Nucleus and ribosomes

Structure and function of the nucleus and ribosomes of a cell. How they work together in the production of proteins.

Introduction

Suppose that you have a very precious piece of information. Let's imagine that this piece of information is a blueprint. In fact, it's not just a blueprint for a house, or a car, or even a top-secret fighter jet. It's a blueprint for an entire organism – you – and it not only specifies how to put you together, but also provides the information that enables every cell in your body to keep functioning from moment to moment.

Sounds important, right? You'd probably want to keep information this valuable in a secure spot, perhaps in a protected vault where you can keep an eye on it. In fact, that's exactly what eukaryotic cells do with their genetic material, placing it in a membrane-enclosed repository called the nucleus.

Eukaryotic DNA never leaves the nucleus; instead, it's transcribed (copied) into RNA molecules, which may then travel out of the nucleus. In the cytosol, some RNAs associate with structures called ribosomes, where they direct synthesis of proteins. (Other RNAs play functional roles in the cell, serving as structural components of the ribosome or regulating activity of genes.) Here, we'll look in a little more detail at the structure of the nucleus and ribosomes.

The nucleus

The **nucleus** (plural, **nuclei**) houses the cell's genetic material, or DNA, and is also the site of synthesis for ribosomes, the cellular machines that assemble proteins. Inside the nucleus, chromatin (DNA wrapped around proteins, described further below) is stored in a gel-like substance called **nucleoplasm**.

Enclosing the nucleoplasm is the **nuclear envelope**, which is made up of two layers of membrane: an outer membrane and an inner membrane. Each of these membranes contains two layers of phospholipids, arranged with their tails pointing inward (forming a phospholipid bilayer). There's a thin space between the two layers of the nuclear envelope, and this space is directly connected to the interior of another membranous organelle, the endoplasmic reticulum.

Nuclear pores, small channels that span the nuclear envelope, let substances enter and exit the nucleus. Each pore is lined by a set of proteins, called the nuclear pore complex, that control what molecules can go in or out.

If you look at a microscope image of the nucleus, you may notice – depending on the type of stain used to visualize the cell – that there's a dark spot inside it. This darkly staining region is called the **nucleolus**, and it's the site in which new ribosomes are assembled.

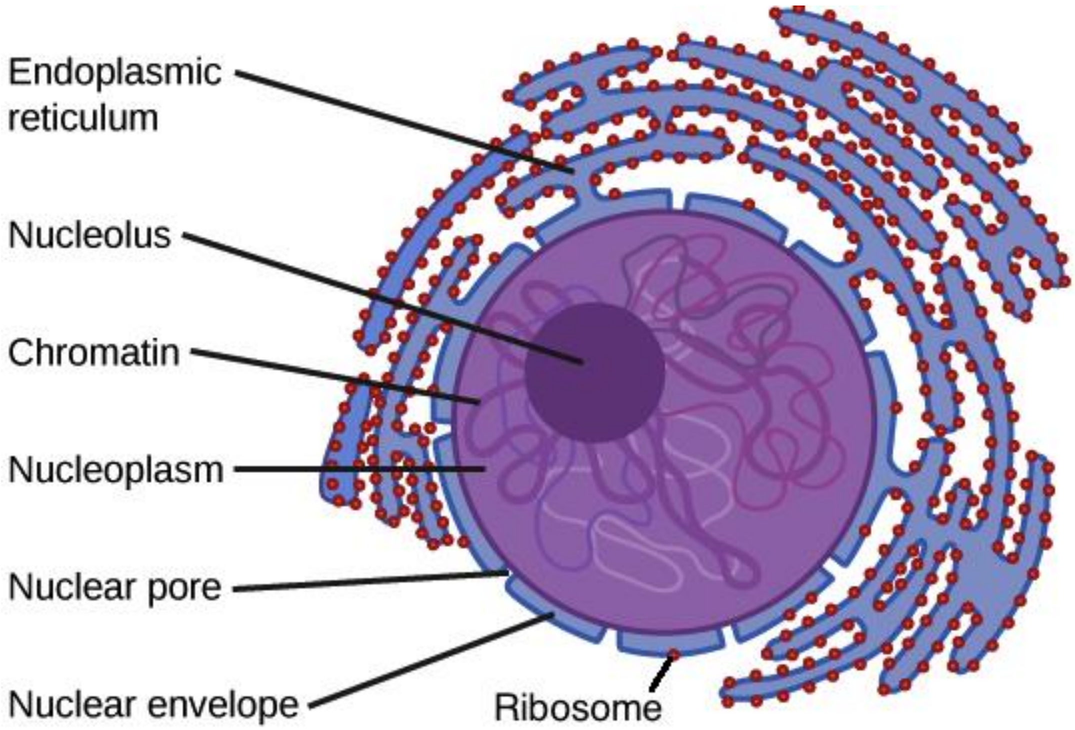


Diagram of the parts of the nucleus of a eukaryotic cell.

How do you make a ribosome? Some chromosomes have sections of DNA that encode ribosomal RNA, a type of structural RNA that combines with proteins to make the ribosome. In the nucleolus, new ribosomal RNA combines with proteins to form the subunits of the ribosome. The newly made subunits are transported out through the nuclear pores to the cytoplasm, where they can do their job.

Some cell types have more than one nucleolus inside the nucleus. For instance, some mouse cells have up to 666 nucleoli^1[1]start superscript, 1, end superscript. Prokaryotes, which do not have a nucleus, don't have nucleoli and build their ribosomes in the cytosol.

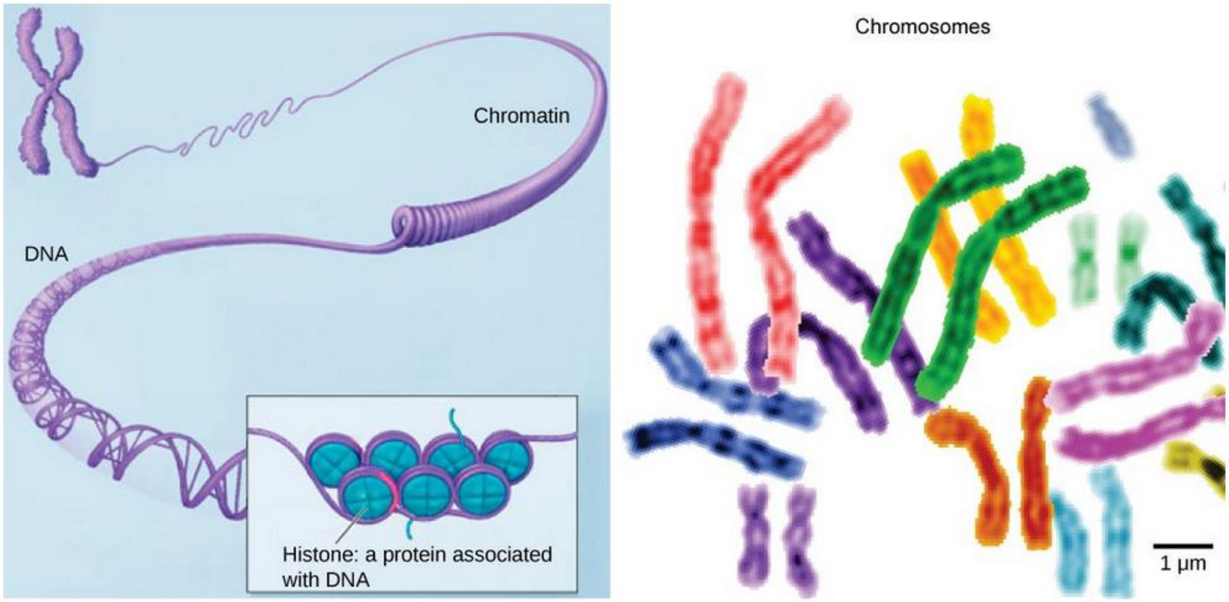
Chromosomes and DNA

Now that we have a sense of the structure of the nucleus, let's have a closer look at the genetic information stored inside it: the DNA. Most of an organism's DNA is organized into one or more **chromosomes**, each of which is a very long string or loop of DNA. A single chromosome can carry many different genes.

In prokaryotes, DNA is typically organized into a single circular chromosome (a loop). In eukaryotes, on the other hand, chromosomes are linear structures (strings). Every eukaryotic species has a specific number of chromosomes in the nuclei of its body's cells. For example, a typical human body cell would have 464646 chromosomes, while a comparable fruit fly cell would have 888.

Chromosomes are only visible as distinct structures when the cell is getting ready to divide. When the cell is in the growth and maintenance phases of its life cycle, the chromosomes instead resemble an unwound, jumbled bunch of threads. In this form, the DNA is accessible to the enzymes that transcribe it into RNA, allowing the genetic information to be put to use (expressed).

In both their loose and compact forms, the DNA strands of chromosomes are bound to structural proteins, including a family of proteins called histones (see picture below). These DNA-associated proteins organize the DNA and help it fit into the nucleus, and they also play a role in determining which genes are active or inactive. The complex formed by DNA and its supporting structural proteins is known as **chromatin**. You can learn more about DNA, chromatin, and chromosomes in the DNA and chromosomes article.



Left: image of a chromosome, showing how it is made up of DNA wound around histones and then arranged in loops and other higher-order structures. Right: false-colored and rearranged micrograph of chromosomes.

To give you a sense of just how important DNA packing is, consider that the DNA in a typical human cell would be about 222 meters long if it were extended in a straight line. All 222 meters of that DNA are squeezed into a tiny nucleus with a diameter of just 0.0060.0060, point, 006 mm. That's a feat "geometrically equivalent to packing 404040 km (242424 miles) of extremely fine thread into a tennis ball" ^4[4]start superscript, 4, end superscript!

Ribosomes

As mentioned above, **ribosomes** are the molecular machines responsible for protein synthesis. A ribosome is made out of RNA and proteins, and each ribosome consists of two separate RNA-protein complexes, known as the small and large subunits. The large subunit sits on top of the small subunit, with an RNA template sandwiched between the two. (A ribosome looks a little like a hamburger with a puffy bun on top, an RNA "patty" threading through it.)

In eukaryotes, ribosomes get their orders for protein synthesis from the nucleus, where portions of DNA (genes) are transcribed to make messenger RNAs (mRNAs). An mRNA travels to the ribosome, which uses the information it contains to build a protein with a specific amino acid sequence. This process is called **translation**. Prokaryotes lack a nucleus, so their mRNAs are transcribed in the cytoplasm and can be translated by ribosomes immediately.

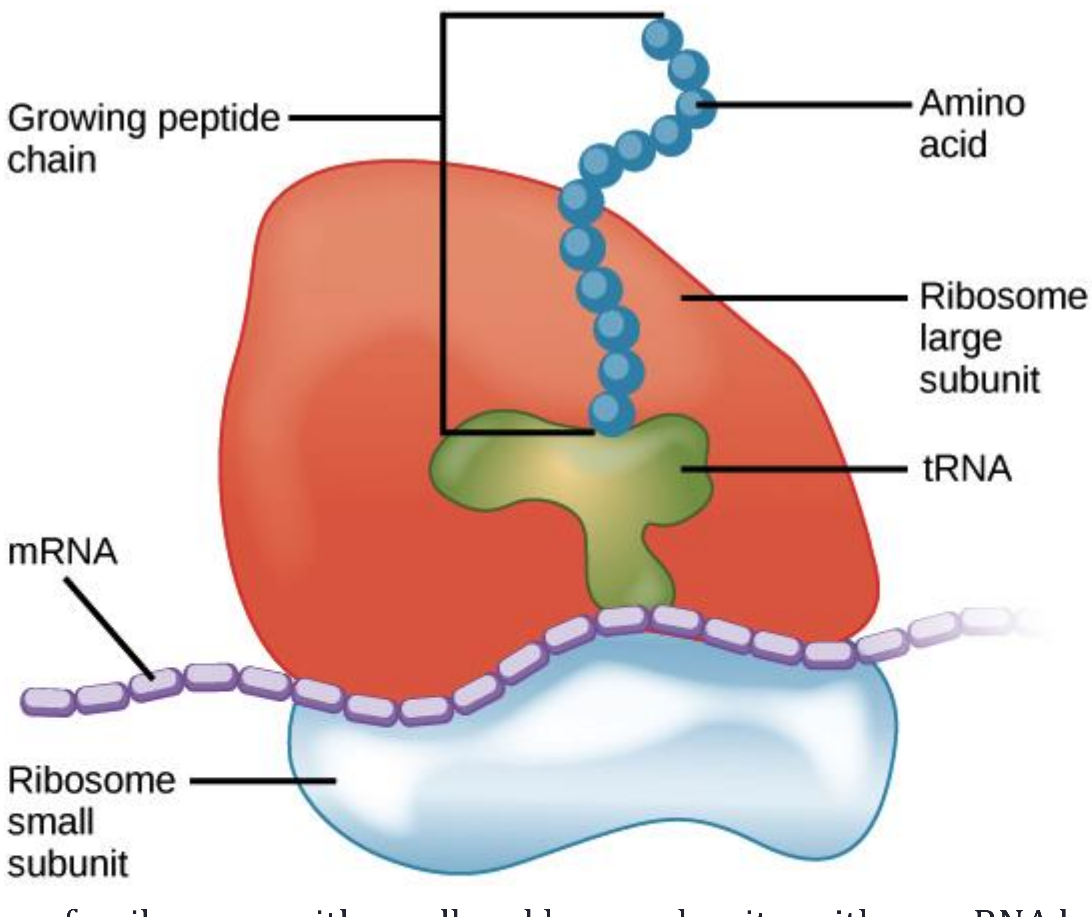


Image of a ribosome with small and large subunits, with an mRNA bound and a polypeptide chain being produced. A tRNA molecule is shown binding to the mRNA and bringing the appropriate amino acid into position for addition to the chain.

Image credit: OpenStax Biology.

Eukaryotic ribosomes may be either free, meaning that they are floating around in the cytoplasm, or bound, meaning that they are attached to the endoplasmic reticulum or the outside of the nuclear envelope. (In the first diagram in this article, the red dots represent bound ribosomes; endoplasmic reticulum with bound ribosomes is known as **rough endoplasmic reticulum**.)

Because protein synthesis is an essential function of all cells, ribosomes are found in practically every cell type of multicellular organisms, as well as in prokaryotes such as bacteria. However, eukaryotic cells that specialize in producing proteins have particularly large numbers of ribosomes. For example, the pancreas is responsible for producing and secreting large amounts of digestive enzymes, so the pancreatic cells that make these enzymes have an unusually high number of ribosomes.

Final fun fact: in a testament to the importance of the ribosome, the 2009 Nobel Prize in Chemistry was awarded to three researchers who mapped its structure and movements down to the level of individual atoms using a technique called X-ray crystallography^5[5]start superscript, 5, end superscript.