

= Cell nucleus =

In cell biology , the nucleus ( pl. nuclei ; from Latin nucleus or nuculeus , meaning kernel ) is a membrane @-@ enclosed organelle found in eukaryotic cells . Eukaryotes usually have a single nucleus , but a few cell types , such as mammalian red blood cells , have no nuclei , and a few others have many .

Cell nuclei contain most of the cell 's genetic material , organized as multiple long linear DNA molecules in complex with a large variety of proteins , such as histones , to form chromosomes . The genes within these chromosomes are the cell 's nuclear genome and are structured in such a way to promote cell function . The nucleus maintains the integrity of genes and controls the activities of the cell by regulating gene expression ? the nucleus is , therefore , the control center of the cell . The main structures making up the nucleus are the nuclear envelope , a double membrane that encloses the entire organelle and isolates its contents from the cellular cytoplasm , and the nuclear matrix ( which includes the nuclear lamina ) , a network within the nucleus that adds mechanical support , much like the cytoskeleton , which supports the cell as a whole .

Because the nuclear membrane is impermeable to large molecules , nuclear pores are required that regulate nuclear transport of molecules across the envelope . The pores cross both nuclear membranes , providing a channel through which larger molecules must be actively transported by carrier proteins while allowing free movement of small molecules and ions . Movement of large molecules such as proteins and RNA through the pores is required for both gene expression and the maintenance of chromosomes . Although the interior of the nucleus does not contain any membrane @-@ bound sub compartments , its contents are not uniform , and a number of sub @-@ nuclear bodies exist , made up of unique proteins , RNA molecules , and particular parts of the chromosomes . The best @-@ known of these is the nucleolus , which is mainly involved in the assembly of ribosomes . After being produced in the nucleolus , ribosomes are exported to the cytoplasm where they translate mRNA .

= = History = =

The nucleus was the first organelle to be discovered . What is most likely the oldest preserved drawing dates back to the early microscopist Antonie van Leeuwenhoek ( 1632 ? 1723 ) . He observed a " lumen " , the nucleus , in the red blood cells of salmon . Unlike mammalian red blood cells , those of other vertebrates still contain nuclei .

The nucleus was also described by Franz Bauer in 1804 and in more detail in 1831 by Scottish botanist Robert Brown in a talk at the Linnean Society of London . Brown was studying orchids under microscope when he observed an opaque area , which he called the " areola " or " nucleus " , in the cells of the flower 's outer layer .

He did not suggest a potential function . In 1838 , Matthias Schleiden proposed that the nucleus plays a role in generating cells , thus he introduced the name " cytoblast " ( cell builder ) . He believed that he had observed new cells assembling around " cytoblasts " . Franz Meyen was a strong opponent of this view , having already described cells multiplying by division and believing that many cells would have no nuclei . The idea that cells can be generated de novo , by the " cytoblast " or otherwise , contradicted work by Robert Remak ( 1852 ) and Rudolf Virchow ( 1855 ) who decisively propagated the new paradigm that cells are generated solely by cells ( " Omnis cellula e cellula " ) . The function of the nucleus remained unclear .

Between 1877 and 1878 , Oscar Hertwig published several studies on the fertilization of sea urchin eggs , showing that the nucleus of the sperm enters the oocyte and fuses with its nucleus . This was the first time it was suggested that an individual develops from a ( single ) nucleated cell . This was in contradiction to Ernst Haeckel 's theory that the complete phylogeny of a species would be repeated during embryonic development , including generation of the first nucleated cell from a " monerula " , a structureless mass of primordial mucus ( " Urschleim " ) . Therefore , the necessity of the sperm nucleus for fertilization was discussed for quite some time . However , Hertwig confirmed his observation in other animal groups , including amphibians and molluscs . Eduard Strasburger

produced the same results for plants in 1884 . This paved the way to assign the nucleus an important role in heredity . In 1873 , August Weismann postulated the equivalence of the maternal and paternal germ cells for heredity . The function of the nucleus as carrier of genetic information became clear only later , after mitosis was discovered and the Mendelian rules were rediscovered at the beginning of the 20th century ; the chromosome theory of heredity was therefore developed .

= = Structures = =

The nucleus is the largest cellular organelle in animal cells . In mammalian cells , the average diameter of the nucleus is approximately 6 micrometres (  $\mu\text{m}$  ) , which occupies about 10 % of the total cell volume . The viscous liquid within it is called nucleoplasm , and is similar in composition to the cytosol found outside the nucleus . It appears as a dense , roughly spherical or irregular organelle .

= = Nuclear envelope and pores = =

The nuclear envelope , otherwise known as nuclear membrane , consists of two cellular membranes , an inner and an outer membrane , arranged parallel to one another and separated by 10 to 50 nanometres (  $\text{nm}$  ) . The nuclear envelope completely encloses the nucleus and separates the cell 's genetic material from the surrounding cytoplasm , serving as a barrier to prevent macromolecules from diffusing freely between the nucleoplasm and the cytoplasm . The outer nuclear membrane is continuous with the membrane of the rough endoplasmic reticulum ( RER ) , and is similarly studded with ribosomes . The space between the membranes is called the perinuclear space and is continuous with the RER lumen .

Nuclear pores , which provide aqueous channels through the envelope , are composed of multiple proteins , collectively referred to as nucleoporins . The pores are about 125 million daltons in molecular weight and consist of around 50 ( in yeast ) to several hundred proteins ( in vertebrates ) . The pores are 100 nm in total diameter ; however , the gap through which molecules freely diffuse is only about 9 nm wide , due to the presence of regulatory systems within the center of the pore . This size selectively allows the passage of small water @-@ soluble molecules while preventing larger molecules , such as nucleic acids and larger proteins , from inappropriately entering or exiting the nucleus . These large molecules must be actively transported into the nucleus instead . The nucleus of a typical mammalian cell will have about 3000 to 4000 pores throughout its envelope , each of which contains an eightfold @-@ symmetric ring @-@ shaped structure at a position where the inner and outer membranes fuse . Attached to the ring is a structure called the nuclear basket that extends into the nucleoplasm , and a series of filamentous extensions that reach into the cytoplasm . Both structures serve to mediate binding to nuclear transport proteins .

Most proteins , ribosomal subunits , and some DNAs are transported through the pore complexes in a process mediated by a family of transport factors known as karyopherins . Those karyopherins that mediate movement into the nucleus are also called importins , whereas those that mediate movement out of the nucleus are called exportins . Most karyopherins interact directly with their cargo , although some use adaptor proteins . Steroid hormones such as cortisol and aldosterone , as well as other small lipid @-@ soluble molecules involved in intercellular signaling , can diffuse through the cell membrane and into the cytoplasm , where they bind nuclear receptor proteins that are trafficked into the nucleus . There they serve as transcription factors when bound to their ligand ; in the absence of ligand , many such receptors function as histone deacetylases that repress gene expression .

= = Nuclear lamina = =

In animal cells , two networks of intermediate filaments provide the nucleus with mechanical support : The nuclear lamina forms an organized meshwork on the internal face of the envelope , while less organized support is provided on the cytosolic face of the envelope . Both systems provide structural

support for the nuclear envelope and anchoring sites for chromosomes and nuclear pores .

The nuclear lamina is composed mostly of lamin proteins . Like all proteins , lamins are synthesized in the cytoplasm and later transported to the nucleus interior , where they are assembled before being incorporated into the existing network of nuclear lamina . Lamins found on the cytosolic face of the membrane , such as emerin and nesprin , bind to the cytoskeleton to provide structural support . Lamins are also found inside the nucleoplasm where they form another regular structure , known as the nucleoplasmic veil , that is visible using fluorescence microscopy . The actual function of the veil is not clear , although it is excluded from the nucleolus and is present during interphase . Lamin structures that make up the veil , such as LEM3 , bind chromatin and disrupting their structure inhibits transcription of protein @-@ coding genes .

Like the components of other intermediate filaments , the lamin monomer contains an alpha @-@ helical domain used by two monomers to coil around each other , forming a dimer structure called a coiled coil . Two of these dimer structures then join side by side , in an antiparallel arrangement , to form a tetramer called a protofilament . Eight of these protofilaments form a lateral arrangement that is twisted to form a ropelike filament . These filaments can be assembled or disassembled in a dynamic manner , meaning that changes in the length of the filament depend on the competing rates of filament addition and removal .

Mutations in lamin genes leading to defects in filament assembly cause a group of rare genetic disorders known as laminopathies . The most notable laminopathy is the family of diseases known as progeria , which causes the appearance of premature aging in its sufferers . The exact mechanism by which the associated biochemical changes give rise to the aged phenotype is not well understood .

= = = Chromosomes = = =

The cell nucleus contains the majority of the cell 's genetic material in the form of multiple linear DNA molecules organized into structures called chromosomes . Each human cell contains roughly two meters of DNA . During most of the cell cycle these are organized in a DNA @-@ protein complex known as chromatin , and during cell division the chromatin can be seen to form the well @-@ defined chromosomes familiar from a karyotype . A small fraction of the cell 's genes are located instead in the mitochondria .

There are two types of chromatin . Euchromatin is the less compact DNA form , and contains genes that are frequently expressed by the cell . The other type , heterochromatin , is the more compact form , and contains DNA that is infrequently transcribed . This structure is further categorized into facultative heterochromatin , consisting of genes that are organized as heterochromatin only in certain cell types or at certain stages of development , and constitutive heterochromatin that consists of chromosome structural components such as telomeres and centromeres . During interphase the chromatin organizes itself into discrete individual patches , called chromosome territories . Active genes , which are generally found in the euchromatic region of the chromosome , tend to be located towards the chromosome 's territory boundary .

Antibodies to certain types of chromatin organization , in particular , nucleosomes , have been associated with a number of autoimmune diseases , such as systemic lupus erythematosus . These are known as anti @-@ nuclear antibodies ( ANA ) and have also been observed in concert with multiple sclerosis as part of general immune system dysfunction . As in the case of progeria , the role played by the antibodies in inducing the symptoms of autoimmune diseases is not obvious .

= = = Nucleolus = = =

The nucleolus is a discrete densely stained structure found in the nucleus . It is not surrounded by a membrane , and is sometimes called a suborganelle . It forms around tandem repeats of rDNA , DNA coding for ribosomal RNA ( rRNA ) . These regions are called nucleolar organizer regions ( NOR ) . The main roles of the nucleolus are to synthesize rRNA and assemble ribosomes . The structural cohesion of the nucleolus depends on its activity , as ribosomal assembly in the nucleolus

results in the transient association of nucleolar components , facilitating further ribosomal assembly , and hence further association . This model is supported by observations that inactivation of rDNA results in intermingling of nucleolar structures .

In the first step of ribosome assembly , a protein called RNA polymerase I transcribes rDNA , which forms a large pre 45S rRNA precursor . This is cleaved into the subunits 5.8S , 18S , and 28S rRNA . The transcription , post-transcriptional processing , and assembly of rRNA occurs in the nucleolus , aided by small nucleolar RNA ( snoRNA ) molecules , some of which are derived from spliced introns from messenger RNAs encoding genes related to ribosomal function . The assembled ribosomal subunits are the largest structures passed through the nuclear pores .

When observed under the electron microscope , the nucleolus can be seen to consist of three distinguishable regions : the innermost fibrillar centers ( FCs ) , surrounded by the dense fibrillar component ( DFC ) , which in turn is bordered by the granular component ( GC ) . Transcription of the rDNA occurs either in the FC or at the FC-DFC boundary , and , therefore , when rDNA transcription in the cell is increased , more FCs are detected . Most of the cleavage and modification of rRNAs occurs in the DFC , while the latter steps involving protein assembly onto the ribosomal subunits occur in the GC .

== Other subnuclear bodies ==

Besides the nucleolus , the nucleus contains a number of other non-membrane delineated bodies . These include Cajal bodies , Gemini or coiled bodies , polymorphic interphase karyosomal association ( PIKA ) , promyelocytic leukaemia ( PML ) bodies , paraspeckles , and splicing speckles . Although little is known about a number of these domains , they are significant in that they show that the nucleoplasm is not a uniform mixture , but rather contains organized functional subdomains .

Other subnuclear structures appear as part of abnormal disease processes . For example , the presence of small intranuclear rods has been reported in some cases of nemaline myopathy . This condition typically results from mutations in actin , and the rods themselves consist of mutant actin as well as other cytoskeletal proteins .

=== Cajal bodies and gems ===

A nucleus typically contains between 1 and 10 compact structures called Cajal bodies or coiled bodies ( CB ) , whose diameter measures between 0.2  $\mu$ m and 2  $\mu$ m depending on the cell type and species . When seen under an electron microscope , they resemble balls of tangled thread and are dense foci of distribution for the protein coilin . CBs are involved in a number of different roles relating to RNA processing , specifically small nucleolar RNA ( snoRNA ) and small nuclear RNA ( snRNA ) maturation , and histone mRNA modification .

Similar to Cajal bodies are Gemini or Cajal bodies , or gems , whose name is derived from the Gemini constellation in reference to their close " twin " relationship with CBs . Gems are similar in size and shape to CBs , and in fact are virtually indistinguishable under the microscope . Unlike CBs , gems do not contain small nuclear ribonucleoproteins ( snRNPs ) , but do contain a protein called survival of motor neuron ( SMN ) whose function relates to snRNP biogenesis . Gems are believed to assist CBs in snRNP biogenesis , though it has also been suggested from microscopy evidence that CBs and gems are different manifestations of the same structure . Later ultrastructural studies have shown gems to be twins of Cajal bodies with the difference being in the coilin component ; Cajal bodies are SMN positive and coilin positive , and gems are SMN positive and coilin negative .

=== RAFA and PTF domains ===

RAFA domains , or polymorphic interphase karyosomal associations , were first described in microscopy studies in 1991 . Their function remains unclear , though they were not thought to be associated with active DNA replication , transcription , or RNA processing . They have been found to

often associate with discrete domains defined by dense localization of the transcription factor PTF , which promotes transcription of small nuclear RNA ( snRNA ) .

===== PML bodies =====

Promyelocytic leukaemia bodies ( PML bodies ) are spherical bodies found scattered throughout the nucleoplasm , measuring around 0 .5 - 1 .5  $\mu$ m . They are known by a number of other names , including nuclear domain 10 ( ND10 ) , Kremer bodies , and PML oncogenic domains . PML bodies are named after one of their major components , the promyelocytic leukemia protein ( PML ) . They are often seen in the nucleus in association with Cajal bodies and cleavage bodies . PML bodies belong to the nuclear matrix , an ill - defined super - structure of the nucleus proposed to anchor and regulate many nuclear functions , including DNA replication , transcription , or epigenetic silencing . The PML protein is the key organizer of these domains that recruits an ever - growing number of proteins , whose only common known feature to date is their ability to be SUMOylated . Yet , pml<sup>-/-</sup> mice ( which have their PML gene deleted ) cannot assemble nuclear bodies , develop normally and live well , demonstrating that PML bodies are dispensable for most basic biological functions .

===== Splicing speckles =====

Speckles are subnuclear structures that are enriched in pre - messenger RNA splicing factors and are located in the interchromatin regions of the nucleoplasm of mammalian cells . At the fluorescence - microscope level they appear as irregular , punctate structures , which vary in size and shape , and when examined by electron microscopy they are seen as clusters of interchromatin granules . Speckles are dynamic structures , and both their protein and RNA - protein components can cycle continuously between speckles and other nuclear locations , including active transcription sites . Studies on the composition , structure and behaviour of speckles have provided a model for understanding the functional compartmentalization of the nucleus and the organization of the gene - expression machinery splicing snRNPs and other splicing proteins necessary for pre - mRNA processing . Because of a cell 's changing requirements , the composition and location of these bodies changes according to mRNA transcription and regulation via phosphorylation of specific proteins . The splicing speckles are also known as nuclear speckles ( nuclear specks ) , splicing factor compartments ( SF compartments ) , interchromatin granule clusters ( IGCs ) , B snurposomes . B snurposomes are found in the amphibian oocyte nuclei and in Drosophila melanogaster embryos . B snurposomes appear alone or attached to the Cajal bodies in the electron micrographs of the amphibian nuclei . IGCs function as storage sites for the splicing factors .

===== Paraspeckles =====

Discovered by Fox et al. in 2002 , paraspeckles are irregularly shaped compartments in the nucleus ' interchromatin space . First documented in HeLa cells , where there are generally 10 - 30 per nucleus , paraspeckles are now known to also exist in all human primary cells , transformed cell lines , and tissue sections . Their name is derived from their distribution in the nucleus ; the " para " is short for parallel and the " speckles " refers to the splicing speckles to which they are always in close proximity .

Paraspeckles are dynamic structures that are altered in response to changes in cellular metabolic activity . They are transcription dependent and in the absence of RNA Pol II transcription , the paraspeckle disappears and all of its associated protein components ( PSP1 , p54nrb , PSP2 , CFI ( m ) 68 , and PSF ) form a crescent shaped perinucleolar cap in the nucleolus . This phenomenon is demonstrated during the cell cycle . In the cell cycle , paraspeckles are present during interphase and during all of mitosis except for telophase . During telophase , when the two daughter nuclei are formed , there is no RNA Pol II transcription so the protein components instead form a perinucleolar

cap .

=== Perichromatin fibrils ===

Perichromatin fibrils are visible only under electron microscope . They are located next to the transcriptionally active chromatin and are hypothesized to be the sites of active pre mRNA processing .

== Function ==

The nucleus provides a site for genetic transcription that is segregated from the location of translation in the cytoplasm , allowing levels of gene regulation that are not available to prokaryotes . The main function of the cell nucleus is to control gene expression and mediate the replication of DNA during the cell cycle .

The nucleus is an organelle found in eukaryotic cells . Inside its fully enclosed nuclear membrane , it contains the majority of the cell 's genetic material . This material is organized as DNA molecules , along with a variety of proteins , to form chromosomes .

=== Cell compartmentalization ===

The nuclear envelope allows the nucleus to control its contents , and separate them from the rest of the cytoplasm where necessary . This is important for controlling processes on either side of the nuclear membrane . In most cases where a cytoplasmic process needs to be restricted , a key participant is removed to the nucleus , where it interacts with transcription factors to downregulate the production of certain enzymes in the pathway . This regulatory mechanism occurs in the case of glycolysis , a cellular pathway for breaking down glucose to produce energy . Hexokinase is an enzyme responsible for the first the step of glycolysis , forming glucose 6 phosphate from glucose . At high concentrations of fructose 6 phosphate , a molecule made later from glucose 6 phosphate , a regulator protein removes hexokinase to the nucleus , where it forms a transcriptional repressor complex with nuclear proteins to reduce the expression of genes involved in glycolysis .

In order to control which genes are being transcribed , the cell separates some transcription factor proteins responsible for regulating gene expression from physical access to the DNA until they are activated by other signaling pathways . This prevents even low levels of inappropriate gene expression . For example , in the case of NF  $\kappa$ B controlled genes , which are involved in most inflammatory responses , transcription is induced in response to a signal pathway such as that initiated by the signaling molecule TNF , binds to a cell membrane receptor , resulting in the recruitment of signalling proteins , and eventually activating the transcription factor NF  $\kappa$ B . A nuclear localisation signal on the NF  $\kappa$ B protein allows it to be transported through the nuclear pore and into the nucleus , where it stimulates the transcription of the target genes .

The compartmentalization allows the cell to prevent translation of unspliced mRNA . Eukaryotic mRNA contains introns that must be removed before being translated to produce functional proteins . The splicing is done inside the nucleus before the mRNA can be accessed by ribosomes for translation . Without the nucleus , ribosomes would translate newly transcribed ( unprocessed ) mRNA , resulting in malformed and nonfunctional proteins .

=== Gene expression ===

Gene expression first involves transcription , in which DNA is used as a template to produce RNA . In the case of genes encoding proteins , that RNA produced from this process is messenger RNA ( mRNA ) , which then needs to be translated by ribosomes to form a protein . As ribosomes are located outside the nucleus , mRNA produced needs to be exported .

Since the nucleus is the site of transcription , it also contains a variety of proteins that either directly

mediate transcription or are involved in regulating the process . These proteins include helicases , which unwind the double @-@ stranded DNA molecule to facilitate access to it , RNA polymerases , which synthesize the growing RNA molecule , topoisomerases , which change the amount of supercoiling in DNA , helping it wind and unwind , as well as a large variety of transcription factors that regulate expression .

= = = Processing of pre @-@ mRNA = = =

Newly synthesized mRNA molecules are known as primary transcripts or pre @-@ mRNA . They must undergo post @-@ transcriptional modification in the nucleus before being exported to the cytoplasm ; mRNA that appears in the cytoplasm without these modifications is degraded rather than used for protein translation . The three main modifications are 5 ' capping , 3 ' polyadenylation , and RNA splicing . While in the nucleus , pre @-@ mRNA is associated with a variety of proteins in complexes known as heterogeneous ribonucleoprotein particles ( hnRNPs ) . Addition of the 5 ' cap occurs co @-@ transcriptionally and is the first step in post @-@ transcriptional modification . The 3 ' poly @-@ adenine tail is only added after transcription is complete .

RNA splicing , carried out by a complex called the spliceosome , is the process by which introns , or regions of DNA that do not code for protein , are removed from the pre @-@ mRNA and the remaining exons connected to re @-@ form a single continuous molecule . This process normally occurs after 5 ' capping and 3 ' polyadenylation but can begin before synthesis is complete in transcripts with many exons . Many pre @-@ mRNAs , including those encoding antibodies , can be spliced in multiple ways to produce different mature mRNAs that encode different protein sequences . This process is known as alternative splicing , and allows production of a large variety of proteins from a limited amount of DNA .

= = Dynamics and regulation = =

= = = Nuclear transport = = =

The entry and exit of large molecules from the nucleus is tightly controlled by the nuclear pore complexes . Although small molecules can enter the nucleus without regulation , macromolecules such as RNA and proteins require association karyopherins called importins to enter the nucleus and exportins to exit . " Cargo " proteins that must be translocated from the cytoplasm to the nucleus contain short amino acid sequences known as nuclear localization signals , which are bound by importins , while those transported from the nucleus to the cytoplasm carry nuclear export signals bound by exportins . The ability of importins and exportins to transport their cargo is regulated by GTPases , enzymes that hydrolyze the molecule guanosine triphosphate to release energy . The key GTPase in nuclear transport is Ran , which can bind either GTP or GDP ( guanosine diphosphate ) , depending on whether it is located in the nucleus or the cytoplasm . Whereas importins depend on RanGTP to dissociate from their cargo , exportins require RanGTP in order to bind to their cargo .

Nuclear import depends on the importin binding its cargo in the cytoplasm and carrying it through the nuclear pore into the nucleus . Inside the nucleus , RanGTP acts to separate the cargo from the importin , allowing the importin to exit the nucleus and be reused . Nuclear export is similar , as the exportin binds the cargo inside the nucleus in a process facilitated by RanGTP , exits through the nuclear pore , and separates from its cargo in the cytoplasm .

Specialized export proteins exist for translocation of mature mRNA and tRNA to the cytoplasm after post @-@ transcriptional modification is complete . This quality @-@ control mechanism is important due to these molecules ' central role in protein translation . Mis @-@ expression of a protein due to incomplete excision of exons or mis @-@ incorporation of amino acids could have negative consequences for the cell ; thus , incompletely modified RNA that reaches the cytoplasm is degraded rather than used in translation .

= = = Assembly and disassembly = = =

During its lifetime , a nucleus may be broken down or destroyed , either in the process of cell division or as a consequence of apoptosis ( the process of programmed cell death ) . During these events , the structural components of the nucleus ? the envelope and lamina ? can be systematically degraded . In most cells , the disassembly of the nuclear envelope marks the end of the prophase of mitosis . However , this disassembly of the nucleus is not a universal feature of mitosis and does not occur in all cells . Some unicellular eukaryotes ( e.g. , yeasts ) undergo so @-@ called closed mitosis , in which the nuclear envelope remains intact . In closed mitosis , the daughter chromosomes migrate to opposite poles of the nucleus , which then divides in two . The cells of higher eukaryotes , however , usually undergo open mitosis , which is characterized by breakdown of the nuclear envelope . The daughter chromosomes then migrate to opposite poles of the mitotic spindle , and new nuclei reassemble around them .

At a certain point during the cell cycle in open mitosis , the cell divides to form two cells . In order for this process to be possible , each of the new daughter cells must have a full set of genes , a process requiring replication of the chromosomes as well as segregation of the separate sets . This occurs by the replicated chromosomes , the sister chromatids , attaching to microtubules , which in turn are attached to different centrosomes . The sister chromatids can then be pulled to separate locations in the cell . In many cells , the centrosome is located in the cytoplasm , outside the nucleus ; the microtubules would be unable to attach to the chromatids in the presence of the nuclear envelope . Therefore , the early stages in the cell cycle , beginning in prophase and until around prometaphase , the nuclear membrane is dismantled . Likewise , during the same period , the nuclear lamina is also disassembled , a process regulated by phosphorylation of the lamins by protein kinases such as the CDC2 protein kinase . Towards the end of the cell cycle , the nuclear membrane is reformed , and around the same time , the nuclear lamina are reassembled by dephosphorylating the lamins .

However , in dinoflagellates , the nuclear envelope remains intact , the centrosomes are located in the cytoplasm , and the microtubules come in contact with chromosomes , whose centromeric regions are incorporated into the nuclear envelope ( the so @-@ called closed mitosis with extranuclear spindle ) . In many other protists ( e.g. , ciliates , sporozoans ) and fungi , the centrosomes are intranuclear , and their nuclear envelope also does not disassemble during cell division .

Apoptosis is a controlled process in which the cell 's structural components are destroyed , resulting in death of the cell . Changes associated with apoptosis directly affect the nucleus and its contents , for example , in the condensation of chromatin and the disintegration of the nuclear envelope and lamina . The destruction of the lamin networks is controlled by specialized apoptotic proteases called caspases , which cleave the lamin proteins and , thus , degrade the nucleus ' structural integrity . Lamin cleavage is sometimes used as a laboratory indicator of caspase activity in assays for early apoptotic activity . Cells that express mutant caspase @-@ resistant lamins are deficient in nuclear changes related to apoptosis , suggesting that lamins play a role in initiating the events that lead to apoptotic degradation of the nucleus . Inhibition of lamin assembly itself is an inducer of apoptosis .

The nuclear envelope acts as a barrier that prevents both DNA and RNA viruses from entering the nucleus . Some viruses require access to proteins inside the nucleus in order to replicate and / or assemble . DNA viruses , such as herpesvirus replicate and assemble in the cell nucleus , and exit by budding through the inner nuclear membrane . This process is accompanied by disassembly of the lamina on the nuclear face of the inner membrane .

= = = Disease @-@ related dynamics = = =

Initially , it has been suspected that immunoglobulins in general and autoantibodies in particular do not enter the nucleus . Now there is a body of evidence that under pathological conditions ( e.g. lupus erythematosus ) IgG can enter the nucleus .



= = Nuclei per cell = =

Most eukaryotic cell types usually have a single nucleus , but some have no nuclei , while others have several . This can result from normal development , as in the maturation of mammalian red blood cells , or from faulty cell division .

= = = Anucleated cells = = =

An anucleated cell contains no nucleus and is , therefore , incapable of dividing to produce daughter cells . The best @-@ known anucleated cell is the mammalian red blood cell , or erythrocyte , which also lacks other organelles such as mitochondria , and serves primarily as a transport vessel to ferry oxygen from the lungs to the body 's tissues . Erythrocytes mature through erythropoiesis in the bone marrow , where they lose their nuclei , organelles , and ribosomes . The nucleus is expelled during the process of differentiation from an erythroblast to a reticulocyte , which is the immediate precursor of the mature erythrocyte . The presence of mutagens may induce the release of some immature " micronucleated " erythrocytes into the bloodstream . Anucleated cells can also arise from flawed cell division in which one daughter lacks a nucleus and the other has two nuclei .

In flowering plants , this condition occurs in sieve tube elements .

= = = Multinucleated cells = = =

Multinucleated cells contain multiple nuclei . Most acanthorean species of protozoa and some fungi in mycorrhizae have naturally multinucleated cells . Other examples include the intestinal parasites in the genus *Giardia* , which have two nuclei per cell . In humans , skeletal muscle cells , called myocytes and syncytium , become multinucleated during development ; the resulting arrangement of nuclei near the periphery of the cells allows maximal intracellular space for myofibrils . Multinucleated and binucleated cells can also be abnormal in humans ; for example , cells arising from the fusion of monocytes and macrophages , known as giant multinucleated cells , sometimes accompany inflammation and are also implicated in tumor formation .

A number of dinoflagelates are known to have two nuclei . Unlike other multinucleated cells these nuclei contain two distinct lineages of DNA : one from the dinoflagellate and the other from a symbiotic diatom . Curiously the mitochondrion and the plastid of the diatom remain functional .

= = Evolution = =

As the major defining characteristic of the eukaryotic cell , the nucleus ' evolutionary origin has been the subject of much speculation . Four major hypotheses have been proposed to explain the existence of the nucleus , although none have yet earned widespread support .

The first model known as the " syntrophic model " proposes that a symbiotic relationship between the archaea and bacteria created the nucleus @-@ containing eukaryotic cell . ( Organisms of the Archaea and Bacteria domain have no cell nucleus . ) It is hypothesized that the symbiosis originated when ancient archaea , similar to modern methanogenic archaea , invaded and lived within bacteria similar to modern myxobacteria , eventually forming the early nucleus . This theory is analogous to the accepted theory for the origin of eukaryotic mitochondria and chloroplasts , which are thought to have developed from a similar endosymbiotic relationship between proto @-@ eukaryotes and aerobic bacteria . The archaeal origin of the nucleus is supported by observations that archaea and eukarya have similar genes for certain proteins , including histones . Observations that myxobacteria are motile , can form multicellular complexes , and possess kinases and G proteins similar to eukarya , support a bacterial origin for the eukaryotic cell .

A second model proposes that proto @-@ eukaryotic cells evolved from bacteria without an endosymbiotic stage . This model is based on the existence of modern planctomycetes bacteria that

possess a nuclear structure with primitive pores and other compartmentalized membrane structures . A similar proposal states that a eukaryote @-@ like cell , the chronocyte , evolved first and phagocytosed archaea and bacteria to generate the nucleus and the eukaryotic cell .

The most controversial model , known as viral eukaryogenesis , posits that the membrane @-@ bound nucleus , along with other eukaryotic features , originated from the infection of a prokaryote by a virus . The suggestion is based on similarities between eukaryotes and viruses such as linear DNA strands , mRNA capping , and tight binding to proteins ( analogizing histones to viral envelopes ) . One version of the proposal suggests that the nucleus evolved in concert with phagocytosis to form an early cellular " predator " . Another variant proposes that eukaryotes originated from early archaea infected by poxviruses , on the basis of observed similarity between the DNA polymerases in modern poxviruses and eukaryotes . It has been suggested that the unresolved question of the evolution of sex could be related to the viral eukaryogenesis hypothesis .

A more recent proposal , the exomembrane hypothesis , suggests that the nucleus instead originated from a single ancestral cell that evolved a second exterior cell membrane ; the interior membrane enclosing the original cell then became the nuclear membrane and evolved increasingly elaborate pore structures for passage of internally synthesized cellular components such as ribosomal subunits .

= = Gallery = =