the blood through the capillary wall and the extremely thin cytoplasmic processes of the alveolar cells type 1, while oxygen diffuses into the blood by the same route.
Glands are aggregations of highly differentiated epithelial cells which release their product either by means of an excretory duct onto the free surface (exocrine glands) or directly into the vascular system (endocrine glands).

During embryonic development, those cells (Figs. A–D, stippled areas) that will later be solely concerned with synthesis of secretory products differentiate at certain points on the surface epithelium. Some of them remain in the surface epithelium (goblet cells, Figs. B1, C1, D1; multilocular endophytic glands, Figs. B2, C2, D2), whereas others form buds by mitotic division (Figs. B3–5, C3–5, D3–5). The subsequent development of these epithelial buds can follow different courses. If a strand of glandular cells remains in contact with the surface by an excretory duct (Fig. C3, asterisk), an exocrine gland results (secretion follows direction of arrow, Fig. D3). Since the functional portion is located beneath the epithelial surface, such a gland is termed exoepithelial. Conversely, if the groups of epithelial cells cease to be connected with the surface epithelium and penetrate the underlying connective tissue, endocrine (ductless) glands develop. Two means of discharging their products (hormones) are available to these glands. One way involves direct hormonal secretion into the blood and/or lymphatic vessels (Fig. D4a, 5a). This mode of secretion accounts for the function of, e.g., the pituitary, parathyroid glands, adrenal glands, paraganglia, and the endocrine parts of the sex glands (Fig. D4, arrows). The thyroid gland (Fig. D5) operates according to a different scheme. Its cells first of all attach the hormones to a globulin and then store this complex in the form of a colloid in small epithelial sacs or follicles (Fig. D5b). The stored hormone is freed from the colloid as required and released into the circulation. As a result of this ability to keep a reserve of hormones, the thyroid gland is referred to as a “storage gland.”

REFERENCES
Plate 33. Glandular Epithelia. Classification of Exocrine Glands

This plate demonstrates the various criteria according to which glands can be systematized. Classification according to form (tubular, tubuloacinar, tubuloalveolar, and alveolar) is discussed in Plate 34. According to the appearance of the terminal secretory portions and the type of secretion, the distinction can be made between mucous, serous, and seromucous exocrine glands. In transverse section, the tubular terminal portions of mucous secretory glands are larger than those of serous glands. Mucous glands have a wide lumen since their well-delimited cells secrete a viscid product. Large amounts of this product are accumulated, causing the cells to be clear and with a foamlike appearance. The flattened nucleus is displaced toward the basal plasmalemma. The terminal secretory portions of serous glands form mulberrylike acini, the lumen of which is very narrow but perfectly adequate for drainage of the thin, enzyme-containing secretion. The cells here are not so well delimited as in the mucous tubules. Their nuclei are spherical and located in the middle of the cell body. Mixed or seromucous terminal secretory portions are found in many salivary glands; they are characterized by capping of the mucous tubules by serous demilunes. The product of such glands is moderately viscous.

If in an exocrine gland the cells are only of one type and synthesize the same product, the gland is termed homocrine (e.g., acini of the pancreas, pyloric glands of the stomach etc.). The product of a heterocrine gland is mixed since it derives from the different types of cell that make up such a gland (e.g., glands of the body of the stomach, submandibular glands, sublingual glands etc.).
EPITHELIAL TISSUE

Plate 34. Glandular Epithelia. Form of Exocrine Glands

Simple glands (Fig. A) may be tubular (Fig. A1), mulberrylike or tubuloacinar (Fig. A2), vesicular or tubuloalveolar (Fig. A3), and saclike or alveolar (Fig. A4). Each gland has a terminal secretory portion (unshaded arrow) and a more or less developed excretory duct—termed "neck" in tubular glands (solid arrows). It should be noted here that forms A2 and A3 are, at least in humans, purely of theoretical significance. Simple tubular glands include the glands of the body of the stomach, glands of the small intestine, etc. Simple alveolar glands are represented by small sebaceous glands.

When several simple glands empty into one excretory duct (solid arrows), branched glands (Fig. B) develop. Here, the highly convoluted (Fig. B1) sweat glands or glandulae glomiformes represent a special intermediate form between the simple and branched glands. Pyloric glands, duodenal glands, etc. belong to the ramified tubular glands (Fig. B2). Purely tubuloacinar and tubuloalveolar glands (Fig. B3,4) only represent stages in the development toward compound glands. Branched alveolar glands (Fig. B5) include the large sebaceous glands and the tarsal glands of the eyelid. In compound glands (Fig. C), the main excretory duct (double arrows) branches into several smaller excretory ducts (solid arrows), each of which can possess tubular, acinar, tubuloalveolar, and alveolar terminal portions. Compound tubular glands (Fig. C1) are exemplified by the mucous glands of the oral cavity. The main representatives of compound tubuloacinar glands (Fig. C2) are the parotid glands and exocrine pancreas. The submandibular glands are an example of a compound tubuloalveolar gland (Fig. C3), and the secretory mammary gland is an example of a compound alveolar gland (Fig. C4). Large-scale subdivisions of compound glands lead to the development of lobules and lobes.

It should not be supposed that all the glands of the body of a mammal pass neatly into this schematic classification. There always exist individual and, in particular, functional variations which account for the same gland being able to switch rapidly from one category to another.
Goblet cells occur in large numbers in the epithelium of the intestinal and respiratory tracts (see Plates 14, 18). In Fig. A, two goblet cells are depicted within insets. The cell on the left corresponds to Fig. B, the cell on the right to Fig. C. Fully active cells have a narrow base and a broad apex and hence the shape is that of a goblet. The nucleus is slender and contains condensed chromatin and above it is found a very well-developed Golgi apparatus (Figs. B1, C1). Mucigen granules (Figs. B2, C2) are formed in the Golgi apparatus with the assistance of other organelles and move toward the apical cell pole as mucous droplets (Figs. B3, C3). The apical plasma-lemma temporarily opens and the mucus is expelled from the cell. The cell does not lose cytoplasm in the process. This type of discharge is referred to as eccrine secretion. After expulsion of the mucous droplets the goblet cell becomes slender (so-called slender cell; Fig. C). Note the distinct microvilli (Figs. B4, C4) and zonulae occludentes (Figs. B5, C5) on the apical pole. After a pause a new secretory cycle begins; the cell synthesizes its product and discharges it again. A secretory cycle can thus be repeated many times. (See Plates 154, 155 in Krsnić 1979.)

Magnifications: Fig. A, x 700; Figs. B, C, x 5,000

REFERENCES
Plate 36. Glandular Epithelia. Endoepithelial Gland of Human Nasal Mucosa

All the mucus-producing cells (1) of an endoepithelial gland (2) are located in the middle of the pseudostratified columnar epithelium (3). They are somewhat lower than the neighboring ciliated cells (4), with the result that the glandular lumen is situated in the middle of the epithelium. Endoepithelial glands produce mucus for moistening the nasal mucosa.

Magnification: × 2,300
Plate 37. Glandular Epithelia. Terminal Portion of a Simple Tubular Heterocrine Gland from the Rat Stomach

Figure A depicts a section from the mucosa of the body of the stomach. Tubular gastric glands proper (Fig. A 1) open into the gastric pits (Fig. A 2). The area in the inset corresponds to Fig. B. A gastric gland proper is composed of several types of cell: Neck mucous cells (not shown since they are only found in the neck of the gland; Fig. A 3); chief cells; parietal cells and isolated endocrine cells. Columnar chief cells (Fig. B 2) are distinguished by a very well-developed ergastoplasm and large numbers of free ribosomes. Many peptidogen granules are found above the nucleus. Parietal cells (Fig. B 3) are appreciably larger than the chief cells and their basal sections frequently protrude toward the exterior. They have large spherical or ellipsoidal nuclei, and mitochondria are very numerous in the cytoplasm. Particularly characteristic are the deep, occasionally branched intracellular canalculi (Fig. B 5), which are penetrated by great numbers of microvilli. Parietal cells provide the hydrogen ions that are essential for the production of hydrochloric acid of the gastric juice. Endocrine cells (Fig. B 4) are scattered at the base of the gland. They do not extend to the glandular lumen, but their bases are in contact with the capillaries (Fig. B 6). Endocrine cells have spherical nuclei, well-developed organelles, and the infranuclear cytoplasm contains numerous hormone granules. All these cells secrete their products without loss of cytoplasm, i.e., by an eccrine mechanism. Since the glandular secretion is composed of different products, this type of gland is termed heterocrine. (See Plates 42, 43, 160 in Körisch 1979.)

Magnifications: Fig. A, × 70;
Fig. B, × 3,000

REFERENCES
The light-microscopic image of a section from the exocrine pancreas is presented in Fig. A. An acinus (Fig. A1) is the exocrine secretory unit that communicates via its intercalated duct (Fig. A2) with an excretory duct (Fig. A3). Centroacinar cells (Fig. A4) are localized in the interior of the acini. The inset in Fig. A corresponds to Fig. B.

An acinus is a structure made up of simple epithelium and its shape is similar to that of a mulberry. The acinar cells (Fig. B1) are cuboidal with globular, central nuclei and large nucleoli. Ergastoplasm and free ribosomes are noticeably widespread, indicative of a high level of protein synthesis. The supranuclear cytoplasm contains large numbers of zymogen granules of various sizes which are discharged in a rather diffuse fashion. For the sake of clarity, the acinar lumen is shown as a broad space, though in reality it is a narrow cleft.

Centroacinar cells (Fig. B2), characteristic of the exocrine pancreas, also occur in the acinus. They form an incomplete layer of the tissue, with the gap between the outer surface of the gland and the intercalated duct (Fig. B3).

For the same reason, no myoepithelial cells are found around the pancreatic acini.

There is a well-developed blood supply to the enzyme-synthesizing glandular units. Thus, on their external surface, which is separated from the secretory cells by a basal lamina (Fig. B4), many capillaries are found in addition to unmyelinated nerve fibers (Fig. B6). (See Plate 155 in Krstic 1979.)

Magnifications: Fig. A, ×400; Fig. B, ×1,000

REFERENCES


Terminal Portion of a Mixed Salivary Gland.
Example: Human Submandibular Gland

In a section through a mixed salivary gland, the mucous secretory portions or mucous tubules (Fig. A1) are weakly stained with hemalum and eosin, whereas the serous acini (Fig. A2) are strongly stained. The mixed elements are distinguished by the presence of dark serous demilunes or crescents of Giannuzzi (Fig. A3) at the end of the mucous tubules. Figure B corresponds to the inset in Fig. A.

The cytoplasm of the columnar mucous cells (Fig. B1) contains such large numbers of mucous droplets that the dark, flattened nucleus is displaced to the basal lamina. These cells develop by a particular process which is characteristic of mixed salivary glands, whereby cells of the intercalated ducts (Fig. B2) transform into mucous cells. For this reason, intercalated ducts are rare or even absent in seromucous glands. If present, they also produce a mucous secretion. Owing to the high viscosity of the product secreted by the mucous cells, the lumen of the tubule is relatively broad.

At the end of the mucous tubule, the ergastoplasm-rich serous cells (Fig. B3) are arranged in a hemispherical fashion. These cells are connected to the tubular lumen by means of intercellular canaliculi (Fig. B4). In this manner, seromucous saliva is produced, and its expulsion is accelerated by contraction of the myoepithelial cells (Fig. B5).

Blood capillaries (Fig. B6) and unmyelinated nerve fibers (Fig. B7) are found close to the terminal portions of mixed glands. (See Plate 161 in Kastner 1979.)

Magnifications: Fig. A, x 400; Fig. B, x 2,800

REFERENCES

Figure A illustrates the light-microscopic image of a lactating mammary gland of the rat. The cells directed toward the lumen are characterized by the presence of pale fat vacuoles (Fig. A 1). A single alveolus is drawn in Fig. B.

The epithelium of the alveolus is composed of a layer of columnar cells, rich in ergastoplasm. In the apical pole, the cytoplasm of these cells contains two types of vacuole: Small, osmiophilic, proteinaceous (black) casein granules (Fig. B 1) are found in the first type; the second, significantly larger, type of vacuole contains fat droplets (Fig. B 2).

Expulsion of the protein granules occurs by means of the exocytic mechanism. The secretion of the fat droplets, however, is associated with a loss of apical cytoplasm and is termed apocrine secretion.

In this manner, milk (Fig. B 3) is formed in the broad alveolar lumen; expulsion of the milk is assisted by contraction of myoepithelial cells (Fig. B 4). (See Plate 156 in Kastner 1979.)

Magnifications: Fig. A, \( \times 500 \);

Fig. B, \( \times 2,300 \)

REFERENCES


EPITHELIAL TISSUE

Plate 41. Glandular Epithelia. Sebaceous Sac of a Holocrine
Pluristratified Alveolar Gland. Example: Human Sebaceous Gland

The majority of sebaceous glands (Fig. A1) open into hair follicles (Fig. A2). They are composed of numerous sacs or alveoli (Fig. A3). A sebaceous alveolus is enlarged in Fig. B.

As in the epidermis, the deepest or basal cells (Fig. B1) in contact with the basal lamina (Fig. B2) are capable of division. They form a germinal layer from which the dead cells that have been transformed into sebum are replaced by mitosis (Fig. B3). The internal cells (Fig. B4) produced by the germinal layer gradually become sebaceous cells by the accumulation of lipid droplets in the cytoplasm; however, all cells remain firmly connected to one another by means of numerous desmosomes.

At a later stage of sebum development, the cells gradually die; the nuclei become very dense, i.e., pyknotic, and shrink (Fig. B5, B6). At the same time, the cell borders disappear, and the sebaceous vacuoles leave the now amorphous cytoplasm, the end product of which is an anuclear fatty mass. The sebum (Fig. B7) reaches the skin surface via the hair follicle.

Pluristratified alveolar glands are, without exception, holocrine. This term signifies a process in which synthesis of the secretory product is accompanied by death of the cell. Thus, such glands constantly require replacement of cells from the germinal layer. (See Plate 157 in KRSTIC 1979.)

Magnifications: Fig. A, ×70; Fig. B, ×2,600

REFERENCES
Plate 42. Glandular Epithelia. Scheme of a Compound Tubuloacinar Gland

This plate is solely intended to clarify the general organization of a compound exocrine gland. For this reason, the acinar lumen, which is usually narrow, has been drawn as a wide space. The acini (1) are connected via narrow intercalated ducts (2) to the striated ducts (3). Several striated ducts unite outside the lobule (4) to form one interlobular or extralobular duct (5); several extralobular ducts unite to form the principal excretory duct (not represented), which in the section reaching the surface is lined by pseudostratified epithelium.

Each gland is supplied with arteries (6) and veins (7). Nervous impulses are transmitted by bundles of unmyelinated nerve fibers (8).

Magnification: ×280

REFERENCE
The pancreas (Fig. A), which fits into a concavity of the duodenum (Fig. A2), is made up of two types of glandular epithelium. Acini (Fig. B1), mentioned in Plate 38, compose the greater part of the exocrine lobules (Fig. B3), which also contain numerous vesicular or tubular cavities, follicles (Fig. D1), which are lined with a simple epithelium. Colloid, carrier of the glandular hormones, is stored in the interior of the follicles. The lobules are fairly well defined and contain numerous vesicular or tubular cavities, follicles (Fig. D1), which are lined with a simple epithelium. Colloid, carrier of the glandular hormones, is stored in the interior of the follicles.

The lobes of the thyroid gland (Fig. C1) are located on the anterior side of the larynx (Fig. C2). The lobules are fairly well defined and contain numerous vesicular or tubular cavities, follicles (Fig. D1), which are lined with a simple epithelium. Colloid, carrier of the thyroid hormones, is stored in the interior of the follicles.
The pancreatic islets are minute endocrine glands scattered within the exocrine pancreas. Their epithelial or islet cells (1) are polygonal elements with lobate, ellipsoidal nuclei and a variable number of secretory granules depending on the functional stage; they form branched interconnected strands. Many blood capillaries (2) run between the epithelial strands, often accompanied by unmyelinated nerve fibers (3) which frequently contact the epithelial cells.

Several types of islet cell have so far been identified (see histology texts for further information); for example, B cells synthesize and secrete insulin into the blood capillaries. This vital hormone reduces the level of sugar in the blood and deficiency leads to diabetes mellitus. An increase in blood sugar level induces release of the hormone glucagon, which is produced in the A cells. (See Plates 163, 164 in Kastner 1979.)

Magnification: × 1,000

REFERENCES
Plate 45. Glandular Epithelium. Endocrine Glands. Thyroid Gland of the Rat. Continuation of Plate 43

The thyroid follicles (1) are spherical, ovoid, or tubular structures, lined by a simple epithelium (2) of varying thickness. Unmyelinated nerve fibers (3) and arterioles (4) occur in the interfollicular connective tissue. The arterioles form a dense capillary network (5) around the follicle, through which every epithelial or thyroid follicular cell is in contact with the blood circulatory system. The epithelial cells synthesize and discharge homogeneous colloid into the lumen of the follicle. Two iodine-containing thyroid hormones (tri- and tetraiodothyronine) are bound to the globulins of colloid. The epithelial cells thus ensure production and storage of thyroid hormones. If thyroid hormones are required by the organism, the hitherto viscous colloid becomes more fluid, the hormone-protein complexes are split, and the hormones are released into the blood.

The second type of epithelial cells in the thyroid, the C cells (6), stem from the ultimobranchial body and do not form colloid. Their product—the hormone calcitonin—is released directly into the blood. For the sake of clarity, the basal laminae of the capillaries and epithelial cells have not been drawn. It should be noted that the majority of endocrine epithelial cells possess a small intracellular hormone reserve.

Magnification: ×1,000

REFERENCES
Changes in functional conditions lead to alterations in the form and structure of glandular epithelium. A particularly clear example of this is seen in the dynamics of thyroid epithelium. Resting thyroid follicles are large (Fig. A), colloid is viscous, and the follicular cells and their nuclei are flattened. In the electron microscope, sparse cisternae of rough endoplasmic reticulum (Fig. B1) and occasional secretory granules (Fig. B2) are evident in the low cells. A relatively small number of microvilli (Fig. B3) occur on the apical cell surface. With an increased requirement for tri- and tetraiodothyronine on the part of the organism, the cells mobilize colloid and the follicles become smaller (Fig. C). The epithelial cells become columnar, and their nuclei larger, ellipsoidal, and invaginated. The cytoplasm contains well-developed Golgi apparatus (Fig. D1), and the cisternae of the rough endoplasmic reticulum (Fig. D2) are significantly broader. Many secretory granules (Fig. D3) appear directly beneath the apical plasmalemma. Microvilli become very much more numerous. At the same time, globular or cuplike cell processes (Fig. D4) develop, which increase the resorptive surface area. (See Plate 40 in KASTIC 1979.)

Magnifications: Figs. B, D, × 5,000

REFERENCES
EPITHELIAL TISSUE

The functions of surface and many glandular epithelia are associated with a continuous loss of cells; thus, these cells have to be constantly replaced by new ones. Mitoses play a major role in compensating for the lost cells, and they usually occur as far as possible from the sites of consumption, e.g., in stratified squamous epithelia mitoses only occur in the germinal layer (Fig. A, arrows). The regeneration of enterocytes takes place solely in the intestinal crypts (Fig. B, arrows; see Plate 118). The basal cells (Fig. C, arrows) of sebaceous glands are responsible for replacing sebaceous cells that disintegrate during holocrine secretion (see Plate 41).

Epithelial regeneration that proceeds in a cyclic manner, as in the monthly changes that take place in the endometrium of the uterus during the reproductive period of women, is termed physiological or cyclic regeneration. During the first 4–5 days of a menstrual cycle, a large part of the endometrium is rejected (menstrual hemorrhage) if no blastocyst has implanted. An approximately 1-mm-thick basal layer or pars basalis (Fig. D, asterisk) and bases of the uterine glands (Fig. D1) are all that persist in the uterus. Regeneration of the epithelial coating and subendothelial connective tissue of the endometrium takes place in the course of the next 9–10 days, proceeding from the epithelium of the glandular remnants. During this proliferative stage, there is a high degree of mitoses (Fig. D2) in the glandular epithelium and neighboring connective tissue (Fig. D3), which regenerates from the remnants of the interglandular tissue. The time from the 1st day of menstrual hemorrhage until complete regeneration of the desquamated endometrium is about 14 days.

Following a surface wound of the skin (Fig. E), the germinal layer of the wound periphery begins to cover the lesion, accompanied by a great deal of mitotic activity, leading to epithelial migration (Fig. F, arrows). The cells of the hair follicles (Fig. F1) and excretory ducts of sweat glands (Fig. F2) also take part in epidermal regeneration.

With larger wounds, the defect is filled with regenerated vascular connective tissue, called granulation tissue (Fig. G1), from subepidermal layers. Since the epidermis moves slowly over the granulation tissue from the wound periphery, a skin transplant is necessary to accelerate this process. In Fig. H, as an example, a patch of epidermis is shown being grafted (with underlying loose connective tissue of the stratum papillare) according to the method of Oller-Thiersch.

From the examples given, it is clear that surface epithelia and many glandular epithelia regenerate well under normal and pathological conditions. Highly differentiated glandular epithelia, however, regenerate significantly poorer than surface epithelia.

Magnifications: Fig. A, x 550; Figs. B, C, x 700; Fig. D, x 70; Figs. E–H, x 40

REFERENCES