STRUCTURAL ORGANIZATION OF THE RETINA IN THE TREE SHREW (*TUPAIA GLIS*)

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ABSTRACT

This investigation was undertaken to establish the gross and ultrastructural organization of the photoreceptors and retina in the Malayan tree shrew (*Tupaia glis*). Photographs of the fundus revealed no specialization or differentiation of a central foveal region. Histologic sections revealed a single row of relatively short and thick cones distributed uniformly throughout the retina. Electron micrographs of the retina indicated that the receptor outer segments are closely invested by pigment-filled epithelial processes and an amorphous interstitial material. The internal fine structure of the receptor outer segments revealed the characteristic stacks or arrays of bimembranous discs. The ellipsoid portions of the cone inner segments include tightly packed and extraordinarily large mitochondria. These mitochondria consist of unique patterns of concentric cristae arranged in highly ordered whorls of lamellar configurations. The cone synaptic pedicles contain a unique system of tubules not previously described in synaptic endings. Histologic sections indicated that only cone populations are located in the central region of the retina, whereas histologic, histochemical, and ultrastructural comparisons suggested that photoreceptors with some "rodtype" features are located more peripherally. The relatively small proportion of these rodtype receptors among the great preponderance of cone populations is in general accord with the tree shrew's diurnal habits as well as its great reliance on photopic vision and its visually guided behavior.

INTRODUCTION

Visual responses to light are based on complex neurodynamic events occurring in the retina and in the visual pathways and centers of the brain. However, some of the most fundamental and initial processes involved in vision at the retinal level depend to a considerable extent upon the size, shape, density, and distribution of the rods and cones as well as upon the structural organization of these photoreceptors.

Although vision plays a much more prominent role in the primate order than in many lower mammals, most of the recently reported observations on the ultrastructural and functional organization of the retina have been made

predominantly on lower vertebrates (5). While it is commonly accepted that a more comprehensive understanding of vision in man can only be obtained from comparative observations on visual mechanisms of other primates, the evolutionary changes in the morphologic organization or specialization of the retina in relation to the development of high acuity and spectral sensitivity have remained relatively unexplored in most lower subhuman primates. Within the primate order, basic knowledge on the anatomic organization of the retina is particularly sparse and fragmentary for tree shrews, lemurs, and other lower primate species (9).

Originally, biologists included the Malayan tree shrew (*Tupaia glis*) with other shrews within the order insectivora. However, more recently it has been proposed that the tree shrews may represent a primitive or transitional form between insectivores and primates (21), that they may be classified as a separate order (13, 28), and that they may be included with the lowest primates (17). While the inclusion of the tree shrews into the primate order on the basis of morphologic similarities in orbital and basicranial regions has not been accepted by all primatologists (31), recent comparative investigations on vision have indicated that the tree shrew has a pure cone retina (22, 32) and shows great reliance on color vision (30). Although a more unanimous agreement concerning the taxonomic position of the tree shrews may be provided ultimately in terms of more specific genetic and biochemical criteria (2), comparative studies on vision have generally emphasized that color vision and high visual acuity in man and the higher diurnal primates are most closely associated with cones and the differentiation of a central region or fovea in the duplex

rod and cone retina. Since the diurnal habits of the Malayan tree shrew have suggested great reliance on photopic vision and visually guided behavior, the present investigation was undertaken to establish the structural organization of the retina in this species. Specific aims were as follows: (a) to examine the ophthalmologically observable patterns of pigmentation, topographic distribution of vascular elements, and differentiation of retinal light reflexes by fundus photography; (b) to establish the size, density, and distribution of the photoreceptors in relation to the pigment epithelium and the bipolar and ganglion layers of the retina by histologic procedures; (c) to identify specific metabolic and cytologic constituents within the retina by histochemical localization of reaction products associated with the presence of blood vessels and mitochondria; and (d) to examine the ultrastructural organization of the photoreceptor outer and inner segments in relation to the pigment epithelium in the central and peripheral regions of the retina by electron microscopy.

FIGURE 1 Photograph of fundus of an adult tree shrew eye showing a radial distribution of the central retinal blood vessels and nerve fibers. There is no noticeable demarcation of a macular region in the temporal quadrant of the eye. This undifferentiated fundusoscopic appearance is in sharp contrast to the typical demarcation of a macula and fovea observable in the temporal region of the duplex rod and cone retina of man and most of the higher diurnal primates.

MATERIALS AND METHODS

The animals for this investigation were five adult Malayan tree shrews (*Tupaia glis*). Two of the animals were lightly anesthetized with intravenous injections of 5-allyl-5-(1-methylbutyl)-2-thiobarbiturate (Suri-tol (Parke Davis & Co., Detroit, Michigan), 6 mg/kg body weight) and subjected to ophthalmologic examination and fundus photography of the central region of the eye with a Zeiss Fundus Camera. The remaining three animals were sacrificed and the eyes were removed and processed for examination of the retina by histologic, histochemical, and electron microscope methods.

Histology

For the histologic examination, whole eyes were fixed briefly either in Zenker's solution, or in a 1:1:8 mixture of formalin, acetic acid, and methyl alcohol (7). Within a few hours after initial fixation, the eyes were cut along the equator and the posterior half of each eye was again immersed in fixative for an additional 24 hr. After fixation, the retinal tissue was further dissected into smaller pieces containing the optic disc as well as segments from central and peripheral portions of the eye. These sections were then processed for embedding in paraffin. Sections cut at 8 μ were stained with hematoxylin and eosin. Small pieces of the retina were also processed for staining of mitochondria by Altmann's method (12).

Histochemistry

For the histochemical studies, small segments of fresh retinal tissue were fixed for 12 hr in cold 10% calcium-formalin and cut at 30 μ with a freezing microtome. Both central and peripheral sections of the retina were used for the histochemical localization of NAD and NADH₂ (the oxidized and reduced forms of nicotinamide adenine dinucleotide) diaphorase, succinic dehydrogenase, cytochrome oxidase (1), and alkaline phosphatase activity (3).

Electron Microscopy

The electron microscope observations were made on selected segments of retinal tissue fixed for 12 hr in 4% glutaraldehyde buffered to pH 7.2 with cold (4°C) 0.2 M cacodylate buffer. After fixation, tissues from the central and peripheral portions of each eye were trimmed under a dissecting microscope into smaller pieces (1 to 2 mm) which were then further fixed in cold 1% osmium tetroxide in 0.2 M cacodylate buffer for 2 hr. After dehydration in solutions of cold ethyl alcohol, tissue segments were embedded in Maraglas (27). Ultrathin sections (400 to 800 Å) were obtained with an LKB ultratome, mounted on carbonized grids, stained with lead tartrate (14), and examined with a Siemens Elmiskop I at 60 kv.

For appropriate orientation of photoreceptors in relation to other retinal layers, unstained sections cut at 1 μ were examined with phase-contrast microscopy.

RESULTS

Fundus Photography

Fig. 1 illustrates the ophthalmologically observable fundusoscopic organization of the tree shrew retina. The central retinal artery and vein are prominent features of the optic disc. Branches of these vessels radiate uniformly over the surface of the retina. This figure also shows bundles of optic nerve fibers represented by fine white lines radiating out from the elliptic optic papilla. There is no noticeable demarcation of a macular region in the temporal quadrant of the eye. This undifferentiated fundusoscopic appearance is in sharp contrast to the typical demarcation of a macula and fovea observable ophthalmologically by light reflexes in the temporal region of the duplex rod and cone retina of man and most of the higher diurnal primates.

Histology

The gross morphologic organization of the tree shrew retina can be seen in Figs. 2 and 3. The pigment epithelium consists of a single row of cells with numerous pigment granules located within their protoplasmic processes. A single layer of short and thick cones can also be observed in close apposition to the pigmented epithelial cell processes. This single layer of cones extends uniformly across the central and peripheral regions of the eye. Large spherical structures can be resolved, by light microscopy, within the inner segments of the visual cells (Fig. 3). In the central region of the eye, the inner nuclear layer of the retina consists of 5 to 8 rows of closely packed nuclei. This bipolar layer gradually diminishes in thickness to 2 or 3 rows in the periphery of the eye. The cells of the ganglion layer also extend in 2 rows across the retina without the characteristic thinning observable in the foveal depression of the duplex rod and cone retina of man and the higher diurnal primates.

Histochemistry

The distribution of retinal blood vessels in the central retina is illustrated in Fig. 4. The blood vessels can be visualized histochemically by their high content of alkaline phosphatase. Some of the

vessels extend outwardly as far as the inner nuclear layer and form two connecting systems of "arcades" above and below the nuclei of the bipolar cells. A fairly uniform arrangement of blood vessels can also be observed across the inner plexiform and nerve fiber layers of the retina. No differences in the distribution of these blood vessels were apparent between the central and peripheral areas of the retina. The intense reactions obtained after staining for succinic dehydrogenase (Fig. 5), NAD and NADH₂ diaphorase, and cytochrome oxidase suggest high metabolic activity in the inner segments of the cones. With these histochemical methods, the distribution of reduced tetrazolium is supposedly intramitochondrial (19). The identification of mitochondria at the reactive sites was also confirmed, in the present study, by the localization of large spherical inclusions within the inner segments by a cytologic staining procedure (Fig. 6). An interesting observation on the photoreceptor cells in the peripheral portions of the retina was a mitochondrial distribution extending to the outer plexiform layer (arrows in Fig. 6). Various other

differences in the morphologic features of these visual cells in the peripheral retina suggest the possibility of rods in the so called pure cone retina of *Tupaia glis*. A more detailed examination of the submicroscopic organization of these receptor cells, by electron microscopy, in adjacent thin sections confirmed the tentative identification of several photoreceptors with some rodlike morphologic features (Figs. 7, 14, and 15).

Electron Microscopy

Figure 8 is a survey electron micrograph which shows a longitudinal section of the retina containing a cone photoreceptor in close relation to the pigment epithelium. The subsequent micrographs illustrate, in greater detail, portions of pigment epithelial cells, receptor outer and inner segments, connecting cilia, as well as some terminal pedicles and synaptic contacts.

PIGMENT EPITHELIAL CELLS: The pigment epithelial cells contain numerous mitochondria with prominent dense granules (~300 Å) and great masses of tightly packed cisternae of smooth endoplasmic reticulum (Fig. 9). The

FIGURES 2 and 3 Vertical histologic sections of the tree shrew retina. Fig. 2 illustrates the relation between the cone photoreceptors and the pigment epithelium (above) and the bipolar cells (below). Fig. 3 shows that aggregates of mitochondria in the receptor inner segments (arrows), an outer limiting membrane, and large elongated visual cell nuclei are the more prominent features. Stained with hematoxylin and eosin. Fig. 2, $\times 440$; Fig. 3, $\times 1200$.

FIGURE 4 Vertical section showing alkaline phosphatase activity in retinal blood vessels located in the central region. Blood vessels from the inner part of the retina are shown extending laterally between the layer of nerve fibers (*Nf*) and ganglion cells (*G*), in the inner plexiform layer (*Ip*), and by two main routes above and below the nuclei of the inner nuclear layer (*In*). Other layers indicated are the outer plexiform (*Op*), photoreceptor (*Pr*), pigmented epithelium (*P*), choroid (*C*), and sclera (*S*). $\times 150$.

FIGURE 5 Frozen-cut section of the retina. Localization of mitochondrial-linked succinic dehydrogenase occurs mainly in the ellipsoid portion of the photoreceptor inner segments (arrows). $\times 900$.

FIGURE 6 Section of peripheral retina stained for mitochondria by Altmann's procedure. Most of the photoreceptors contain a few large mitochondria in the ellipsoid part of the inner segment, but some of them contain numerous small mitochondria distributed throughout the inner segment (arrows). These two different patterns of mitochondrial distribution in the visual cells of the tree shrew may differentiate cones and rods, respectively. $\times 1200$.

FIGURE 7 Photoreceptors of the peripheral retina in relation to pigment epithelium. Numerous cones and possibly a rod (arrow) are identified by phase-contrast microscopy. Electron micrographs of this rodlike visual cell are also shown in Figs. 14 and 15. $\times 1200$.

FIGURE 8 Survey electron micrograph of a section of retina illustrating the relationship between a cone photoreceptor and adjacent pigment epithelium. The inset is a magnified portion of a cone showing apparent contact between several saccules and the cell membrane (arrows). Bruch's membrane, *B*; nucleus, *N*; mitochondria, *M*; pigment granules, *P*; receptor, outer segment *Os*; receptor, inner segment *Is*; and interstitial material, circles. Fig. 8, $\times 10,000$. inset, $\times 60,000$.

FIGURE 9 Micrograph of two adjacent pigment epithelial cells showing lateral apposition (arrows). The smooth basal surface rests upon Bruch's membrane (B). The cytoplasm contains mitochondria (M), smooth endoplasmic reticulum (SER), some scattered granular reticulum (double-shafted arrows), and many pigment granules. The cone outer segment (Os) is surrounded by an amorphous interstitial material (circles) and pigment-containing epithelial cell processes. $\times 20,000$.

basal cytoplasm of these epithelial cells underlies Bruch's membrane without the extensive cytoplasmic invaginations characteristic of this region in the adult duplex retina of man and the higher primates. Large spherical melanin pigment granules can be seen in the apical portions of each cell. Scattered elements of granular endoplasmic reticulum can also be observed distributed within the apical portions of the cells. An amorphous interstitial material and numerous epithelial cell processes or fringes filled with elongated pigment granules envelop each cone outer segment. It should be noted that in previously reported studies a good preservation of the interstitial material was obtained only by freeze-substitution (23).

RECEPTOR OUTER SEGMENTS: The relatively short and thick cone outer segments measure approximately $10\ \mu$ in length and $4\ \mu$ in diameter in the retina of the tree shrew. The internal structure of the receptor outer segments consists of the characteristic discontinuous stacks of flattened bimembranous discs or saccules. Although separated by uniform intradisc spaces, some of the saccules may be continuous with the cell membrane as illustrated in the inset of Fig. 8. A more detailed examination suggested that spatial continuity between the bimembranous discs or saccules and the cell membrane may occur along various portions of the outer segment. However, these inferences are tentative since various structural irregularities in the discs and some of the large vesicles at the base and occasionally along the edge of some receptor outer segments may also indicate a variety of processing artifacts (11, 16). Consequently, the fine structural interrelationships of the saccular membranes as well as the arrangements of their contact with the receptor outer cell membrane surrounding them may be subject to some distortion.

RECEPTOR INNER SEGMENTS: The ellipsoid portion of each cone inner segment is composed of a tightly packed mass of extraordinarily large mitochondria. Structurally, at least two main types of these mitochondria can be noted. Some are round and unusually large, frequently measuring 6 to $8\ \mu$ in diameter. These mitochondria contain unique patterns of concentric cristae arranged in highly ordered lamellar configurations merging in some areas with a more delicate retiform variety of cristae as illustrated in Fig. 10. The central rings of the concentric cristae in the whorls appear isolated. However, the outer

cristae of the lamellar configurations appear contiguous with those of adjacent units as well as with the delimiting mitochondrial membrane. In most cases both lamellar and retiform arrangements of the cristae are present in a single mitochondrion. Smaller and elongated mitochondria measuring approximately $1\ \mu$ in length can be seen in the inner region of the ellipsoid (Fig. 11). Such mitochondria contain a few well defined, longitudinally oriented cristae and occasional dense granules. Variations in the spacing and density of the membranes surrounding the mitochondria are not apparent, and the interstitial matrix has a dense and homogeneous appearance. Although fine structural criteria represent only one aspect of photoreceptor organization, it is interesting to speculate that there may be a significant correlation between mitochondrial size, complexity of cristae, and high metabolic activity (26).

CONNECTING CILIUM AND SYNAPTIC CONTACTS: Fig. 11 illustrates a more vitreal portion of the cone inner segment, between the ellipsoid and nucleus. In the tree shrew, this region is characterized by a moderate quantity of rough endoplasmic reticulum, the Golgi apparatus, and structures resembling lysosomes. The cone nuclei are large, elongated, and arranged in a radial orientation. Packed between the inner segments at a level slightly above the cone nuclei are the interdigitating scleral processes of the Müller cells forming the outer limiting membrane.

The synaptic pedicle of the cone is attached to the nuclear region of the photoreceptor by a long and thin connecting fiber which contains dispersed smooth endoplasmic reticulum and many synaptic vesicles distributed as far scleral as the nucleus. The inner surface of each pedicle is reflected irregularly over several synaptic contacts (Fig. 12). Each cone process contains a dense concentration of synaptic vesicles, with an average diameter of ~ 500 to $550\ \text{\AA}$, and some synaptic ribbons. This form of synaptic structure most closely resembles that of the so called β -type of retinal receptor (24, 25). An examination of numerous additional synaptic pedicles, based on micrographs obtained from the eyes of two different animals, did not reveal mitochondria, synaptic spindles (15), or flattened attachment plaques (20). The identity of the different types of receptor or bipolar cells making contact with the cone pedicle was not determined in the present investigation.

FIGURE 10 Vertical section showing an enlargement of the junction between the inner and outer segments of the cone illustrated in Fig. 8. In the ellipsoid, both giant circular and small elongated mitochondria are present and characterized by concentric whorls and/or longitudinal arrays of cristae, respectively. In some of the giant mitochondria, the cristae may be dispersed in delicate strands (arrows) but the organized concentric forms predominate. $\times 20,000$.

A curious finding in many synaptic pedicles of the cone photoreceptor is the system of tubules situated in close relationship to the synaptic membranes. Each pedicle contains at least one concentration of tubules. The average diameter of these tubules is the same as that of the synaptic vesicles (~ 500 Å) although the membrane thickness of the tubules appears to be slightly greater than that of the vesicles. Occasionally, a tubule complex is in close relation to a synaptic ribbon as shown in Fig. 13. Another feature of these tubules in the synaptic pedicle is their proximity to dendritic invaginations. These "synaptic tubules" apparently are not present or have not been identified in the retina of other animals. Variations in the spacing and density of the membranes surrounding the synaptic endings were not apparent in sections of the retina fixed immediately in glutaraldehyde after removal of the eye. However, it should be noted that alterations in the structure of the synapse of the retina may be seen as early as 3 min after oxygen and glucose deprivation, and some of the observed fine ultrastructural features may be subject to distortion by processing (33).

CLASSIFICATION OF PHOTORECEPTORS: Previously reported studies on possible morphologic differences between rods and cones in the primate duplex retina have suggested a variety of ultrastructural differences between the receptor outer and inner segments, connecting cilia, and synaptic contacts (10). At the ultrastructural level, it has also been suggested that the internal structure of the rod outer segments may be less susceptible to fixation and processing artifacts (11). The histologic, histochemical, and ultrastructural observations of the present study indicated that only cone populations are located in the central region of the retina, whereas a number of histologic histochemical, and ultrastructural criteria suggested that photoreceptors with some rodlike features are present more peripherally. The outer

segments of these rodtype receptors of the tree shrew are not only smaller in diameter (1.5μ as opposed to 4μ) than those of cone receptors but also do not extend as far in the direction of the pigment epithelium. The outer segments are, as in the cones, composed of membrane-limited stacks of discs (Fig. 14). Each bounding membrane is approximately 50 Å wide. The intradisc space in these receptors is also greater than in the cones (80 Å as opposed to 60 Å). While the interdisc space is smaller (120 Å as opposed to 190 Å), the repeating unit distance is 280 Å and 360 Å, respectively, for these receptors and for the cones. The bounding membranes of each disc in these so called "rods" are connected with each other peripherally, but do not appear to contact the surface membrane.

Differences in the length and width of the connecting elements between the outer and inner limbs of photopic and scotopic receptors have been established in some mammals (8). However, the mass of the cone inner segments and the lack of midsagittally sectioned receptors precluded the specific identification of ultrastructural differences between the connecting elements of the two types of photoreceptors in the retina of the tree shrew.

Some major differences were also observable in the inner segments between these two types of cells. The electron micrographs (Figs. 14 and 15) illustrate some ultrastructural features of the rodtype receptor inner segments previously also identified tentatively as possible rods by phase-contrast microscopy (Fig. 7). Both histologically and histochemically, the level of the nuclei of the rodtype receptors appeared considerably lower and the elongation of the nuclei was also characterized by a horizontal orientation (Fig. 16). A greater density was also evident in the cytoplasm of these rodtype cells and was observable by phase-contrast (Fig. 7) as well as by electron microscopy (Fig. 16).

At the ultrastructural level, only elongated

FIGURE 11 Vertical section of scleral part of a cone inner segment containing mitochondria (*M*), rough endoplasmic reticulum (*RER*), the Golgi complex (*G*), and a portion of a nucleus (*N*). Müller fibers (*Mf*) forming the external limiting membrane are shown in this plane of section. $\times 8000$.

FIGURE 12 Vertical section of inner part of a cone photoreceptor with a nucleus (*N*), long connecting fiber (outlined by arrows), and a complex synaptic pedicle containing many vesicles and several invaginated dendritic processes (circles). $\times 11,000$.

mitochondria appeared distributed evenly throughout these rodtype receptor inner segments (Fig. 15). The cytoplasm of these receptor inner segments contained both rough and smooth endoplasmic reticulum, concentrations of free ribosomes, various vesicular bodies, a Golgi complex, and some unit membrane-bounded structures resembling lysosomes. In addition, a few synaptic vesicles appeared scattered throughout these inner segments. Connecting elements and synaptic pedicles could not be identified in the electron micrographs, although their outline was indicated in the histologic sections (Fig. 6).

DISCUSSION

Whatever the taxonomic position of the tree shrews, major differences in visual acuity and color vision observable in the evolutionary sequence ranging from the tree shrews to the monkey, anthropoids, and man can be attributed to anatomical and functional differences in the retina as well as in the visual pathways and centers of the brain. A binocular minimum separable visual acuity of 1 min of arc has been established for the tree shrew (18). These behavioral findings suggest that the visual acuity of the tree shrew is comparable to that of the higher diurnal primates and man (34). In considering the anatomic basis for the high acuity in relation to the duplex rod and cone retina of the higher diurnal primates and man, it is known that the greatest concentration of cones occurs in the highly specialized central fovea (17). However, the photographs of the fundus of the eye of the tree shrew revealed no specialization or differentiation of a central foveal

region. The histologic and histochemical findings also revealed an all cone retina centrally, whereas both cones and possibly some rodtype receptors were observed more peripherally. Consequently, in view of the high visual acuity established for the tree shrew, the funduscopy, histologic, and histochemical findings of the present study strongly suggest that the entire retina of the tree shrew may function physiologically as a crude central area or "fovea." It is also of interest to note that other previously reported behavioral studies on four related subspecies of tree shrews have shown a more rapid visual learning and longer memory or retention when visual discrimination was based upon color rather than black and white patterns (29, 30). These behavioral findings suggest considerable reliance on photopic mechanisms and color vision in the tree shrew.

Numerous comparative observations with the electron microscope on photoreceptors in the retina of adult vertebrates have demonstrated that the outer segments of both rods and cones possess characteristic stacks of laminated saccules or flattened discs enclosed within a cell membrane and are in close association with the cell processes of the pigment epithelium. It has recently been shown that in the retina of monkeys and man most of the flattened saccules or discs in the rod outer segments are not connected with each other or the cell membrane, whereas some of the saccules in the basal part of the cone may be continuous with the cell membrane (4, 6). The observations with the electron microscope in the present study indicated comparable ultrastructure of the laminated discs in the receptor outer segments of the tree shrew.

FIGURE 13 Part of a cone synaptic pedicle. Elements of a system of tubular profiles are located in close relation to a synaptic ribbon (arrow) and an invaginated dendritic process (circle). The Golgi complex (G) and nucleus (N) of a bipolar cell are shown below. $\times 23,000$.

FIGURE 14 Micrograph of a peripheral region of the retina of the tree shrew illustrating an oblique section of the junction between the outer and inner segments of a photoreceptor with some rodlike features. The outer segment consists of a pile of membrane-limited discs. Some irregular discs above the junction may signify membrane damage. An adjacent section of this cell is illustrated in Fig. 7. $\times 22,000$.

FIGURE 15 Vertical section through the ellipsoid part of the same rodlike cell represented in Figs. 7 and 14. Note the electron-opaque cytoplasm containing elongated mitochondria, rough endoplasmic reticulum, the Golgi complex (G), and a unit membrane-bounded structure which may be a lysosome (arrow). Parts of two different cone nuclei are present laterally. $\times 22,000$.

FIGURE 16 Nuclear region of a "rod"-type photoreceptor. Note the differences in the arrangement of mitochondria, rough endoplasmic reticulum, and lysosomes (*L*) within an electron-opaque cytoplasm. The nucleus is elongated along a horizontal axis and contains nuclear pores (short arrows) and strands of nuclear material (long arrow). This cell is surrounded by portions of two cones (upper left and right) and Müller fiber (*Mf*) processes (below). $\times 22,000$.

Also, continuity between the membranous saccules and the cell membrane was more evident in cones than in the receptors identified tentatively as rods. Previous observations on the fine internal structure of foveal receptor outer segments in the rhesus monkey retina have indicated that the intradisc spaces in rods are generally greater than in the cones, whereas the interdisc spaces may be considerably smaller (10). The findings in this study indicate that these previously reported ultrastructural differences in the internal structure of the receptor outer segments can also be identified outside of a macular area in a much lower, more primitive, transitional primate species.

Of all the ultrastructural comparisons, one of the most novel and striking observations in this study involves the extraordinary arrangement of the whorls of cristae in the extremely large and unique mitochondria located in the cone inner segments. These mitochondria contain some unique patterns of concentric cristae arranged in highly ordered lamellar configurations. Although mitochondrial morphology in the receptor inner segments may represent only one aspect of photoreceptor specialization, it has been suggested previously that there may be a significant correlation between mitochondrial size, complexity of cristae, and high metabolic activity (26). The great preponderance of cones as well as the great reliance on photopic vision would support such an interpretation in the retina of the tree shrew.

In considering some of the characteristic dif-

ferences generally noted between rods and cones in the duplex primate retina in relation to photopic and scotopic vision, the observations of the present study on the tree shrew indicated that only cone populations are located in the central region of its retina, whereas a number of histologic, histochemical, and ultrastructural comparisons suggested that photoreceptors with some rodlike features are present in the periphery of its retina. In interpreting some of the possible evolutionary changes in the morphologic specialization of the primate retina, comparative studies on vision have usually emphasized that color vision and high visual acuity in man and the diurnal primates are most closely associated with cones and the differentiation of a central fovea in the duplex rod and cone retina. Although a number of rodlike features were observed in some of the photoreceptors in the Malayan tree shrew in this investigation, the relatively small proportion of such receptors among the great preponderance of cone populations throughout its retina is in general accord with this animal's diurnal habits as well as its great reliance on photopic vision and its visually guided behavior.

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