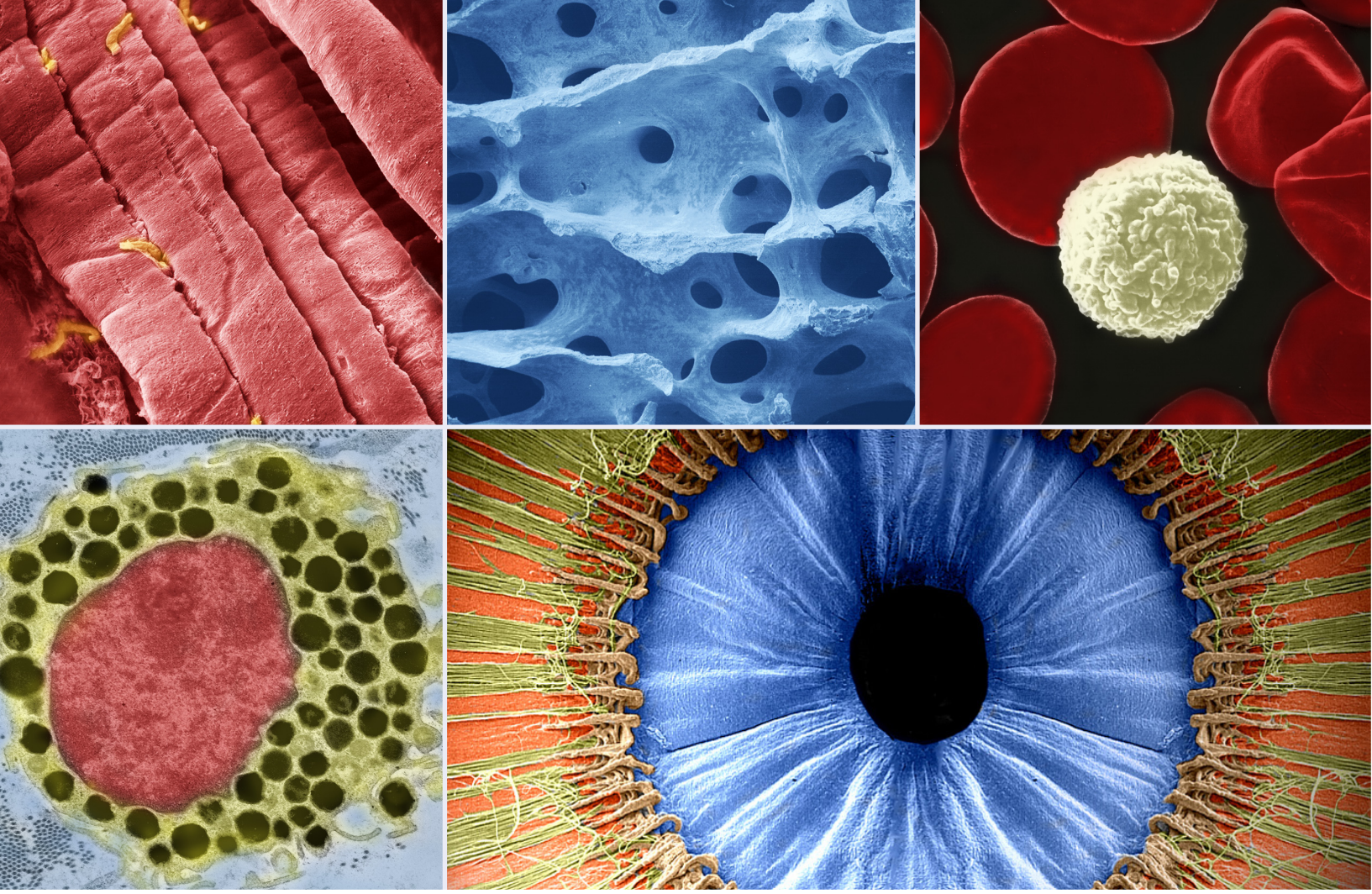

Ultrastructure Atlas of Human Tissues

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WILEY Blackwell

ULTRASTRUCTURE ATLAS OF HUMAN TISSUES

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This atlas is dedicated to my parents, Leroy E. and Mildred E. Hossler, who taught me to appreciate the beauty of living things and the value of fine, detailed images of them. Mildred was a well-known water color artist and school teacher in Hamburg, Berks County, Pennsylvania.

CONTENTS

PREFACE

Because of the complexity of the human body and because of the difficulty in obtaining useful samples of some tissues for electron microscopy, this atlas is not completely comprehensive. For example, only a few images of the human brain were obtained, and no images of the human pituitary gland, the pineal gland, and the inner ear are included. However, in regard to the inner ear, several images of the cochlea of the guinea pig, which show many similarities to that of the human, are included here. However, the atlas presents a variety of scanning and transmission electron microscope images of most of the major systems of the human body, and except for some images of the inner ear (guinea pig) and a few images of the liver (rat), the images in the atlas were prepared exclusively from human tissues. Many of the scanning electron microscopic images were also recorded as stereo pairs. These are included in the atlas with a folding viewer for 3D viewing. Thus the two unique features of this atlas are: (1) the images were prepared almost exclusively from human tissues; and (2) the atlas includes a number of viewable 3D image pairs. In most cases microscopic-sized human tissue samples were recovered from biopsies obtained for the purpose of disease diagnoses or from organ donor tissues. In no case were tissue samples obtained for the sole purpose of preparing images for this atlas. In every case, permission for tissue use was obtained from all donors, and this was properly monitored by the Institutional Review Board at the College of Medicine. Except for the sex and age of the tissue donor (when relevant), no information on the source of the tissues was recorded. All tissues were fixed in a sodium cacodylate buffered formaldehyde–glutaraldehyde mixture. For scanning electron microscopy all samples were critical point dried, and for transmission electron microcopy all samples were embedded in epon–araldite resin for thin sectioning.

"Photography with the electron microscope records views of the intricate substructures and micro-designs of objects and tissues, and reveals details within them inaccessible to the naked eye or light microscope. Many of these views have significance in our understanding of normal structure and function and of disease processes. Just as the size of objects increase by powers of ten as one compares our human realm with the earth, our solar system, the milky way, and beyond, it is natural to anticipate that the substructure of objects similarly diminishes by orders of magnitude in the opposite direction, each subunit being composed of its own subunits, and so forth. Evidence indicates that increasing our understanding of the structure and function of tissues at the subcellular and molecular levels improves our chances of finding cures for diseases."

Fred E. Hossler

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NOTE TO READERS

A unique feature of this atlas is that most of the chapters contain sets of 3D images that should be viewed with 3D glasses. Folding 3D glasses are available for purchase at SPI Supplies, Structure Probe, West Chester, PA, USA. The item number is 04001-AB and the 3D glasses are also available at the website: www.2SPI.com.

CHAPTER

I

CELLULAR ORGANELLES AND SURFACE SPECIALIZATIONS

A. NUCLEI AND NUCLEOLI

Cell nuclei vary somewhat with regard to size, shape, chromatin pattern, and number among the various types of human tissues, as is shown in the images in this section (Figs. I-1 to I-14). Probably the most common morphology consists of a round to oval shape, with a single eccentric nucleolus, and a mixture of inactive (heterochromatin) and active (euchromatin) DNA. The darker staining heterochromatin is scattered throughout the lighter staining euchromatin, but is often concentrated along the edge of the inner nuclear membrane. The ratio of heterochromatin to euchromatin is often altered with cell maturation and with changes in cellular synthetic activity. While most cells contain a single nucleus, liver cells and myocardial muscle cells often contain two nuclei, skeletal muscle cells are multinucleated (Figs. I-13 and I-14), and red blood cells (Fig. I-10) discard their nuclei at maturity. Nuclei may be indented (Fig. I-11), lobed (Figs. I-10 and I-12), or distorted in shape (Figs. I-8 and I-9) to match the outline of a cell. There is usually one nucleolus in each nucleus, and its size may increase with cellular synthetic activity. The nucleolus appears to be made up of a three-dimensional network of fibrils with which are associated lighter staining regions as well as heterochromatin-like material. DNA within the nucleolus codes for ribosomal RNA and the nucleolus functions in the synthesis and assembly of ribosomal subunits. Ribosomal proteins enter the nucleus and ribosomal subunits formed in the nucleolus leave the nucleus through complex, selective nuclear pores (Figs. I-61 and I-62) in the nuclear envelope.

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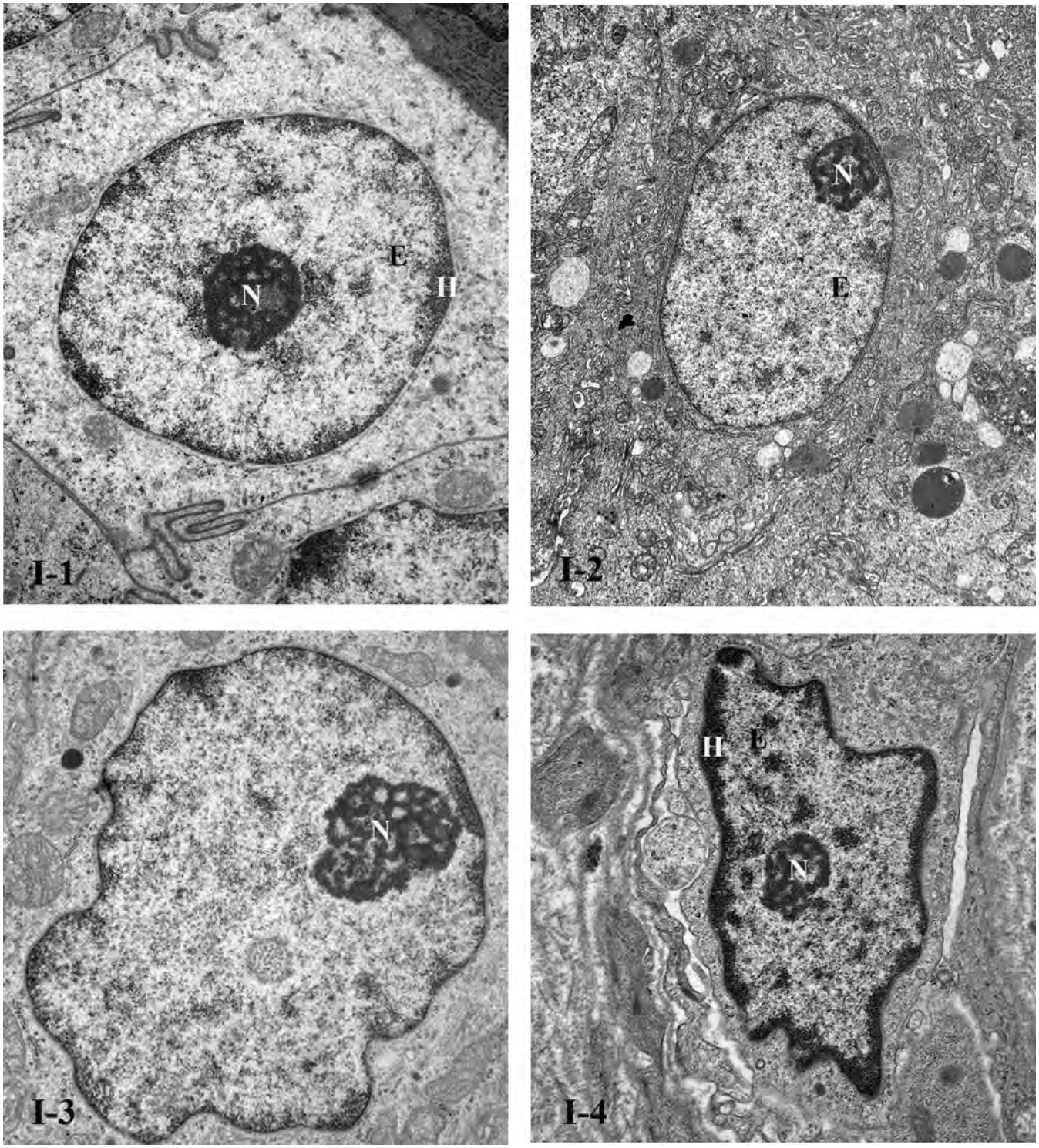
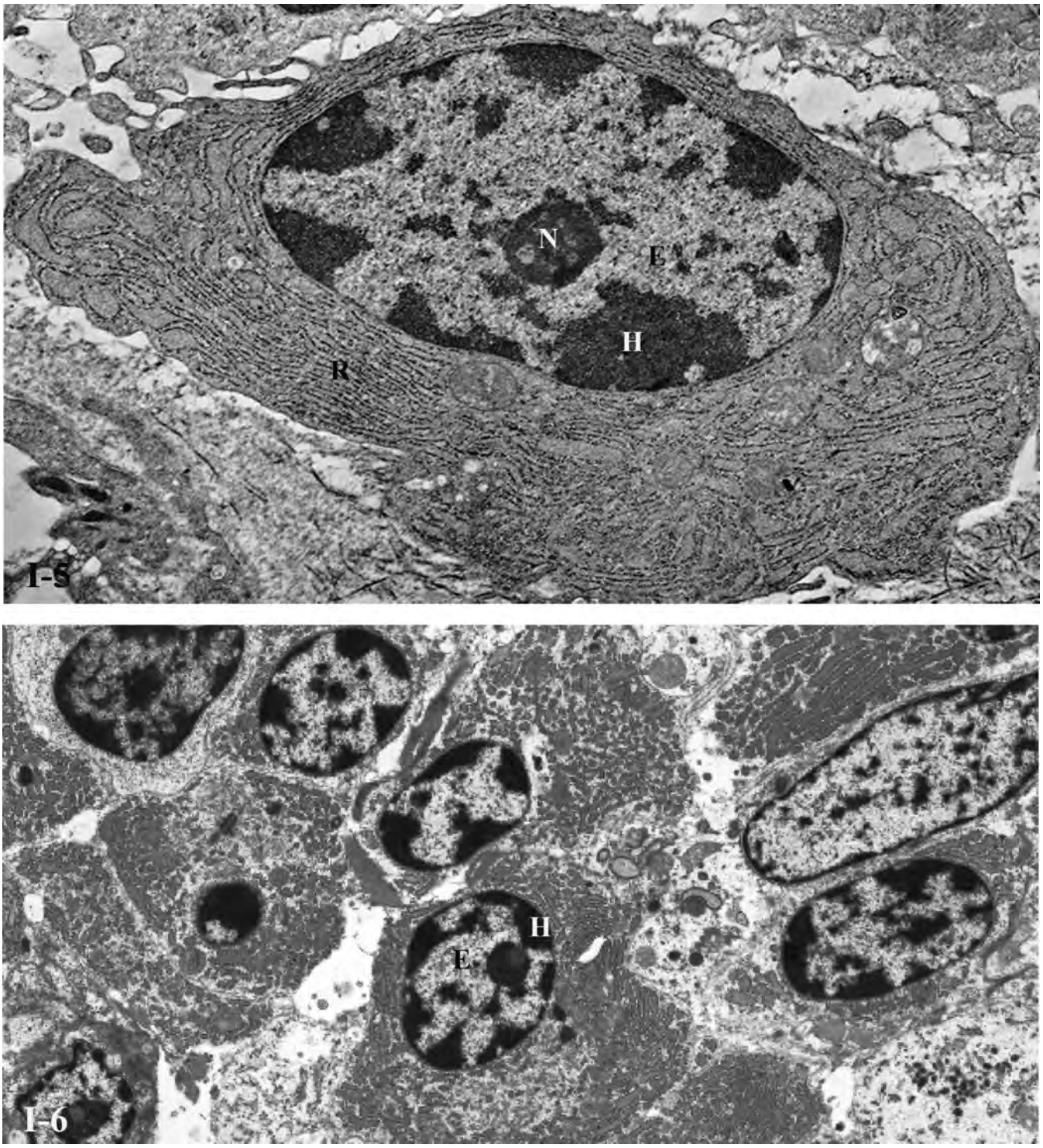
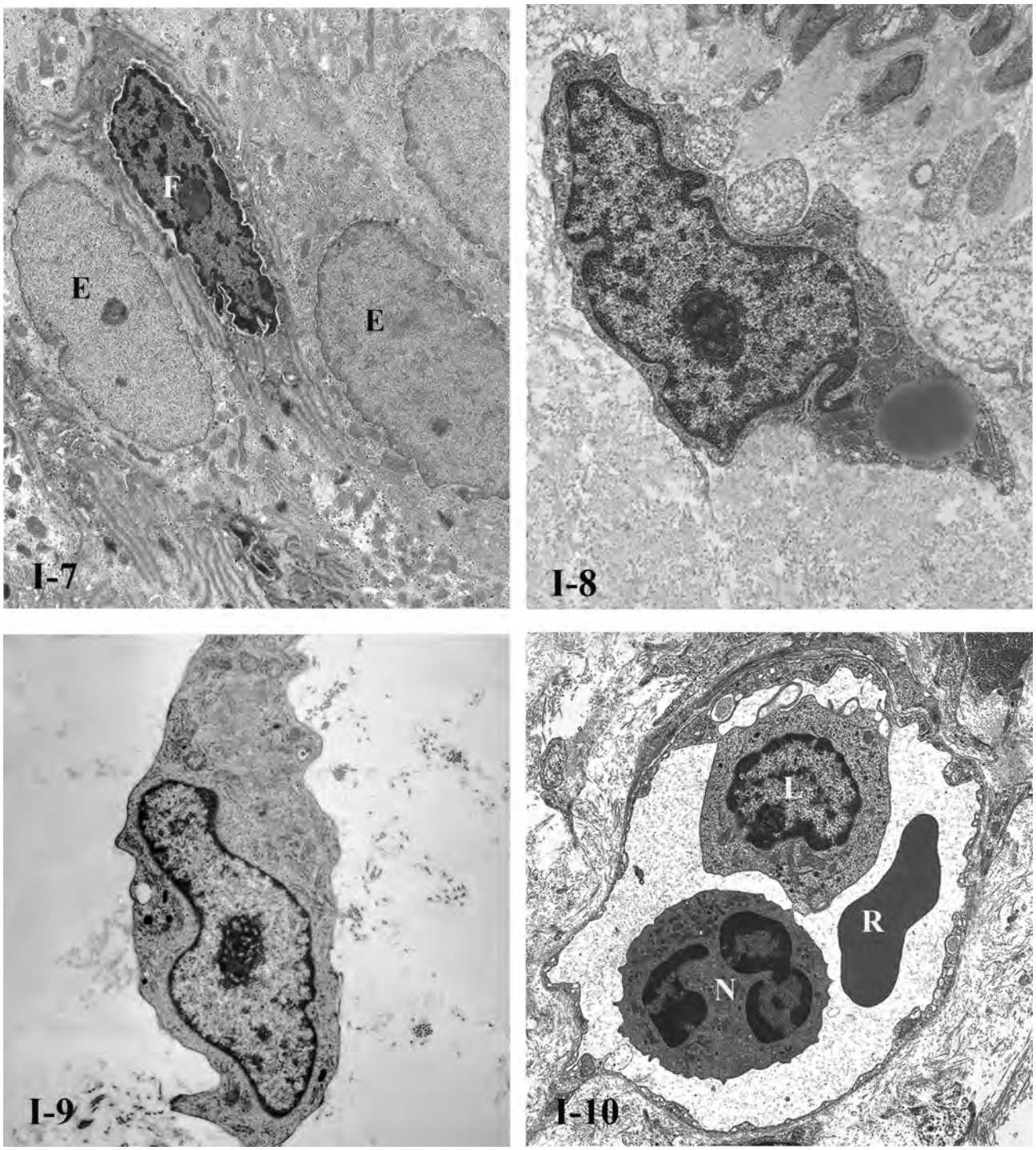


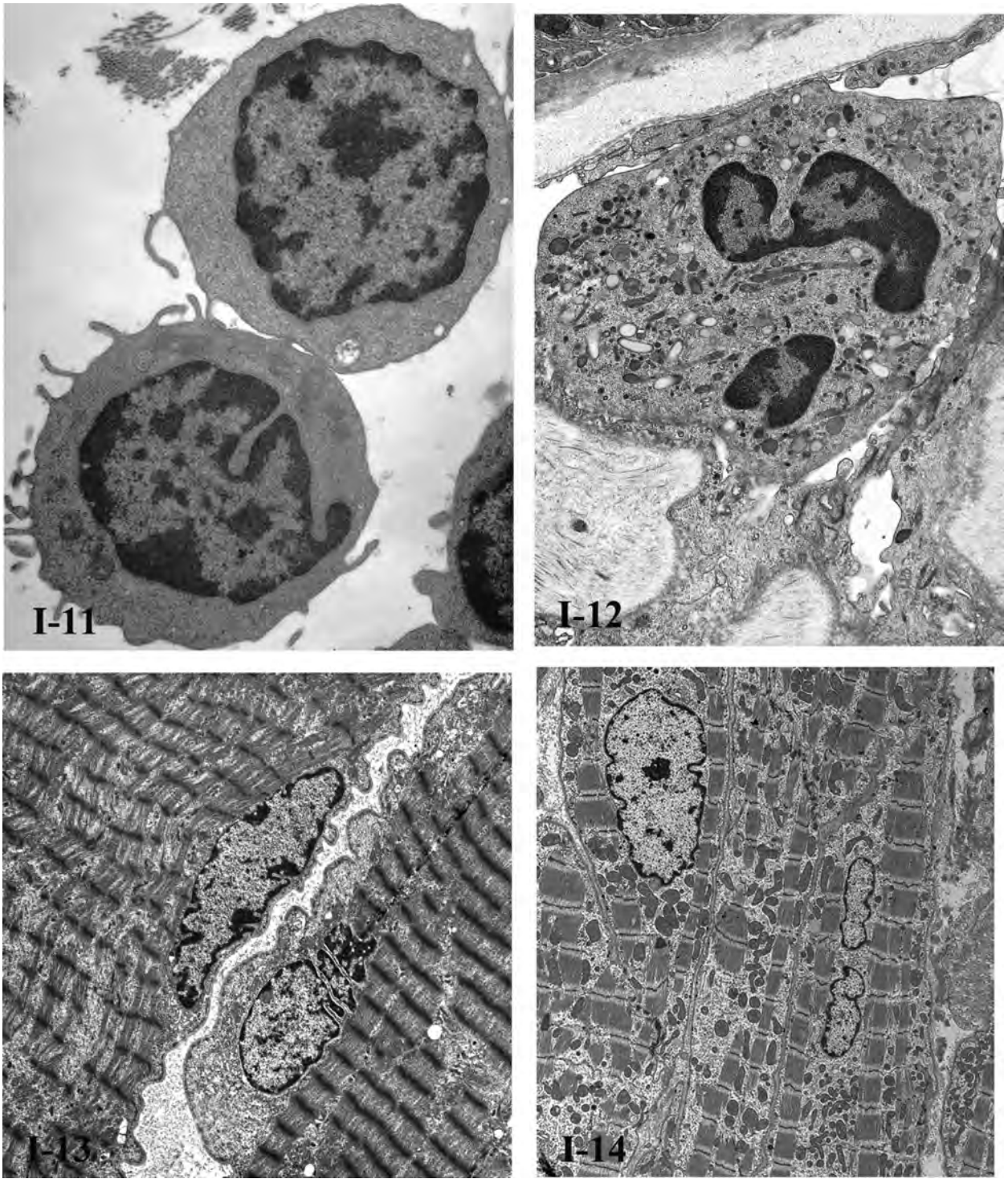
FIGURES I-1 and I-4. I-1 Nucleus of epithelial cell from human jejunum. ×14 167. I-2 Nucleus of cell from human gall bladder. ×8409. I-3 Nucleus (N) of human kidney tubule cell. ×25 000. I-4 Nucleus of fibroblast from human kidney. ×20 521. N, nucleolus; E, euchromatin; H, heterochromatin.



FIGURES I-5 and I-6. I-5 Plasma cell from human colon. Note "spoke wheel" pattern of nucleolus (N) and heterochromatin (H). ×15286. I-6 Plasma cell cluster from human jejunum. Again note peripheral heterochromatin pattern in nuclei. ×2250. E, euchromatin; R, rough endoplasmic reticulum; H, heterochromatin.



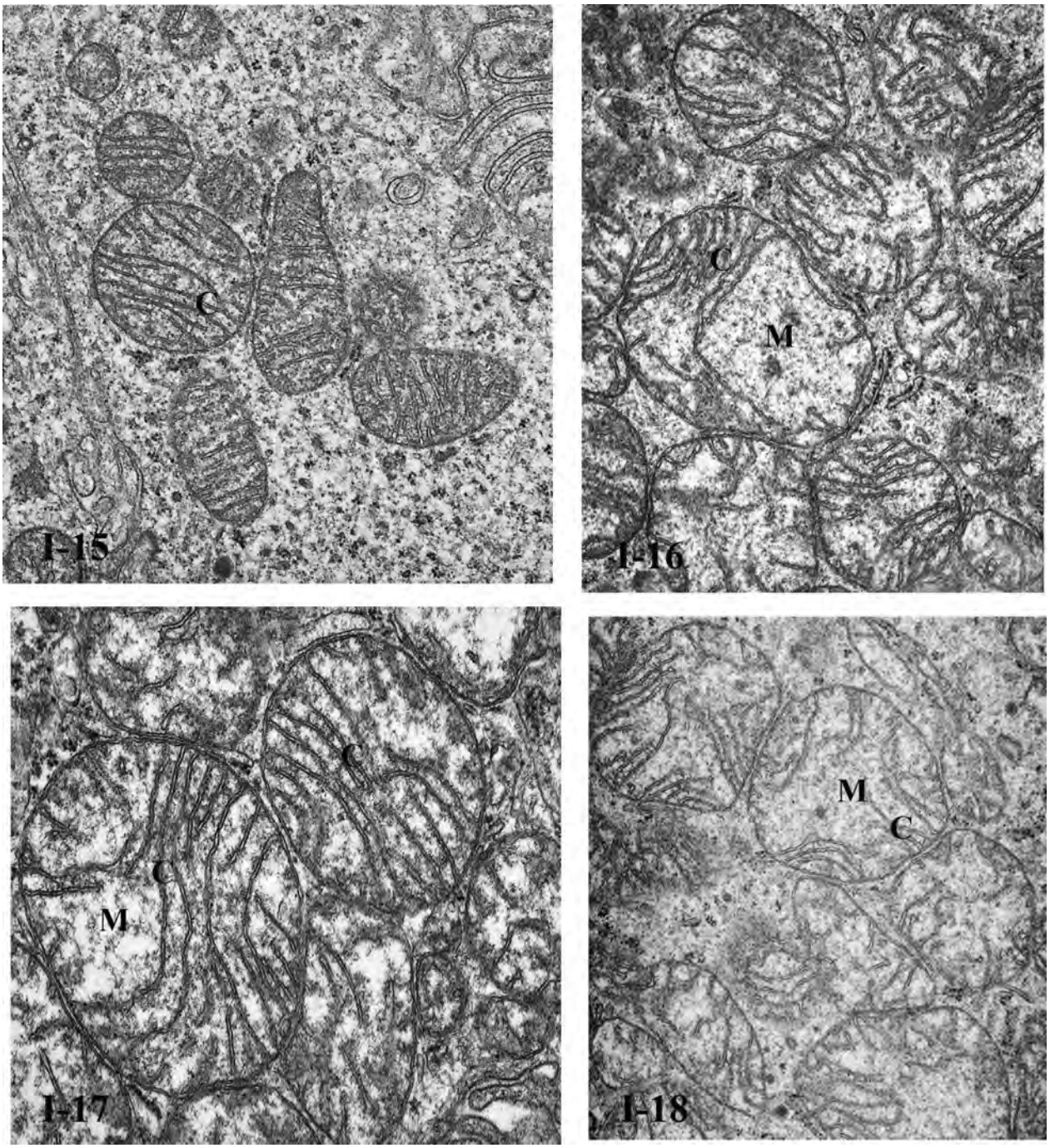
Figures I-7 and I-10. I-7 Comparison of nuclei of fibroblast (F) and epithelial lining cells (E) from human colon. I-8 and I-9 Human fibroblasts demonstrating irregular nuclear shapes influenced by cell shapes. ×23 000 and ×21 585. I-10 Cells within a capillary in the wall of the human ureter demonstrate variations in nuclei. The lymphocyte (L) has a somewhat rounded and condensed nucleus, the neutrophil (N), exhibits a highly condensed, multilobed nucleus, while the red blood cell (R) has given up its nucleus. ×15 400.



FIGURES I-11 and I-14. I-11 Human lymphocytes showing rounded, somewhat indented, and condensed nuclei. ×34 367. I-12 Human neutrophil with extensive nuclear lobation. ×7600. I-13 Human skeletal muscle from the tibialis anterior. Skeletal muscle cells are multinucleated. Seen here are two adjacent muscle cells, each showing a single nucleus along its periphery. ×5106. I-14 Cardiac myocytes from the human atrium. Cardiac myocytes may contain one or two nuclei. The cell at the right center may have two nuclei or, more likely, the tissue section may have been cut along the edge of a single nucleus. ×5000.

B. MITOCHONDRIA

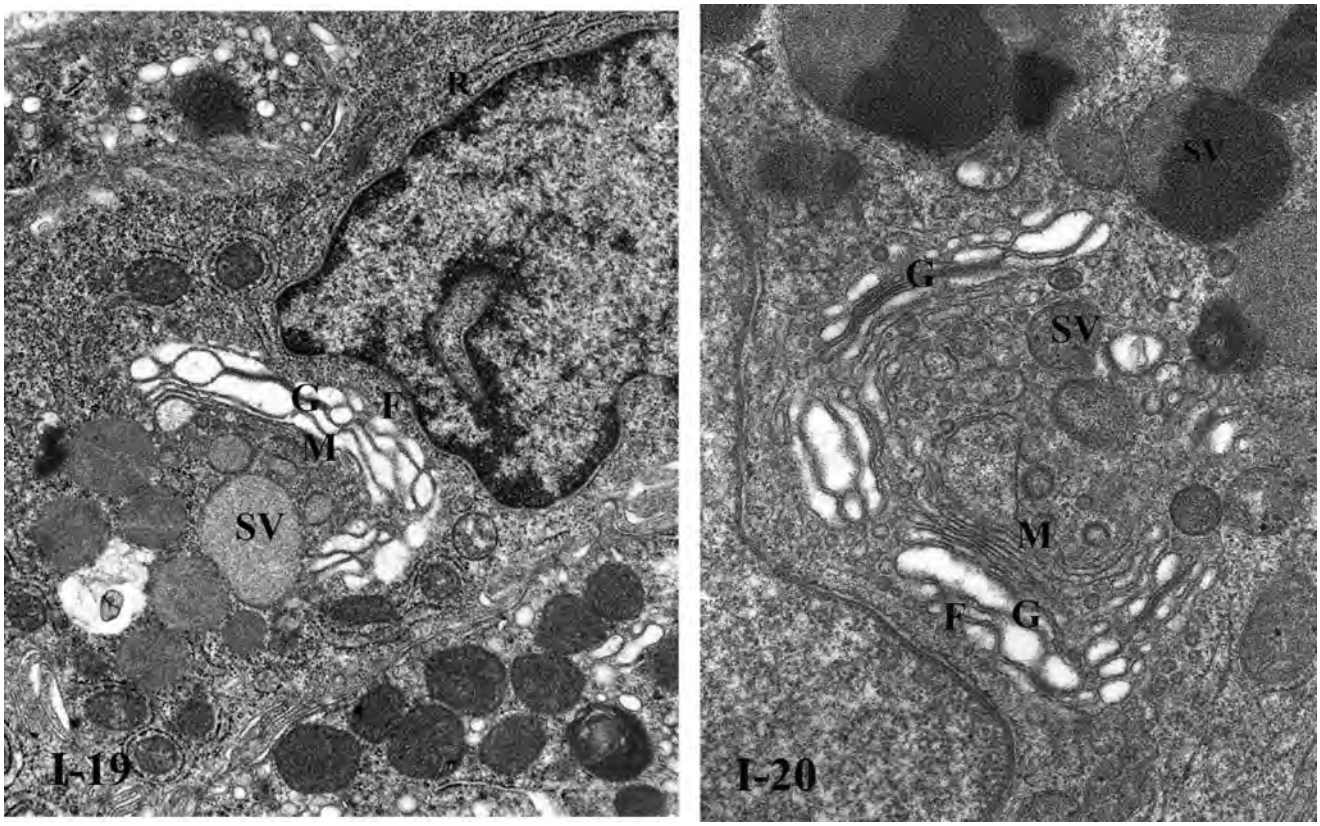
Like nuclei, mitochondria are bound by a double membrane. Folds in the inner membrane, called cristae, extend toward the interior, or matrix space, of the mitochondrion (Figs. I-15 to I-18). Mitochondria are self-replicating and their matrix space contains its own unique segment of DNA, and unique RNA species (evidence to support the belief that these organelles were originally derivatives of a symbiotic bacterium). The outer membrane contains pores that facilitate the free flow of small molecules. The inner membrane is essentially impermeable and is rich in proton pump enzymes (NADH dehydrogenase complex and cytochrome chain complex), and ATP synthase. Enzymes involved in the citric acid cycle as well as some enzymes involved in fatty acid oxidation are located within the matrix space. This functional relationship between the matrix and the inner membrane defines the primary function of the mitochondrion, ATP synthesis. Because of this basic function, most cells contain mitochondria, but this organelle is especially abundant in synthetically active cells and in cells involved in active transport.



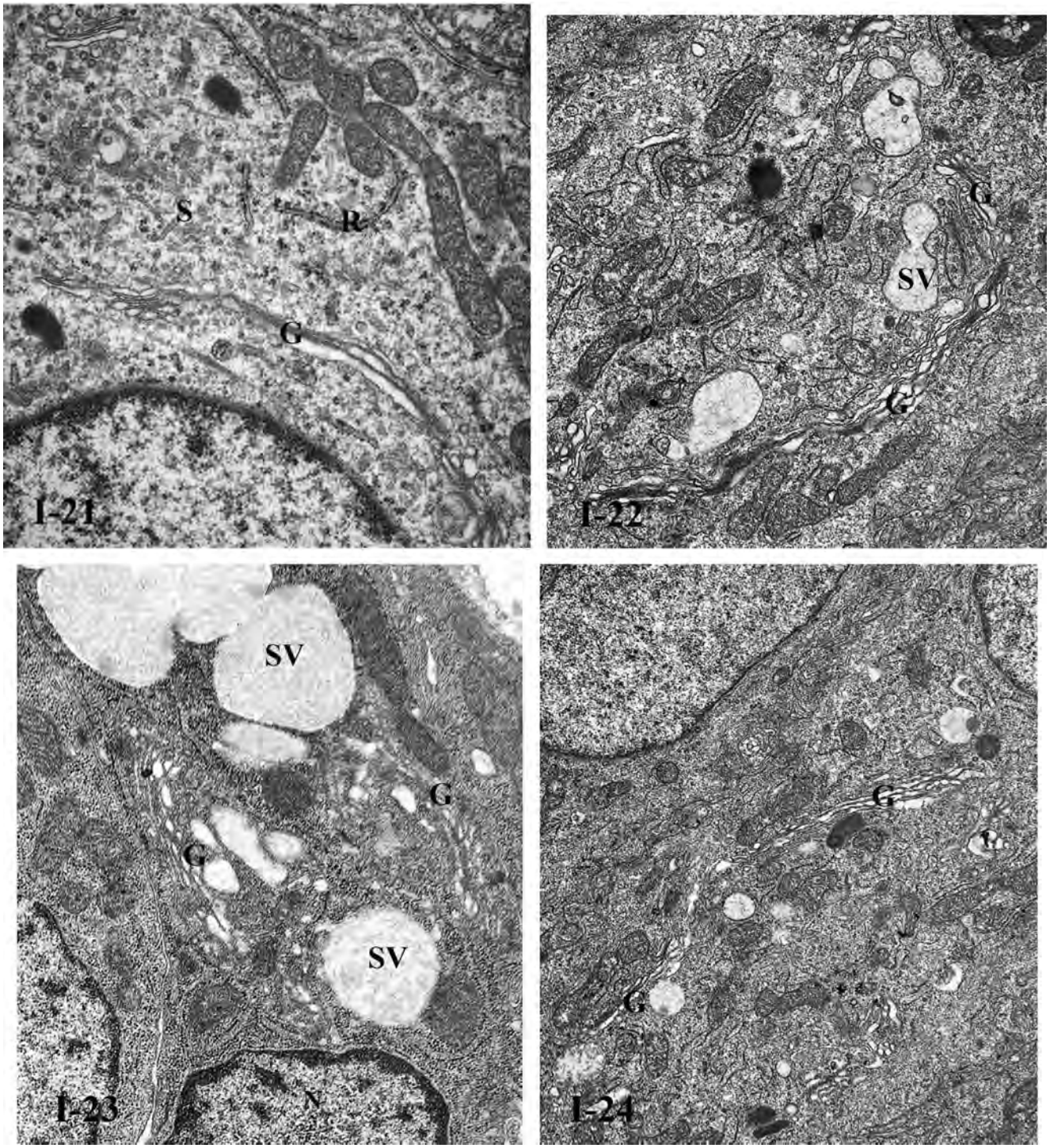
FIGURES I-15 to I-18. Clusters of mitochondria from distal tubule cells in the human kidney. M, matrix space; C, cristae. ×45 625, ×61 818, ×81 820, and ×53 500.

C. GOLGI COMPLEX

The Golgi complex consists of a stack of flattened membrane vesicles or cisternae (Figs. I-19 to I-24). The stack is usually concave on one side (the forming face or *cis*-face) and convex on the opposite side (maturing face or *trans*-face). The Golgi complex is an essential component in the process of cell secretion and in the movement of membrane vesicles between the cytoplasmic organelles and the cell surface. Most cells contain a Golgi complex, but Golgi complexes are especially well developed and abundant in cells involved in secretion and in lysosome synthesis. In secretory cells the forming face of the Golgi complex is closely associated with rough endoplasmic reticulum (RER) and the maturing face is associated with secretory vesicles. As the secretory proteins pass through the Golgi complex they are sorted, packaged, and chemically modified.



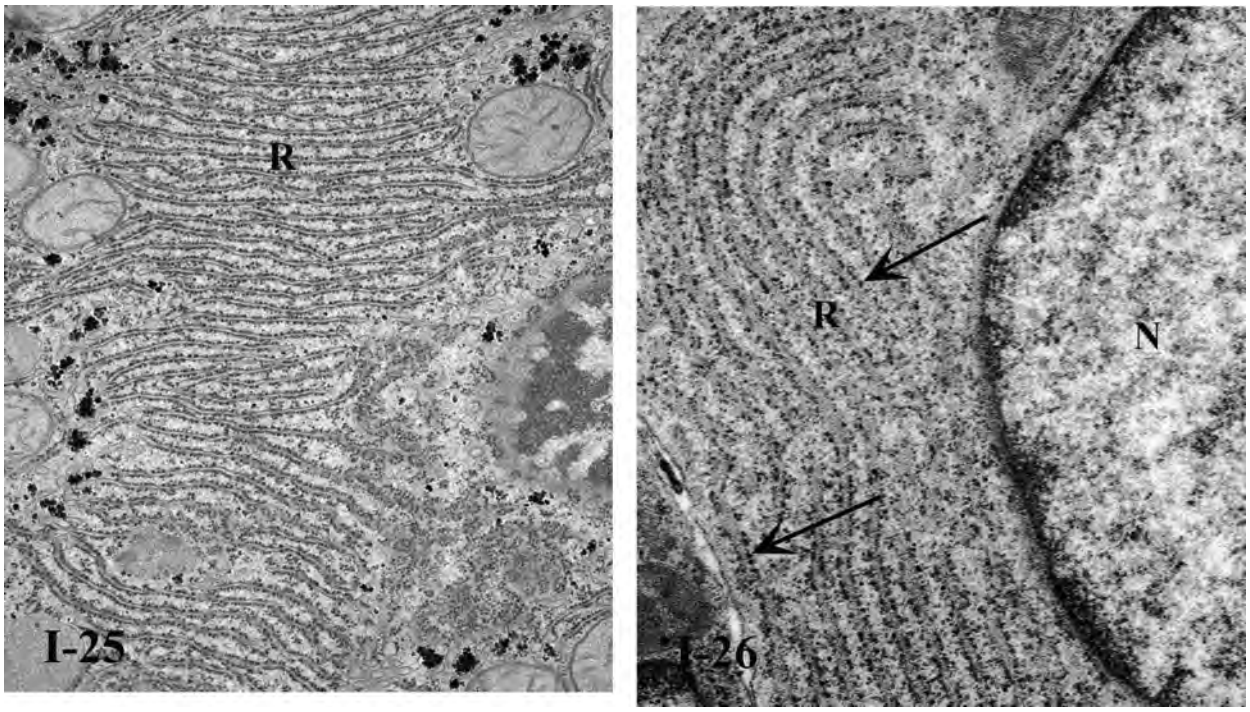
FIGURES I-19 to I-20. I-19 Golgi complex in chief cell of human fundus. ×15 000. I-20 Golgi complex in chief cell of human fundus. ×26 700. G, Golgi complex; F, forming face of Golgi; M, maturing face of Golgi; R, rough endoplasmic reticulum; SV, secretory vesicle.



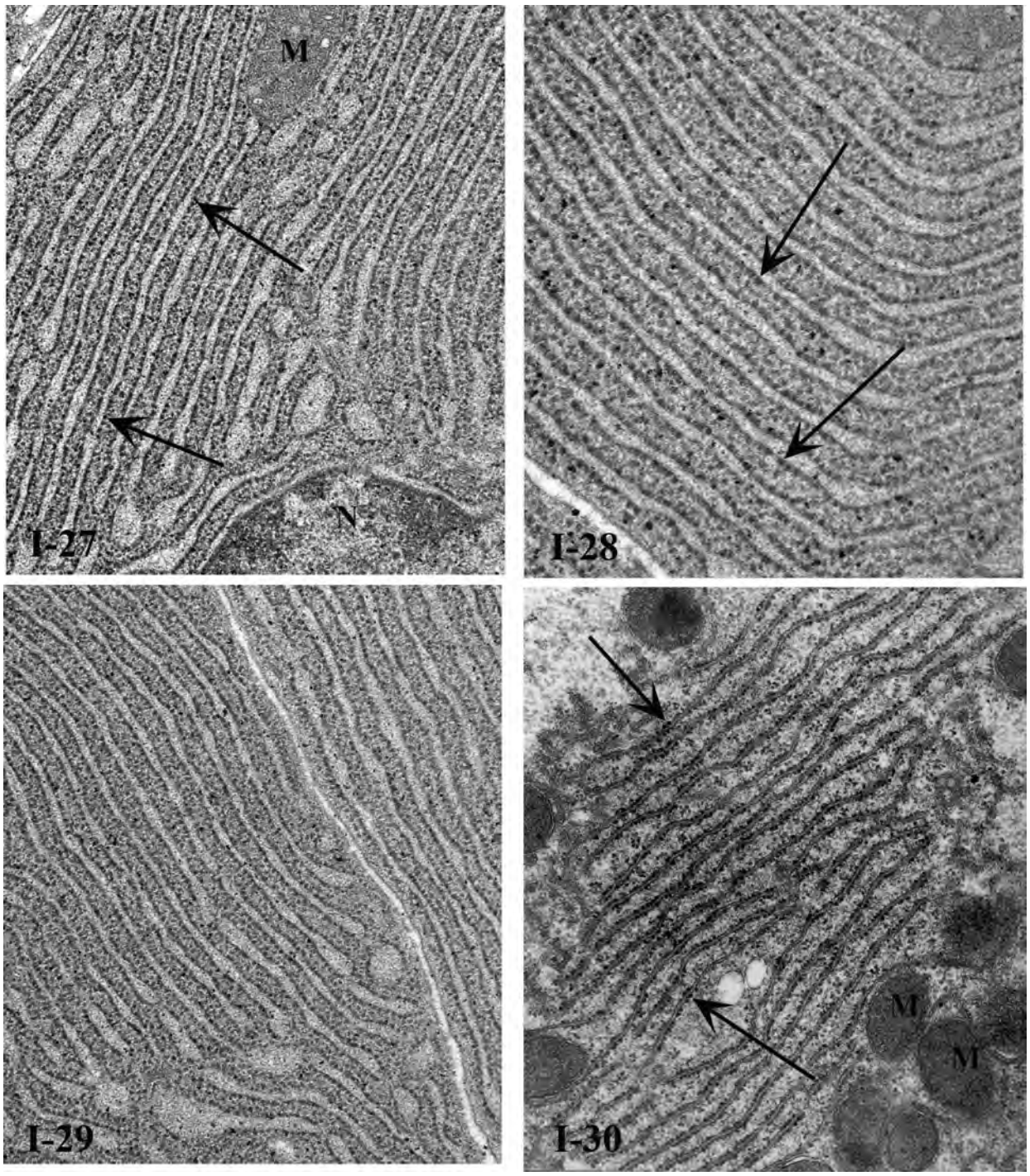
FIGURES I-21 to I-24. I-21 Golgi complex in distal tubule cell of human kidney. ×55 652. I-22 Golgi complex in epithelial cell in human gall bladder. ×7800. I-23 Epithelial cell in human colon. ×11 923. I-24 Epithelial cell in human gall bladder. ×13 000. G, Golgi complex; F, forming face of Golgi complex; M, maturing face of Golgi complex; SV, secretory vesicles; S, smooth endoplasmic reticulum; R, rough endoplasmic reticulum.

D. ROUGH ENDOPLASMIC RETICULUM AND SMOOTH ENDOPLASMIC RETICULUM

Free ribosomes become involved in protein synthesis when they attach to a messenger RNA and form polysomes. Polysomes within the cell cytoplasm (free polysomes) synthesize proteins for use within the cell. However, when the polysomes are attached to membrane complexes (endoplasmic reticulum) within the cytoplasm, they synthesize proteins for secretion, for incorporation into the cell membrane, or for lysosome formation. Polysomes attached to cytoplasmic membranes are referred to as RER (Figs. I-25 to I-30). When a cell is stimulated to increase its secretory activity, the amount of RER within a cell's cytoplasm can increase dramatically. One example of this is the conversion of a relatively dormant lymphocyte into a plasma cell which then synthesizes and secretes abundant amounts of antibody. Endoplasmic reticulum within the cytoplasm that does not have attached ribosomes is smooth endoplasmic reticulum (SER) (Fig. I-21). SER is less abundant in most cells than RER, but because it is involved in lipid synthesis, steroid synthesis, and drug detoxification, SER is found in liver cells and in endocrine glands. A special form of SER is found in striated muscle cells where it forms complex networks around muscle fibrils and actively sequesters calcium between contractions.



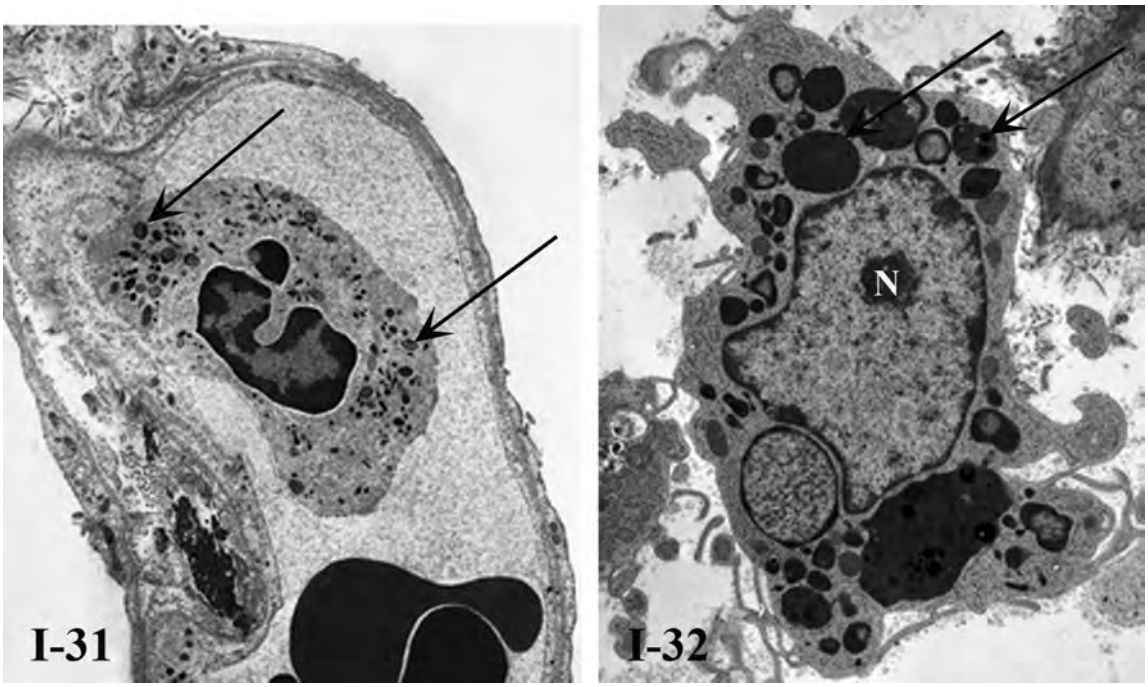
FIGURES I-25 to I-26. I-25 Human hepatocyte. I-26 Epithelial cell in human ileum. N, nucleus; R, rough endoplasmic reticulum; arrows, ribosomes.



FIGURES I-27 to I-30. I-27 to I-29 Rough endoplasmic reticulum in human pancreatic islet cells. ×40 000, ×50 000, and ×40 000. I-30 Rough endoplasmic reticulum in a human hepatocyte. ×24 000. N, nucleus; M, mitochondria; arrows, ribosomes.

E. LYSOSOMES

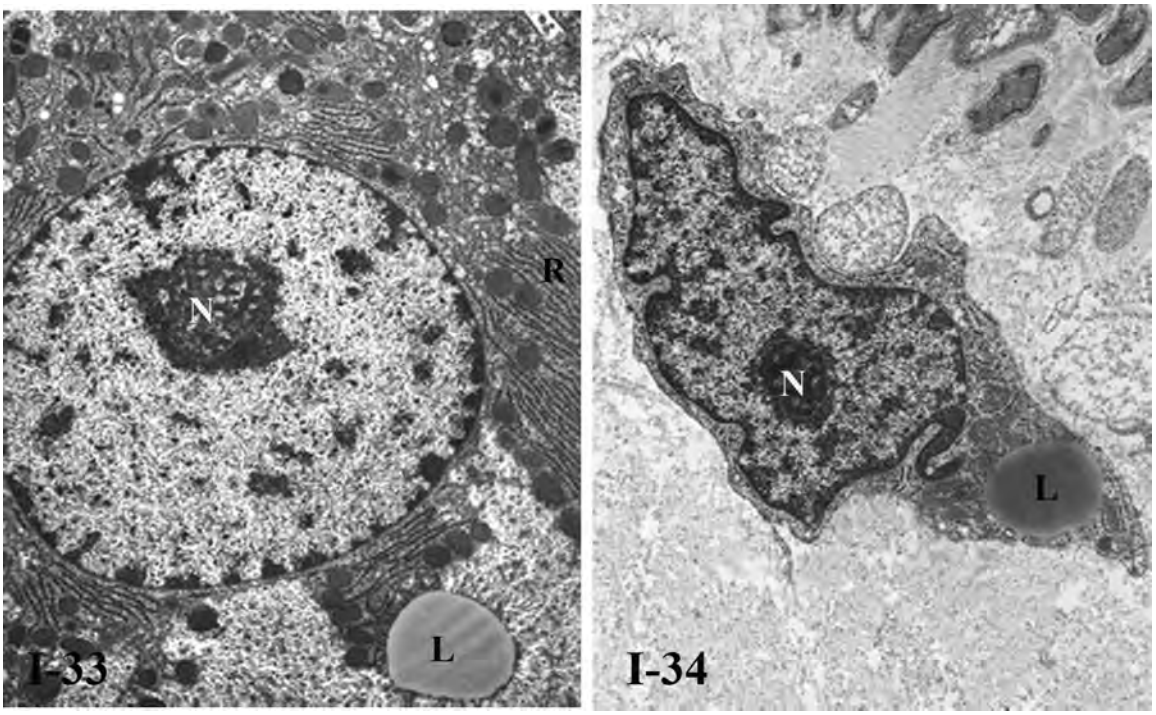
Lysosomes are cytoplasmic membrane-bound vesicles that contain a variety of digestive enzymes, including proteases, lipases, glycosidases, phosphatases, nucleases, and sulfatases (Figs. I-31 and I-32). Proteins destined for lysosomes contain a phosphorylated mannose residue that tags them for delivery into a lysosomal vesicle as they are passed through the Golgi complex. The marker enzyme for lysosomes is acid phosphatase, and most of the enzymes in lysosomes exhibit optimal activity at an acid pH. These organelles are most abundant in neutrophils and macrophages where they are involved in intracellular digestion of phagocytized material such as bacteria or cellular debris. A few specialized cell types release lysosomal granules for extracellular digestive processes. An example of the latter is the osteoclast that is involved in bone remodeling.



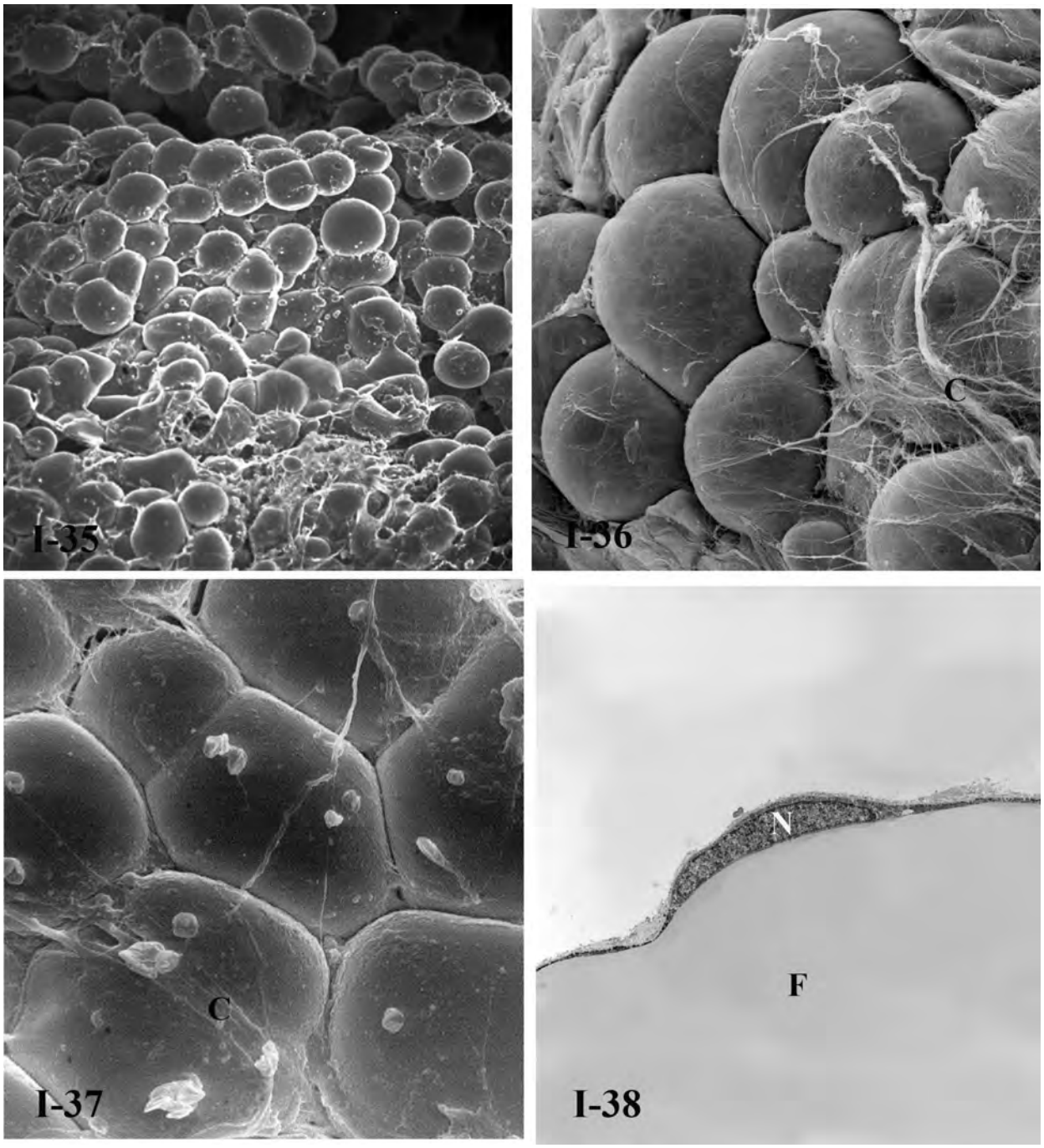
FIGURES I-31 to I-32. I-31 Neutrophil within a capillary in the human lung. ×18 139. I-32 Active macrophage in the lamina propria of the human ileum displaying unusually large lysosomes. ×18 750. N, nucleus; arrows, lysosomes.

F. CYTOPLASMIC INCLUSIONS

In addition to organelles, some cells include inclusions in their cytoplasm (Figs. I-33 to I-42). Some inclusions function as energy stores while others serve specialized functions. Probably the most readily observed form of energy storage function is evident as lipid storage in adipocytes (Figs. I-35 to I-38) and other cells (Figs. I-33 and I-34), and as glycogen storage in hepatocytes (Figs. I-39 and I-40). Another example of important cytoplasmic inclusions is the melanin pigment granules which the skin keratinocytes ingest as protection against potential ultraviolet radiation damage (Figs. I-41 and I-42).



FIGURES I-33 to I-34. I-33 Human hepatocyte. ×6923. I-34 Fibroblast in the lamina propria of the human colon. ×23 000. N, nucleolus; R, rough endoplasmic reticulum; L, lipid droplets.



Figures I-35 to I-38. I-35 Adipose tissue from human dermis. ×77. I-36 Fat cells from human dermis. ×500. I-37 Fat cells from human dermis. ×580. I-38 Cross section of edge of a fat cell from human dermis. ×2500. N, nucleus; F, fat deposit; C, collagen fibrils.