READINGS FROM

Introduction to the Science of Cancer

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Anatomy of a Cell

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Anatomy of a Cell

All cancers begin in a cell. This chapter will help you learn more about cells and their components. Cells are the basic building blocks of the human body. All human beings begin life as a single cell — a fertilized egg. That one cell contains all the genetic information needed to make a human being. The fertilized egg divides to produce two daughter cells, each with the same set of genetic information. The cell division continues in a very controlled way, producing generation upon generation of cells until a human being is formed. Along the way, certain cells differentiate to form the roughly 200 different types of cells that make up the tissues found in the human body. Here are a few interesting numbers about cells:

- The average human cell is about 10 microns across, or about 1/10th the thickness of a human hair
- The human body is made up of an estimated 37.2 trillion cells
- An estimated 1 x 10^{16} cell divisions take place in the human body over an average lifespan[1]

Cells take many shapes, depending on their task in the body. They can be cubes, rectangles, spheres, flattened or star-like, like certain cells in the brain. Some cells even change shape as they mature. Cells of the skin, for example, begin as cubes but flatten to become squamous cells at the skin's surface, where they are sloughed off.

A typical cell has three main areas. Envision an avocado or a hard-boiled egg as a model of a cell:

- Inside, a typical cell has a nucleus, just as the avocado and egg have a pit and yolk. The cell nucleus contains the cell's genetic information, which is stored in the form of long strands of DNA
- While the avocado and egg are bounded by a skin and a shell, a cell is bounded by a membrane. But while avocado skins and egg shells are hard, the membrane surrounding a cell is a thin, delicate layer of lipid (fat) and protein
- Just as the avocado has fruit between the pit and the skin, and egg white lies between the yolk and the shell, cells have a region called the cytoplasm between the nucleus and cell membrane. The cytoplasm contains structures called organelles that maintain the life and health of the cell—just as the human body has organs that maintain life and health. The organelles carry out

[1] From: Molecular Biology of the Cell. Alberts B., Johnson A., Lewis J, et al. 4th ed. 2002.

critical processes such as producing the energy and making the proteins and other molecules needed to keep the cell and body alive.

Cell membrane

The cell membrane, also called the plasma membrane, encapsulates the cell and plays an important role in cancer. The membrane is made of fat-like lipid molecules. These molecules have a head that is water-loving, or hydrophilic, and two tails that are water-hating, or hydrophobic. In the cell membrane, these lipid molecules lie side by side — heads out, tails in — to form a double layer called a lipid bilayer.

The lipid bilayer is the structural framework of the cell membrane. From the outside, it might appear like a ball formed of marbles. Penetrating this spherical wall of marbles are potato-shaped and spaghetti-like objects. These are protein molecules that carry out the activities of the membrane. Many membrane proteins fall into one of three groups:

- **Receptor molecules**, also called cell-surface receptors. These molecules work like switches. They are activated by hormones, growth factors and other substances in the body and cause changes in cells. Receptor molecules play an important role in cancer

- **Transport molecules** help control what enters and leaves cells

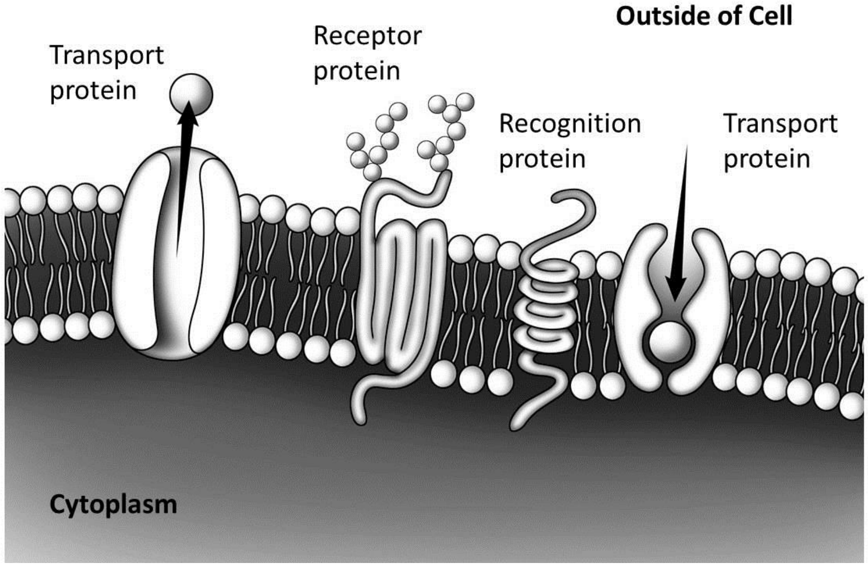
- **Recognition molecules** function like flags and signposts. They allow cells to identify and interact with one another

A closer look at receptor molecules

Cell-surface receptor molecules extend from the cell surface at one end and poke down below the cell membrane at the other end. There are many types of receptor molecules, and each is sensitive to a particular substance, such as a hormone and growth factors. When a hormone links to, or binds with, its receptor, it sends a message to one or more genes in the cell nucleus. The message can turn on or turn off the activity of that gene or genes and cause the cell to divide or behave in a certain way.

In some cancers, cells have too many of certain receptor molecules, causing the cells to grow when they shouldn’t. For example, in many cases of breast cancer, breast cells have too many receptors for the hormone estrogen. As a result, estrogen in the body stimulates the growth of such tumors. Similarly, many cases of prostate cancer occur because certain prostate cells have too many androgen (male hormone) receptors. The hormone testosterone promotes the growth and progression of these tumors. Such estrogen-receptor-positive and androgen-receptor-positive tumors are treated with drugs that block the receptors so that the hormone cannot activate the receptor and promote tumor growth. (Note: Estrogen and androgen receptors are found inside the cell, not on the cell surface.)

Transport molecules help control which molecules enter and leave cells. Some form pores in the cell membrane; others open and close like gates to control the movement of molecules into and out of the cell. Certain transport proteins are present in cancer cells at abnormally high levels, enabling the cells to resist chemotherapy drugs. When the transport protein called P-glycoprotein, for example, is overactive in cancer cells, it pumps an anticancer drug out of the cell before the drug can kill the cancer cell.



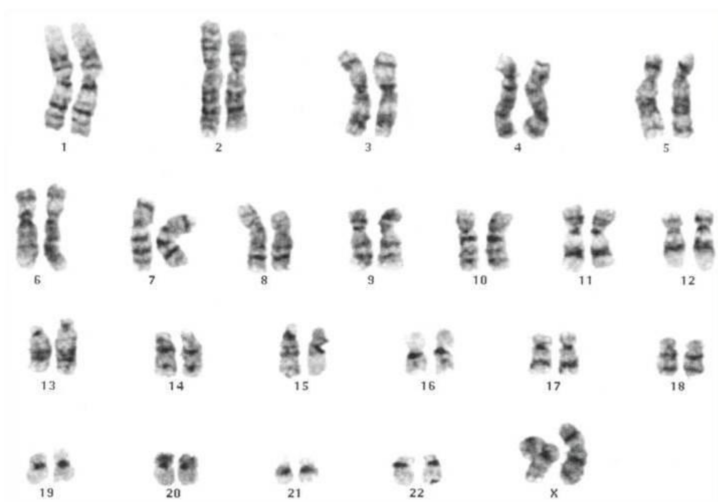
The cell membrane consists of a lipid bilayer embedded with protein molecules that do a variety of jobs.

Recognition proteins help cells identify and interact with one another. Recognition proteins, or the lack of them, play important roles in cancer. When healthy cells touch one another through their recognition, this contact inhibits their further growth (cell division). Cancer cells overcome this control to form a tumor, invade neighboring tissues and spread or metastasize to other areas of the body.

Immune cells use recognition proteins to tell whether another cell is foreign and should be destroyed. Bone marrow transplants are used to treat leukemias and other cancers. If the donated immune cells come from another person, they sometimes recognize the patient's tissue as foreign and attack it. This response is called graft-versus-host disease, and it can be fatal if not successfully treated.

The nucleus

The nucleus is a sphere within the cell that contains genetic information. The nucleus is also bounded by a lipid bilayer. The nuclear membrane also has pores that allow molecules to move between the nucleus and the cytoplasm. The genetic information in the nucleus is stored as 23 pairs of chromosomes—one pair comes from the person's mother and one from the



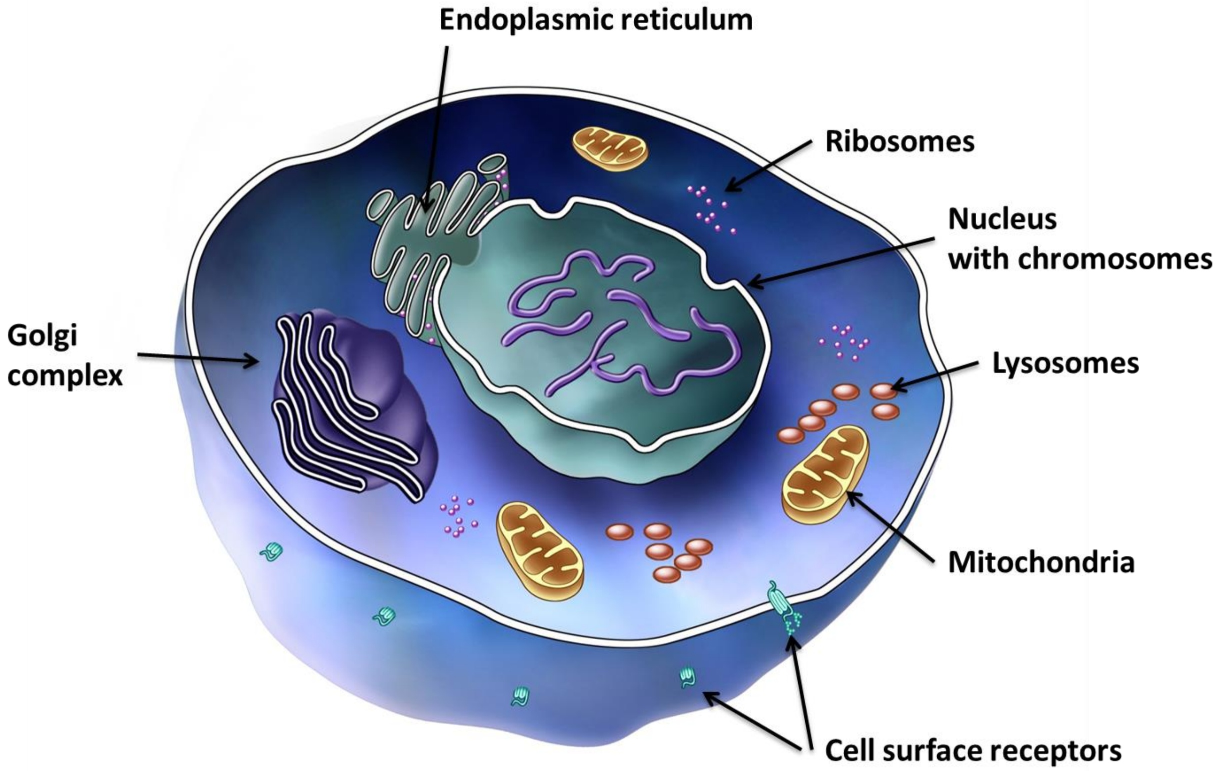
Humans have 23 pairs of chromosomes. They are shown here specially prepared for comparison. There are two X chromosomes, so this set came from a female.

father.

Each chromosome is a strand of DNA that is divided into genes and has a coating of proteins. Human beings have about 20,000 genes total. The entire set is called the genome. Damage to a cell's DNA results in changes to one or more genes, and sometimes to chromosomes. Such damage is the fundamental cause of cancer.

Cell cytoplasm

Cells have a variety of organelles located in the cytoplasm. Each performs specific functions that help maintain the life and health of the cell and enable cells to carry out their function in the body. This diagram of a generalized cell shows the key cell organelles.



- **Nucleus with chromosomes** – The nucleus is also an organelle and the largest in the cell
- **Mitochondria** are factories that produce the energy needed by the cell and the body for life; they produce this energy using glucose, oxygen and water
- **Lysosomes** are packages of enzymes used to break down (metabolize) nutrients and other things cells take up
- **Ribosomes** are tiny organelles involved in synthesizing proteins

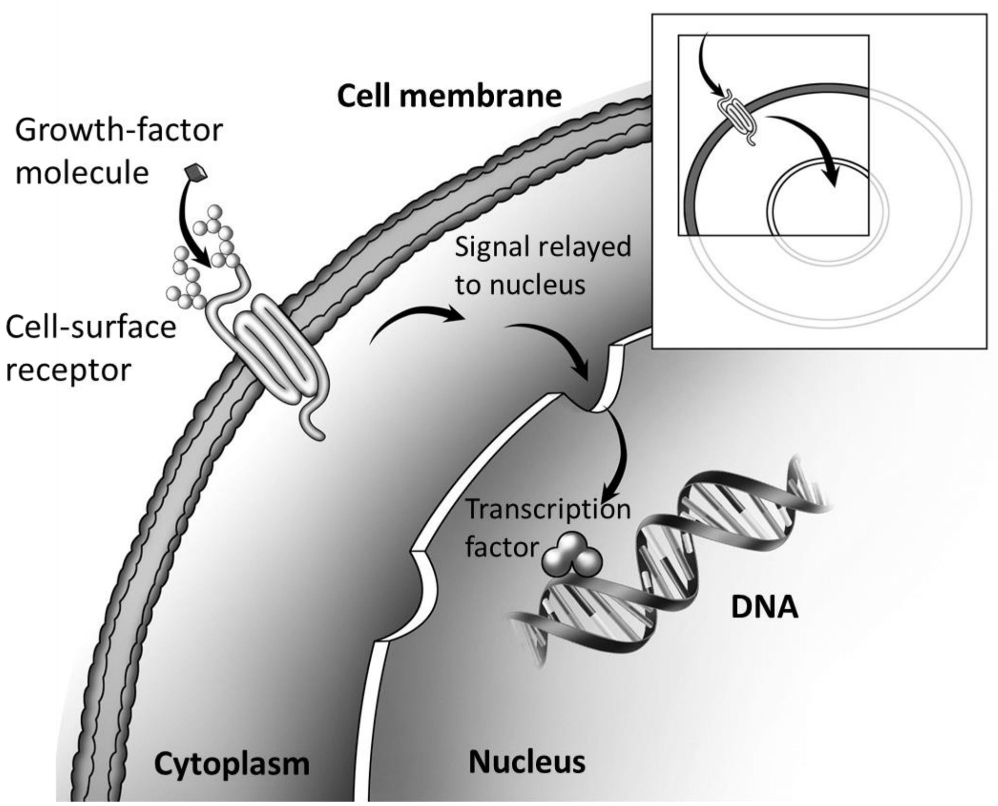
- **Endoplasmic reticulum** consists of channels within cells that are involved in synthesizing proteins and lipids
- **Golgi complex** consists of layers of sack-like spaces that package proteins that are to be released, or secreted, by the cell
- **Microtubules** (not shown) form a cell's skeleton and help move chromosomes during cell division.

Much of the business of cells involves producing energy and making proteins and other molecules needed for life. Cancer cells in particular need energy and produce molecules needed for growing and dividing. Cells complete these tasks using the information stored in their DNA and the organelles in their cytoplasm. Often, how cells behave, whether they grow and divide, is controlled by chemical messages received by the receptor molecules on their surface.

Signal transduction pathways

Messages received by receptors at the cell surface cause changes in genes deep inside the cell nucleus. Such signals can tell breast tumors to grow, for example. Cells in a woman's breast have receptors for growth factors. When growth factor molecules in the bloodstream attach to, or bind with, these receptors, they activate the receptor, causing the end of the molecule inside the cell to change shape.

Here's a simplified diagram showing how signals are transmitted through cells. When a growth factor binds with the receptor, it triggers a chemical signal that travels through the cytoplasm to the nucleus. There, special proteins called transcription factors bind with DNA and activate genes that cause the cancer cells to grow and divide.

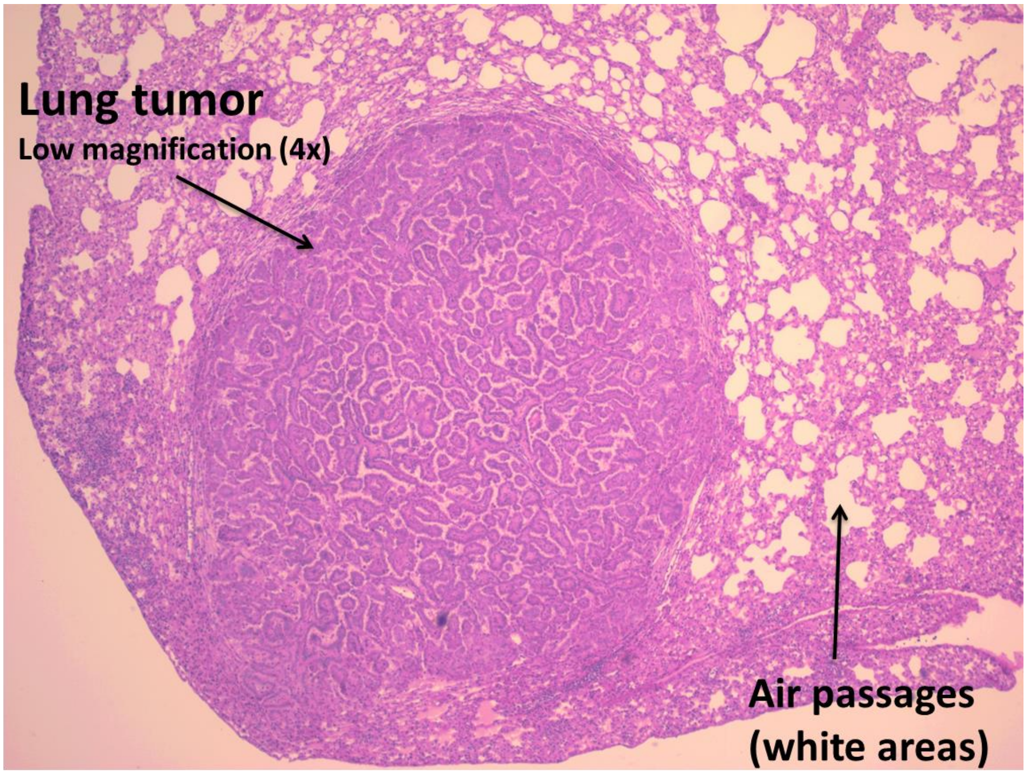


Healthy cells use the same "signal transduction pathways" to transmit chemical messages to genes, but in cancer cells these pathways are overactive due to gene mutations.

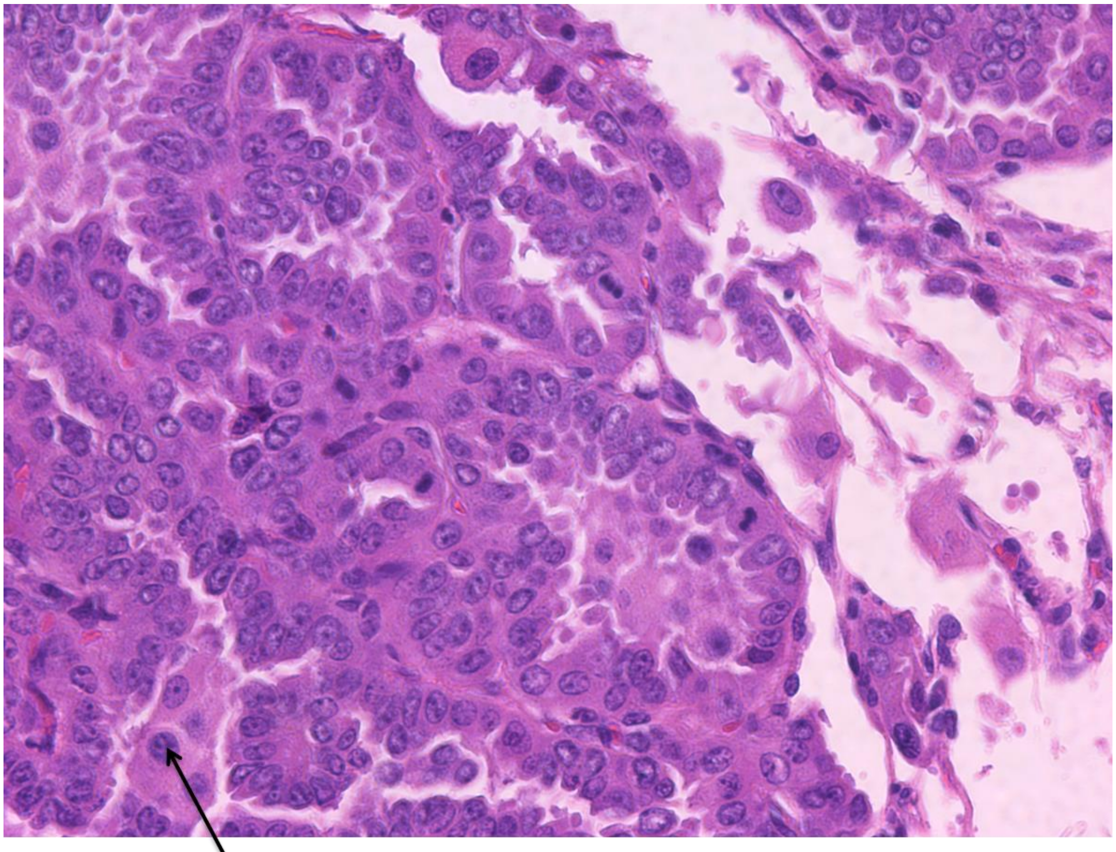
How cells look under a microscope

Cancer researchers learn a great deal about healthy cells and cancer cells by preserving them, staining them in different ways and then studying them under different kinds of microscopes. Below are a few examples of cells that have been prepared and stained in three different ways to bring out particular features:

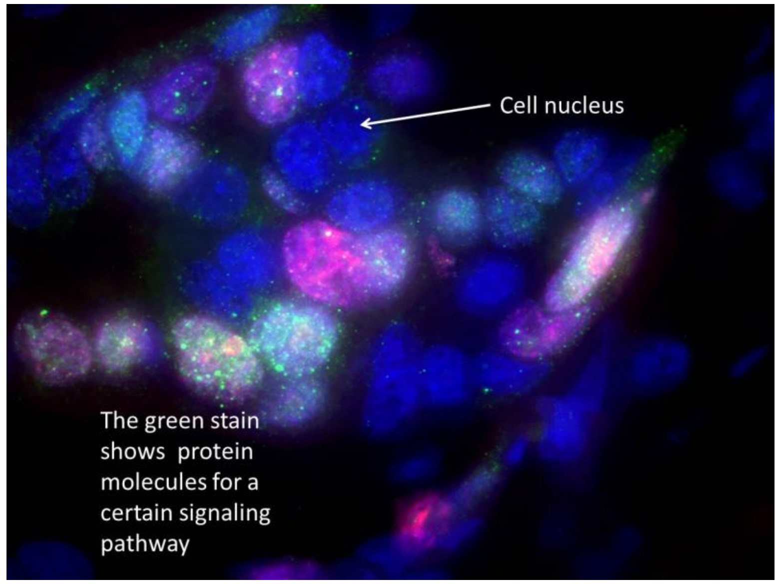
Here is an example of light microscopy. These are sections of tissue sliced very thin and stained in a way that colors the nucleus blue and the cytoplasm pink. This is an example of a tumor that was growing in a human lung. The large round mass is the tumor; the white areas are air passages in the lung. This image was taken at low magnification (4x).



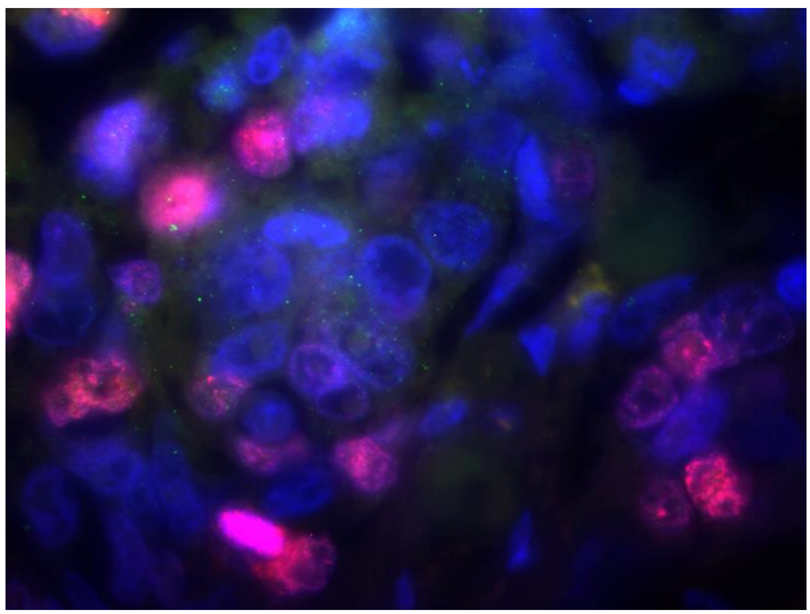
Here is an image of the lung tumor taken at much higher magnification (400x), which shows more of the cellular features of the tumor. The tumor mass is on the right side of the image. The cells shown are cancer cells. Each darker-blue circle is a cell nucleus. The nucleus of each cell is stained blue; the cytoplasm is stained pink. The air passages are white.



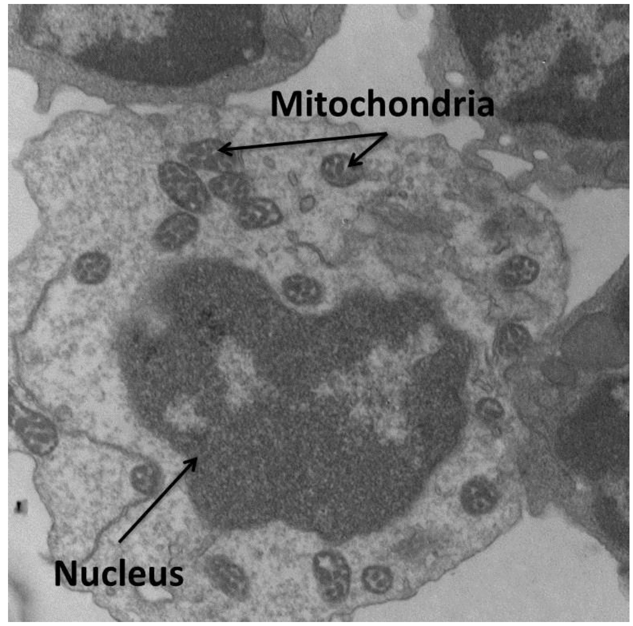
Next are two examples of immunofluorescent microscopy. The cells have been stained with dyes that emit light of different colors when exposed to ultraviolet light (UV). The cells are viewed through special UV microscopes. The image is also of a lung tumor from a patient photographed at much higher magnification. In the image at right, the blue color is cell nuclei. The green or yellowish color shows the presence of protein molecules for a particular signaling pathway that transmits signals from the cell surface to the nucleus.



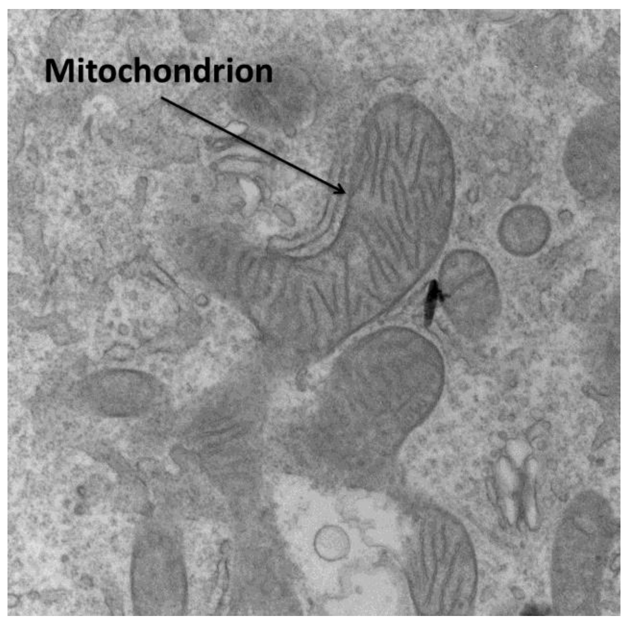
This second image shows a lung tumor from a different patient that was stained in the same way. The blue nuclei are visible, but the green stain is absent. This means that the particular cell-signaling pathway is not activated in this patient's tumor. Whether this signaling pathway is active, as in the previous photo, or not active, as in the photo at right, helps guide how best to treat these lung-cancer patients.



The third type of microscopy is electron microscopy. It uses a stream of electrons rather than light to view the cells. The cells are usually stained with gold or a metal that is electron dense. Cells can be viewed at much high magnification and resolution this way. In the image at right shows a cell from a lymphoid tumor. The nucleus is dark and clearly visible, along with mitochondria, the power-producing organelles of the cell.



The image at right of even greater magnification shows details of individual mitochondria. One difference between normal cells and cancer cells is that cancer cells have many more mitochondria.



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About The Ohio State University Comprehensive Cancer Center – Arthur G. James Cancer Hospital and Richard J. Solove Research Institute (OSUCCC – James)

The Ohio State University Comprehensive Cancer Center – Arthur G. James Cancer Hospital and Richard J. Solove Research Institute strives to create a cancer-free world by integrating scientific research with excellence in education and patient-centered care, a strategy that leads to better methods of prevention, detection and treatment. Ohio State is one of only 45 National Cancer Institute-designated Comprehensive Cancer Centers and one of only four centers funded by the NCI to conduct both phase I and phase II clinical trials on novel anticancer drugs. As the cancer program's 306-bed adult patient-care component, The James is one of the top cancer hospitals in the nation as ranked by U.S.News & World Report and has achieved Magnet® designation, the highest honor an organization can receive for quality patient care and professional nursing practice. At 21 floors with more than 1.1 million square feet, The James is a transformational facility that fosters collaboration and integration of cancer research and clinical cancer care. For more information, please visit cancer.osu.edu.