The Putative Evolution of the Animal Eukaryote Cell Ultrastructure

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Abstract

Research in the field of molecular biology and cell ultrastructure has revealed that a vastly greater level of complexity exists in the cell than was envisioned to exist in the entire human body before 1960. Cells are complex machines and, like all machines, their many parts (trillions in the case of cells) must all work in complete harmony yet not interfere with the function of other parts. The cell is not an amorphous bag of water, minerals, grains and food as once thought. Modern research has eloquently revealed it as the most complex machine in the universe. We now know that the eukaryote cell is vastly more complex than the gross anatomy of the entire human body. This review briefly summarizes the enormous complexity of the eukaryotic cell. Also discussed is the lack of evidence for the evolution of these organelles, revealing a "missing link" much larger and of far greater significance than all others. The gap between organelle containing cells, the eukaryotes, and those cells lacking them, the prokaryotes, is greater than any morphological gap between animal body types.

Introduction

All cells can be divided into two major types, *prokaryotes*, cells without organelles, and *eukaryotes*, cells with them. The organelles and other structures that form the complex machine called the cell are collectively called the cell *ultrastructure*. To study organelles, cell membranes can be broken so as to allow most of their organelles to remain intact, then separated by centrifuging the mixture for several hours in a sucrose solution density gradient. Cell ultrastructure research is so important in the origins of life question that has put the question of macroevolution on trial: " To Darwin ...as to every other scientist of the time, the cell was a black box" (Behe, 1996, p. 9). The cell is so complicated that Trefil asked, could not what the cell does:

> ...be done more simply? When you look at the complex structure of a cell, Rube Goldberg springs to mind. This leads to the question just posed. Is the complexity of the cell due to the long evolutionary history, or is this really the most efficient structure capable of doing what a cell does? As far as I know, biologists haven't even begun to address this question (1992, p. 104).

Actually research has addressed this question and has found the cell is over-designed and can achieve well beyond what evolution would predict. Naturalism must explain the origin of the cell, and so far the extensive century-long search for how cell organelles evolved has produced "an eerie and complete silence." (Behe, 1996, p. 5) A review of the many enormously complex cell structures that Darwinism must explain follows.

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Received 2 November 1996; Revised 30 July 1998

The Nucleus

The *nucleus* (Greek: kernel or nut) is the main control center of the cell and also its headquarters. The largest structure in the cell, the nucleus is located appropriately in the approximate physical center of the cell. Some cells are multinucleated: an osteoclast has as many as 15 to 20 nuclei. Many multinucleated cells are formed by the process of syncytium, the fusing of several cells, and other multinucleated cells form by nuclear proliferation. The DNA, the master blueprint that directs the building of the body, is safely stored in this membrane-bound structure. The nuclear membrane itself is a double envelope structure with many pores that extend through both the outer and inner membranes. The pores are not open continuities but are bridged in their centers by a controllable diaphragm that functions as a selective gate (Bozzola and Russell, 1992, p. 43) In between the two membranes is a narrow space called the *perinuclear cisterna* (pl. *cisterna*; singular *cisternae*, a *cistern* is a closed fluid filled sac or vesicle).

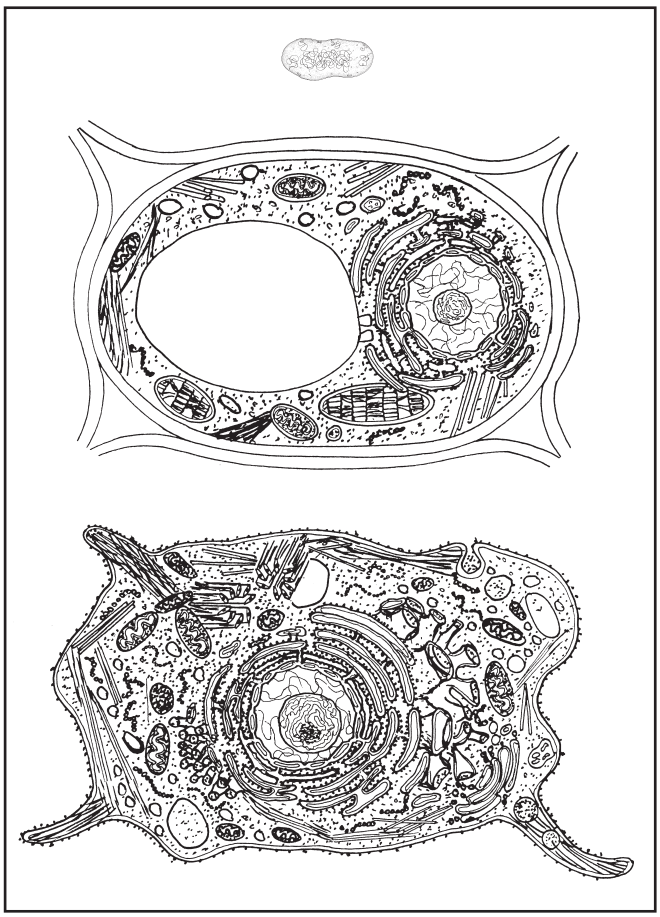

Figure 1. Three types of cells, not drawn to scale. At the top is a generalized prokaryotic cell which shows examples of the major structures, primarily DNA, a cell wall, and various proteins. In the center is a generalized plant eukaryotic cell, and at the bottom is a generalized animal eukaryotic cell. Illustrated in both eukaryotic cells are some of the major structures, which include thousands of organelles. Drawings by Richard Geer.

The nuclear membranes are constructed of phospholipid bilayers in a organization that is similar to the cell membrane. The nuclear pores are about 10 times larger than the cell membrane pores so that large molecules such as mRNA can pass though them. Although much is known about the nucleus, it is still largely a mystery (Gerhart and Kirschner, 1997). The nucleus is filled with *nucleoplasm*, a jellylike substance also called *karylymph*. The organization of the nucleus is controlled by a completed network of protein strands often called the *nuclear matrix* (Hickman, Roberts, and Larson, 1996, p. 46). The nuclear matrix serves as a "shop supervisor" and organizes the various nuclear components that are necessary for DNA and RNA synthesis.

Humans and most mammals have about two meters of DNA in each cell. The DNA is usually divided up into two classes. The first is *heterochromatin*, which is mostly DNA that is being stored for use later or is not needed for this particular cell. Heterochromatin is usually clustered together into small areas near the cell wall and the nucleolus and appears dark under an electron microscope. The second DNA type is *euchromatin* which is scattered throughout the middle of the nucleus and often appears as a light shade of gray in standard electron microscope photographs. Euchromatin is active DNA that is regularly used for that specific cell, and the DNA a specific cell uses depends on the cell type: nerve cells use different sections of their DNA than muscle cells. The ratio of euchromatin to heterochromatin also varies with the cell's metabolic activity. Liver cells produce a wide variety of protein types and contain a large amount of euchromatin. Conversely, cells which produce mucus typically have far less euchromatin than most other cell types (Allen, 1991).

The nucleus also contains many complex structures called enzymes such as *polymerase*, the primary enzyme involved in DNA synthesis. Polymerase is also coded by DNA, raising the question which came first, the polymerase which is necessary to transcribe DNA, or the DNA which contains the code to make the polymerase. Obviously they both must exist in order for the system to work and are another example of a complex irreducible unit. The *zygote*, which is a fertilized cell that develops into a new organism, uses polymerase originally manufactured by the mother's DNA as part of its inheritance from the mother. Both polymerase and DNA plus hundreds of other complex structures are all simultaneously necessary for DNA replication to occur. To assemble DNA as well as RNA, sufficient amounts of *nucleotides*, structures consisting of a base, sugar and phosphate, must first be assembled and transported into the nucleus.

To achieve their purpose in the cell's cytoplasm, both ribosomal and messenger RNA must travel out of the nucleus through the nuclear membrane *pores*. These pores are discreet units that provide structural support and fit like a hollow rivet on the nuclear double membrane. The nucleus' outer membrane also is continuous with the "ER" or *endoplasmic reticulum* (from *endo* within; *plasm* to form and *rete* netlike). The ER consists of a convoluted network of membranes that surround minute tubules called *cisternae*. The cisternae are connected to various organelles and also to the nuclear and cell membranes. They contain many kinds of enzymes that control both catabolic and anabolic activities.

Both the ER and the outer nuclear membrane serve as

attachment sites for *ribosomes*, the structures that direct protein synthesis. Other ribosomes are free floating in the cytoplasm, either singly or in sets called *polysomes*. Polysomes can simultaneously make many copies of a protein from one mRNA strand. The free polysomes usually produce protein for use in the cell, and the ribosomes on the ER usually make protein for export. The typical protein is about 300 amino acids long, but some are many times longer than this. Most dehydrated cells consist of about 20% DNA, 20% RNA and 60% protein.

The Nucleolus

Inside the nucleus is usually one non-membranous but structurally discreet region called the *nucleolus* (plural: *nucleoli*) that synthesizes *ribosomal RNA* (rRNA) and packages it with ribosomal proteins to form ribosomes (Alberts et al., 1989). The *nucleolus* organizer coordinates the rapid transcription of rRNA by RNA polymerase I. Many other molecules guide the ribosome assembly process. When completed, both ribosome subunits are moved out into the cytoplasm where they are assembled to make functional ribosomes. Ribosomes are constructed from one large and one small unit. The larger structure consists of 40 different proteins, one four to five thousand nucleotide long rRNA molecule and two smaller RNA's, each about 150 nucleotides long. The smaller subunit consists of another rRNA strand and about 30 different proteins.

The nucleolus also contains concentrated tRNA and processes *messenger RNA* (mRNA), both which are used in making protein for use in the cell and for export. The mRNA processing involves removing the introns and splicing the exons together by a complex process the author has described elsewhere (Bergman, 1999). The organization of the nucleolus differs widely in different cell types, but three major structures are normally found. These include the *nucleolonema* or *pars fibrosa* which is a dense spongy network that surrounds the *fibrillar centers*, a structure that appears in electron microphotographs as a finely granular, rounded mass. The nucleolonema contains RNA in the process of being transcribed, and the fibrillar center area contains DNA that is not being actively transcribed. The last major component is the *pars granulosa* which contain the workshops for the final manufacturing steps of the ribosomal precursor structures. This area in an electron microscope photograph appears as a fine granular material (Bozzola and Russell, 1992, p. 435). This area is small in size in inactive or dormant cells, and much larger in cells making large amounts of proteins. The many functions of these three primary areas are now the subject of much research.

The Storage of DNA

The DNA is wrapped around histone proteins forming a *nucleosome*, each which contains four histone proteins. These are in turn packed together into *chromatin* which are packaged into structures called *chromosomes* in preparation for cell division. Each side of the chromosome pair is called a *chromatid*, and they are connected together by a *centromere* which is located close to the middle area of each chromosome. The centromere produces four arms; each long arm is called the *q arm*, and each short arm the *p arm*.

The packing is so precise that a particular gene (a segment of DNA flanked by start and stop codons) is normally in the same region of a particular chromosome. Further, the packing is such that some areas are more tightly packed, producing color *bands* which help a researcher determine *where* on the chromosome a specific gene is located. The nucleic acid assembly components (such as the phosphorous compounds) are brought inside of the nucleus through the nuclear membrane to enable DNA and RNA synthesis to occur. DNA is packaged into chromosomes only during cell division to help ensure that each new cell has the proper number of chromosomes so it has all of the necessary genes. Normally DNA is stored in chromatin.

The key to understanding DNA is to focus on the fact that it is an information storing molecule. The chemical properties of its often billions of subatomic parts only hold the information units together, as the information which it contains can be stored by many other systems. Some of these information storage systems humans use include ink on paper in the form of writing, or the binary language used by a computer memory. In other words, the meaning of DNA transcends the chemical properties of the medium. Although the DNA structure may not be the only possible way that genetic information can be stored and utilized by biological organisms, it is the only system that humans are aware exists.

The Cytoplasm

Outside of the nucleus in an area called the *cytoplasm* are located four main cell components which are as follows:

1. The *cytoplasmic matrix* called the *cytosol* consists largely of water (75-90%) and soluble proteins, carbohydrates, lipids and inorganic substances that allow the cytoplasm to change from a *sol* (liquid) to a *gel* consistency and back again as necessary for cell function.

2. The *membrane system* includes the endoplasmic reticulum, the Golgi complex, the mitochondria, and the lysosomes.

3. The *transport system* includes vacuoles, vaults and transport proteins.

4. The *fibrillar system* is a complex network of multithousands of cords and fibers which hold the cell together, help it move and serve other functions. The above four systems will be reviewed in more depth below.

The Membrane System

The *endoplasmic reticulum* (ER) is a complex network (reticulum means net) of membranes which runs roughly parallel to each other to form a set of channels called *cisternae* (meaning reservoir or cavity). The enormous extent of the convoluted channels is such that one square milliliter of ER alone contains a whopping 11 square meters of surface area. A major function of ER is a site for protein synthesis but it also serves to store newly synthesized molecules and as a site to modify protein such as to add sugars to form glycoproteins. On the surface of some ER called *rough* ER are located *ribosomes*, either singly or in groups. The ribosome groups are often arranged in patterns that resemble whirls. The membrane bound ribosomes produce protein that is usually *exported* from the cell and is secreted as cell products such as hormones (important examples include insulin somatostatin, and serotonin). The *free ribosomes* are often grouped together in units called *polysomes*, and these produce protein for use *within* the cell.

The endoplasmic reticulum lacking ribosomes is appropriately called *smooth ER*. This area is the site of the synthesis of certain lipid compounds such as steroid hormones and phospholipids, and also serves to transport and store certain ions. The smooth ER also stores compounds and minerals including fat and glycogen. In muscle cells the sarcoplasmic reticulum releases calcium to trigger muscle contraction. They can even contain enzymes that inactivate or detoxify carcinogens, pesticides, alcohol and other drugs.

The Golgi Complex

The Golgi complex (named after the Italian histologist, Camillo Golgi) is a saucer shaped stack consisting of flat membrane sacks called *saccules*. They are generally located near the nucleus and usually consist of less than 10 stacks of saccules. Two or more saccules are called *dictysomes*. Inside the saccules are chemical factories in the spaces also called the *cisternae*. One function of the Golgi complex is to modify protein produced by ribosomes by adding sugars or carbohydrates (and sometimes other materials) to the proteins, a process called *glycosylation*. An example is sugar molecules must be added in the manufacture of gamma globulin. To do this after proteins are manufactured, they are transported to the Golgi complex and fuse with it on the *cis* or entry cistern.

The Golgi complex also either produces or assists in the production of everything from the *neuropolysaccharides* that the nervous system uses, to the *acromosome* structures used by sperm. The convex surface where the processing begins is called the *forming face*, and the inner concaved surface where the processing ends is called the *maturing face*. The completed products leave at the *trans* or the exit cistern and are carried out in *trans cistern* packages.

Another of its many functions is to sort, store, package and deliver secretatory products to the plasma membrane for excretion. To do this it must build individual protective sacks around the chemicals manufactured for export outside the cell. Called *secretory products*, a well known example is insulin and other hormones. Golgi complexes are extensively developed in cells that function to secrete products. These containers are then pinched off of the Golgi complex in areas called *Golgi vesicles*, eventually forming separate structures that surround the secretory products called *vacuoles*.

This package protects the new proteins or other chemicals as they travel from the cytoplasm to the outer cell membrane. The vacuole then fuses with the external membrane and expels its products outside of the cell in a reverse phagocytosis process called *exocytosis*. The secreted hormones then influence other cells, often by causing them to produce proteins. The secretory vesicle membrane then remains as a permanent addition to the cell membrane and also plays an important role in adding surface area to the cell membrane. The Golgi by adding new cell wall material can even gradually transform the cell membrane from one type to another.

Lysosomes

Lysosomes are single membranous spheres that are part of the cell's internal digestive system. We now know they play a critical role in life and an important part in disease (Allison, 1967). These vacuoles contain over 40 kinds of powerful hydrolytic enzymes that function to break down certain foreign molecules including worn, damaged or unneeded cellular materials. *Hydrolytic* (Hydrolytic means *splitting with water*) *enzymes* use water to cleave chemical bonds. The precursor lysosomal enzymes are first synthesized by the ribosomes and processed in the Golgi apparatus to convert them into the active form. The lysosome's membrane is a safe, secure storage system, impermeable to the outward movement of the stored enzymes and resistant to their digestive action. They also have a low pH which denatures globular proteins in order to open them up to the efficient action of proteolytic enzymes that break the latter's peptide

bonds. Their low pH is achieved by active transport pumps in their membrane which pump hydrogen ions inside, lowering the pH to 5, which is about 100 times more acidic than the cytosolic pH of 7 (Tortora and Grabowski, 1997, p. 73).

Material incorporated into the cell by a process called *phagocytosis*, literally *cell eating*, produces a vacuole called a *phagosome*. This method uses the cell membrane to enclose the material to be brought into the cell so that it is completely encapsulated. When the phagosome reaches the cell's interior, a lysosome fuses with it and hydrolytic enzymes flow from the lysosome into the phagosome, digesting its contents.

The cell may also digest its own waste products and recycle the cells organelles by a similar means. The vacuole surrounds the waste material, a lysosome fuses with it, and digestion occurs. This important process is called *autophagy*, and is in turn called *autolysis* if it destroys the whole cell. The catabolized components can be returned to the cytosol for reuse and waste or undigested materials can also be expelled from the cell by *exocytosis*. During this process the phagosome moves back to the outer cell membrane where it fuses with it and expels its contents by a process similar to reverse phagocytosis. Alternatively, undigested material may simply be stored in the cell in a vacuole package called a *residue body*. The lysosome can even destroy the entire cell if the cell is irreparably damaged, cancerous, aged, defective or in need of removal. Lysosomes are called suicide packets for this reason and cell suicide is termed *apoptosis*. An example of "removing cells" by apoptosis is the atrophy of the uterus that occurs after childbirth and the regression of mammary tissue after the mother weans an infant.

Peroxisomes

Another lysosome type which is similar but smaller than lysosomes is the *peroxisome*. This cell body consists of organelles which have spherical membranous vesicles that contain enzymes. These enzymes detoxify harmful substances such as certain fatty acids, phenol, formic acid, formaldehyde and alcohol by oxidizing them, forming hydrogen peroxide (H_2O_2) or other compounds. H_2O_2 is also highly toxic, thus is broken down to water and oxygen by the enzyme *catalase* (deDuve, 1996, p.56). The peroxisome organelle was named only in 1965 by deDuve a decade after the lyosome was discovered (deDuve, 1997). Since then an explosion of knowledge has produced the modern variegated picture of these critically important organelles. They have numerous roles in the cell; many are only now being explored. For example, we now know that peroxisomes are a complex factory involving urate oxidase, D-amino acid oxidase and other enzymes.

Vaults

Vaults are a basic cell component discovered only in the mid 1980's and have only recently received prominence because of their potential role in explaining why chemotherapy often fails (Travis, 1997). They exist by the thousands in many animal cells including humans. Although their role is still largely a mystery, a number of potential uses have been proposed. They were discovered during research using a stain that latches primarily onto fatty acid molecules. Consequently, because they consist primarily of protein, they did not absorb the stain and appeared as white islands in a sea of stained areas. Some negative staining resulted because small amounts of the stain settled into furrows on top of the vaults, revealing certain fine details of their exterior. Specifically revealed were distinct arches that reminded the researchers of Medieval cathedral ceilings—from whence came the name *vaults*.

Structurally vaults consist of 96 copies of a protein called the *major vault protein* (MVP) and 16 short RNA strands integrated inside of the barrel like vault structure. The flaps evidently open up, appearing like unfolded flowers to reveal the inside of the barrel. Each end of the vault consists of eight petal-like structures attached to a center ring by a small hook. These structures indicate their function, and research is now focusing on a carrier role in which the opening and closing of the petals allows the vaults to pick up and drop off their cargo. Evidence now reveals that they shuffle cargo from the nuclear membrane. The short strands of vault RNA may serve as attachments for mRNA and likely the cargo consists of mRNA and other molecules. The vaults then close and carry their cargo to the appropriate location in the cell.

Although currently controversial, experimental evidence indicates that the nuclear pore complexes can be blocked by plugs, and it is now believed that these plugs are vaults. The vault matches almost perfectly with the size and shape of the nuclear pore complexes—the structures which form the doorway of the nuclear membrane channels. The recent interest in vaults is due to evidence that vaults may be used by cancer cells to remove DNA damaging drugs from the nucleus, explaining why many cancer cells are resistant to chemotherapy (Travis, 1997, p. 57).

Mitochondria

The mitochondria are critically important cell structures because they contain the machinery and enzymes necessary to convert food into energy carrying molecules called *adenosine triphosphates* (ATP). They can process fats, sugars, and protein and are found in all cells except mature red blood cells. Called the *powerhouse* of the cell, we

now know that the more active cells such as muscle, liver, and kidney tubule cells contain large numbers of mitochondria, and the less active cells such as the mucous secreting cells contain few of them. Specifically, the enzymatic process by which the mitochondria converts food to ATP is called *oxidative phosphorylation*. The end process involves converting adenosine diphosphate to adenosine triphosphate, a higher energy molecule. Other functions of the mitochondria are regulatory in nature including to help control the calcium level in the cytoplasm. They are also involved in specific kinds of lipid synthesis.

The mitochondria is a unique organelle because it contains its own DNA (mtDNA) in the form of plasmids. The mtDNA is usually located in the mitochondria's matrix compartment, although it is sometimes attached to the inner mitochondrial membrane. The human mtDNA has been completely sequenced and has 16,569 base pairs (Darnell, Lodish and Baltimore, 1986, p. 926). The mitochondria DNA is used exclusively for the organelle's own functions, specifically to enable it to have *some* control, although not complete, over its own replication.

Structurally, the mitochondria has an outer and inner membrane. The inner membrane has numerous plate-like folds called *cristae* (a fold or crest) which possess membranous sacks that contain enzymes. The cristae produce many small rooms inside of this often hot-dog or spherical shaped double membraned structure. Cristae can be either exclusively lamellar or exclusively tubular, and some mitochondria contain both types. The inner membranes contain a large set of enzymes which cause the conversion of food into ATP by a series of reactions called the *Krebs* or *citric acid cycle* which produces oxidative phosphorylation. The inner area called the *matrix* is filled with gel containing scores of different kinds of enzymes. The inner and outer membranes differ in enzymatic activity and also lipid composition. Some of the enzymes such as *ATPase* are permanently fixed in the mitochondrial membrane.

Centrioles

Centrioles are long, thin, complex, straw-shaped structures that are similar to basal bodies except they normally occur in the *centrosphere*, a region of the cytoplasm located near the nucleolus which contains the Golgi complex. They are the only other cell structure besides the nucleus and mitochondria that contain their own DNA, enabling them to control their own replication. In non-dividing cells, centrioles occur in pairs called *diplosomes* which usually lie at right angles to each other. The centriole pair replicates at the beginning of each cell division, producing two new pairs. Centrioles replicate by producing daughter cells which form long straw shaped structures *perpendicular* to each centriole that they develop from.

The daughter centrioles then increase in length until they reach maturity, and the two diplosomes then separate. One diplosome moves to each pole of the cell and during spindle formation they function as a microtubule organizing center. A *spindle fiber* is a bundle of microtubules which either runs from pole to pole or from a chromosome to a pole. The poles are themselves anchored in the surrounding cytoplasm by radiating microtubules. Centrioles also have a role in the development of cilia or flagellum.

The Fibular System

The cell must have both an internal framework or skeleton system and a means of moving and adjusting to the outside environment. This is achieved by a large complex *fibular system*. The fibrillar system contains three structural families: microtubules, intermediate filaments and microfilaments, each of which are a different size and have somewhat different functions. *Microtubules* are 25 nanometers or less in diameter, *intermediate filaments* are about 10 nanometers, and the *microfilaments* are from five to seven nanometers in diameter.

1. *Microtubules*, elongated, linear hollow phagosome structures, are the largest of the cell's fibers. They are constructed out of a protein appropriately called *tubulin* (Behe, 1996, p. 59). Microtubules employed to construct the cell's skeletal system and are also used to construct the force-generating elements of both *cilia* and *flagella* which allow cells to move. They also function as a conveyor belt to move various substances and organelles around in the cytosol and to assist in the process of phagocytosis. The microtubular skeleton unit termed the *axoneme* contains nine outer doublet microtubules and one central pair. These hollow structures are in turn constructed out of other small hollow tubes made out of *tubulin* protein.

Each microtubule consists of 10 long, thin protofilaments assembled with 13 others to form a structure whose cross section resembles the number eight (thus three protofilaments exist in common with the two tubes). On the side are rows of *dynein arms* which provide a mechanism for the peripheral doublets to slide over each other, causing the flagella to move. Cilia and flagella arise from a complex structure called a *basal body* which consists of nine triplet microtubules located just below the cell membrane. The major center for assembly of microtubules is the organizing region called the *centrosome*, an area near the nucleus that contains the centrioles and other structures.

2. *Intermediate filaments*. We now know that the intermediate filament family plus the microfilaments (actin) and the microtubules (myosin) make up the basic cell cytoskeleton (Ishikawa, Bischoff, and Holtzer, 1996, p. 40-41). The discovery and elucidation of the class of filaments *intermediate* in diameter between actin and myosin was primarily the work of Howard Holtzer (Ishikawa, et al., 1996, p.40) Myosin are the *thickest* filaments, actin the *thinnest*, thus the term intermediate filaments is appropriate to describe them.

This family consists of physically strong and chemically stable fibers that likely serve the role of "high tensile cables" within the cell to help hold organelles in place and give shape to the cell. After the discovery of intermediate filaments in 1968, little attention was given to them until the late 1970s. So far six different types have been distinguished and named according to the cell type in which they occur. Differentiated skin and epithelial cells have many *keratin* filaments called *tonofilaments*, muscle cells have *desmin* filaments, nerve cells contain *neurofilaments* and *nuclear lamins*. The next type *glial filaments* are found in glial cells which underline the nuclear envelope, and *mesenchymal* plus other cell types contain *vimentin* filaments.

3. *Microfilaments*, the thinnest of the three basic types, are the main components of muscle cells and provide their contractile system. They are composed of polymerized *actin* thus are often called actin filaments. They are used in all cell types and are involved in changing the cell's shape and generating force for various functions such as movement. A major function of microfilaments is to move materials in and out of the cell by pinocytosis, exocytosis, and phagocytosis. Actin may appear in highly organized large geometric bundles or scattered throughout the cell. They associate with proteins called *actin-binding proteins* that link them in several ways to form a wide variety of shapes. Actin even forms the contractile ring that produces two daughter cells during telophase.

The Cell Membrane

A critical cell structure is its complex *membrane* system which includes both internal and external membranes. They are constructed primarily out of phospholipids and protein molecules. The cell membrane in plants is much thinner then animals but plant cells contain a strong 7.5-nanometer-thick cellulose cell wall. For muscles, the cell membrane is generally lost as development occurs, forming multinucleated structures called *syncytia*.

The membrane consists of two layers. A major part are the phospholipids which are arranged so that their hydrophilic polar phosphate heads face *outward* and their hydrophobic non-polar fatty acid tails face *inward* toward each other. The membranes are rich in carbohydrates called glycoproteins, some which extend completely through the membrane, others which protrude out of only one or the other side. Since the membrane contains many proteins and is highly fluid, it is described by the term *fluid mosaic model*. The cell membrane also serves as structural support and contains over 200 types of receptors for hormones and other regulatory chemicals which communicate information to the cell nucleus or other cell organelles. The membrane also contains hundreds of cell markers to enable it to enter into immune reactions.

In the majority of tissues, the membrane serves as an effective barrier, preventing entry of some substances and allowing others to move inside the cell. Consequently, the term *semipermeable membrane* accurately describes its role. Permeability is a function of a compound's solubility in lipids, its ionic charge, its size and the presence of specialized carrier molecules. Many ions are small enough that they can pass directly through the membrane, a process labeled *microtransfer*. Larger particles move in and out via phagocytosis or are secreted by granules, a process called *macrotransfer*.

Extending from the outside surface of a bilayer cell membrane are small projections called *microvillas* and on the outer surfaces is often found a layer called the cell coat or *glycocalyx*. This protein-carbohydrate mixture which may extend some distance from the cell surface serves many functions including to help glue cells together. The glycocalyx polysaccharides are also important in cell to cell recognition (Bozzola and Russell, 1992 p. 410). The glycocalyx is negatively charged, thus it also helps to regulate the kinds of charged molecules that can approach the cell surface.

Another means of connecting cells are *tight junctions*, a structural arrangement that prevents fluid leakage and is used in organs such as the bladder. Another major cell junction type is the *desmosomes* which are constructed like spot welds and join cells together by complex *desmin filaments*. The last type is called a *gap junction* which contains what could best be described as rivets that firmly connect the two cells together. In the center of each rivet is a passageway which allows chemical communication between the two cells. Many of the junctions have a special function and some tissues, such as the columnar epithelium which lines the small intestine, utilize all three of these membrane joining structures (Lammerts, 1979, p. 216-218).

Implications for Creationism

In this review, I have only briefly outlined some of the major eukaryote cell structures and some of the many roles they serve in the cell. This review is similar to a tour of a factory involving reading only the titles on each department door and glancing inside. I have said almost nothing about the multi-thousands of different operations that occur continuously inside of each organelle. An estimated 100,000 parts are found in every eukaryotic cell and some of the parts are more complicated than others, but all are exceedingly complex .

The question a Darwinist must answer is, can the "astonishing complexity of subcellular organic structures" evolve? (Behe, 1996, p. 15) Darwin based his theory on gross anatomical similarities but the theory must now deal with ultrastructure and biochemistry. Haeckel, a leading popularizer of Darwin, believed the cell was not much more complicated than a "simple little lump of albuminous combination of carbon" (Mayr, 1991, Chap. 9). When Pukinje coined the term *protoplasm* to describe the cell contents, it was believed to be a thick soup gel-like mixture with special but elusive life properties. Now we realize the "cell components" are so highly organized structurally and functionally that describing its contents as 'protoplasm' is like describing the contents of an automobile engine as 'autoplasm' (Hickman, et al. 1997, p. 14).

Prokaryotic cells also contain many complex structures. For instance the protein machine which transcribes DNA into RNA in bacteria consists of an active pentimere shaped enzyme that contains four separate polypeptide chains. The total molecular weight is a whopping half million, equal to a structure made out of a half million hydrogen atoms. This is only *one* of many proteins which must be perfectly constructed in order for a cell to function properly (Zubay, Parson and Vance, 1995, p. 706). Further, the cell cannot live until all of these parts exist and are functional. For this reason no cell has been found that does not have all of these basic parts. The bacteria *E. coli* has over 4,000 genes and if the "DNA molecules in the single chromosome in *E. coli* were blown up to be the thickness of ordinary clothesline, it would be five moles long." (Trefil, 1992, p. 105). These instructions coded into the DNA must also be organized so that the genes can be located when needed, no easy task.

Evidence for Organelle Evolution

Orthodox evolution teaches that

> ...fossils dated at between 3,000 million and 1,000 million years old are mostly 1 or 2 microns in diameter. The size of these so-called "body fossils" is consistent with their being prokaryotic (bacteria-like) forms of life possessing a simple strand of nucleic acid, and with the chemical machinery of the cell either distributed within the cell fluid or attached to the cell membrane. But about 1,000 million years ago larger microfossils begin to appear, 5 to 15 microns in diameter. These fossils, found in chert rocks, look suspiciously like the remains of eukaryotes—that is, the cells seem to have some of their working parts collected in a central nucleus, which can be seen in the fossil as a darker area (Norman, 1994, p. 28-29).

The evidence for this just-so story, when examined carefully, does not support the view that eukaryotes evolved from prokaryotes. Actually the theory of evolution has completely failed to provide an explanation for the origin of the organelles existing in eukaryotic cells:

> ...the area of greatest ignorance in evolution remains the origin of cells. The key reactions of molecular cell biology—those conferring the coding capacity of the nucleic acids and those involved in the translation of the code into protein and the replication of nucleic acids—must have arisen before the first true cell could exist (Darnell et al. 1986, p. 1126).

For evolution to have occurred, untold millions of transitional forms must have existed between prokaryotes and eukaryotes (Herrmann and Hummell, 1994). This is true for both of the naturalistic theories of organelle origins, endosymbiosis and straight gene mutation plus natural selection evolution. Yet no evidence exists for

> ...a linear evolutionary connection between a primordial prokaryotic cell (one designed like today's prokaryotes) and eukaryotic cells, either those existing as unicellular organisms or those comprising multicellular organisms. As we shall see, the sequence data presently available argues against any such direct connection (Darnell et al., 1986, p.1127).

As a result of this lack of empirical evidence Starr (1996, p. 272) concludes "speculations abound" about the origin of organelles. Although many putative ancient fossils are in very poor condition, multi-thousands of well preserved animals are now known to exist, a few which it is claimed are older than 320 million years (Grimaldi, 1996). Analysis of putative ancient animal cells, such as those embedded in amber so far have not provided *even a hint* of the millions of required transitional forms (Grimaldi, 1996; Poinar and Poinar 1994). One of the oldest known eukaryotes, a poorly preserved protistan claimed to be 1.4 billion years old, shows evidence of clear, well developed, organelles (Starr, 1996, p. 272). A total void of cell structures between eukaryotes and prokaryotes exists and organisms either lack organelles or possess fully functional organelles (Deyer and Obar,

1994). Not even one plausible example of an intermediate organelle has been found to bridge the chasm found between prokaryotes and eukaryotes.

Amber preserved DNA has also been studied and often examples are found to be "very similar to living relatives" (Grimaldi, 1996, p. 128). Termite and bee DNA claimed to be 25 million years old were also remarkably similar to its modern relatives. Evolutionists theorize that eukaryotic cells arose around two billion years ago, thus they claim amber preserved examples do not reach back far enough to shed light on this early history. The amber evidence *does* though show lack of change for the period it documents. The fact that no evidence exists, fossil or otherwise, for the evolution of eukaryotes is a real dilemma for evolution. The popular science writer Trefil (1992, p. 104) called it an "enduring mystery" because:

> The differences between prokaryotic and eukaryotic cells are striking, to say the least. But if the latter evolved from the former, why are there no intermediate stages between the two? Why, for example, are there no cells with loose DNA and organelles? If the evolutionary line really went from prokaryotes to eukaryotes, and we have many living samples of each, why did none of the intermediate stages survive?

Even the simplest eukaryote such as yeast cells and the most primitive eukaryotes contain all of the organelles found in "higher" eukaryotes such as humans. Furthermore, usually only minor differences exist in organelles between the simplest and the most advanced eukaryote, humans. Woods concludes that the:

> ...results of the yeast genome project are surprising, partly because of the similarities between the genetic design of yeast and human cells. Yeast and people are separated by at least one billion years of evolution. Yet both share many of the same genes and function in many similar ways (1996, p. 8).

Research on the ultrastructure of ancient life has found little or no difference between the ultrastructure existing in the so-called ancient life and that existing in modern life, revealing no evidence for evolution. The conclusion of this research is that:

> ...the ultrastructural remains of fossilized insect tissues in Baltic amber corresponded to what one would expect to find in a routine examination of present-day insects. The character of the tissues in the fossil fly resembled present-day tissues that had been dehydrated with ethylene glycol." (Poinar and Hess, 1982, p. 1242)

Some of the ultrastructures and other features in organisms that have been unearthed are so close to modern forms that widespread concerns exist about contamination. Even those who accept that prokaryotes evolved into eukaryotes admit that no evidence exists for their belief. All organelles, whether in a yeast or in humans, ancient or modern, are remarkably similar and no gradual gradation of apparent complexity can be produced as must have occurred if life evolved. In the words of deDuve "no intermediates of this momentous transition have survived or left fossils to provide direct clues" of the evolution of eukaryotes (1996, p. 50). Simpler animals may have streamlined organelles, but a huge unbridged and unbridgeable gap exists between prokaryotes and eukaryotes. These gaps are not only real, but they *must* exist because all organelles such as mitochondria must have specific structures and a minimum complexity level in order to function (Behe, 1996).

In order for a machine to work, even a simple machine, its complexity can only be reduced so far—below this level the machine will not function. An example Behe explains in detail is a standard mouse trap which has five basic parts, a platform, a holding bar, a hammer, a catch and a spring. It will not function until *every* one of these parts is functional and positioned in its proper place. All the parts must be designed properly to articulate with each other. Likewise organelles will not work unless every part exists and is properly in place. Since organelles are complete complex structures consisting of many thousands of parts, this principle also true of organelles. Without fully functional efficient mitochondria, Golgi complexes, the cells skeletal systems and all other organelles, eukaryote animals cannot survive. Furthermore, the time required for the evolution of organelles is believed to be enormous, and would have left many fossils (Mayr, 1991). Ian Crawford notes:

> The fact that it took life on Earth nearly 3 billion years to go from the single-celled to the multicelled stage implies that this step is very hard. Planets with primitive life may be common but not ones with advanced civilizations. (as quoted in Chown, 1996, p. 6)

Few researchers have even tried to speculate on what these millions of putative "transitional cells" may have been like. The physical evidence for the multi-millions of transitional forms necessary to create a reasonable scenario which could bridge the free living single celled organisms and the many kinds of communal cells found in multicellular organisms is at this point also totally lacking. All too often life forms that are touted as "transitional forms" are just another species, a problem Grimaldi noted with a bacteria find but which also exists with most other life forms:

> Widespread skepticism exists in the scientific community, though, as to whether this bacterium is indeed ancient. One problem with trying to determine if the bacteria apparently revived from amber are authentic is that the living flora of bacteria is so poorly known that one may never be sure if a posi-

> tive result is simply due to some unknown modern species contaminating the culture. In a teaspoon of forest soil thrive thousands of species of bacteria, most new to science. What assurance is there, given the most sterile and careful conditions of isolation, that a weird bacterium is authentically ancient? Also, all of the DNA extracted thus far from organisms trapped in amber is extremely fragmented. Given this, how it is possible that an entire genome (the DNA chain in an organism) can remain entirely unbroken? A bacterium with a fragmented genome would never be viable (1996, p. 132).

Endosymbiosis

The two current plausible naturalistic models for organelle formation are "progressive differentiation of descendants via mutations of many kinds and their natural selection" and *endosymbiosis* (Margulis, 1971a, p. 230). Endosymbiosis is the conclusion that mitochondria and other organelles were once free living bacteria which successfully invaded other bacteria and then evolved to specialize in, for example, producing ATP as an energy source for its host.

The common endosymbiosis scenario is that animals which were once free-living have "joined together" in cooperative communities which we now call cells that later became part of multicellular organisms. Within these organisms, groups of cells have taken on specialized roles—some becoming muscle, others brain, bone, skin and so on (Hoagland and Dodson, 1996, p.72). This theory was developed in greatest detail by Lynn Margulis, and this paradigm has moved from an obscure, poorly accepted idea to the most widely acknowledged theory of organelle development today partly through her work and influence (Margulis, 1971b).

The endosymbiosis idea is popular not because of the empirical evidence, but for the reason that no other hypothesis is even remotely plausible because of the complete absence of fossil and other evidence. Thus Battley describes the endosymbiosis theory as "tentative at best" (1996, p. 276). A major problem with endosymbiosis is that it is, has been, and still is, untestable (Margulis, 1971a, p. 230). More research and knowledge, has motivated one researcher at the forefront of this field to conclude that:

> Data published over the past two or three years, much of them from genome-sequencing projects, have hinted that it is time for a new theory. In particular, it is turning out that eukaryotic nuclear genomes carry many genes of bacterial (sometimes a-proteobacteria) origin which have nothing to do with mitochondrial functions. Moreover, mitochondrion-free eukaryotes that we had come to think of as direct descendants of ancient proto-eukaryotes carry mitochondrial genes in their nuclear genomes (Doolittle, 1998, p. 15).

The endosymbiosis theory has come under attack from many other quarters, and no doubt this attack will continue.

Summary

In this short review we have reviewed some of the major cell structures and have briefly discussed what roles they perform in the cell. The more scientists learn about the cell, the more they realize it is a designed, complex marvel which reveals the intelligence of its maker. The evidence for organelle evolution is close to nonexistent and either cells have organelles (all which are eukaryotes) or have none as in the case of prokaryotes (Anderson, 1980). For evolution to have occurred multi-millions of transitional forms must have existed—and no evidence of these has been found in the fossil record in spite of extensive analyzation of thousands of putative ancient cells and years of study of so called primitive animals such as yeast. What is found is either a total absence of organelles or fully functional organelles (Deyer and Obar, 1994).

The gaps between non-life and life and also between prokaryotes and eukaryotes are the largest gaps in the evolution "from chemicals to humans" theory. And all organelles, whether in a yeast or human, are remarkably similar; no gradation of apparent complexity can be produced as has been attempted to explain the evolution of life. Simpler animals such as yeast may have streamlined organelles, but a huge, unbridgeable gap exists between prokaryotes and eukaryotes.

These gaps not only are real, but must occur because a certain minimal level of structural complexity must exist in order for mitochondria and all the other organelles to function. Eukaryotes cannot survive without mitochondria and their other organelles (Zubay et al., 1995). The most plausible scenario that has been developed by evolutionists is endosymbiosis, the idea that the mitochondria, for example, was once a free living archaebacteria which invaded other bacteria and evolved to specialize in producing energy for its host cell. No direct evidence for this theory exists except armchair reasoning, ambiguous evidence such as the fact that mitochondria and centrioles both have DNA which in some ways resembles that in prokaryotes more then eukaryotes. The DNA differences found can be adequately explained by the DNA's function in mitochondria and centrioles, and many problems remain with the theory (Battley, 1996, p. 275-276).

The common scenario, that cells which were once free living have "joined together in cooperating communities

that we call multicellular organisms, also requires cell evolution. Within these organisms, groups of cells have taken on special roles—becoming muscle, brain, bone, skin, and so on" (Hoagland and Dodson, 1996, p.72). Consequently, millions of transitional forms must exist not only between the non-organelle life system found in prokaryote and the organelle system found in eukaryotes, but also between prokaryotes and all the specialized tissue types such as muscle and nerve cells. Few have even endeavored to speculate on what these transitional forms may have been like, let alone endeavor to present evidence for the multimillions of transitional forms necessary to create any reasonable scenario which could bridge the free living cells and the cells used in multicellular organisms.

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