# Genes and Cancer

Cancer begins when some of the genes in a cell become abnormal, causing the cell to grow and divide out of control. Here you can learn more about how changes in a cell's genes can lead to cancer.

Gene Changes and Cancer

Mutations are abnormal changes in the DNA of a gene and can sometimes lead to cancer. Find out common causes.

Oncogenes, Tumor Suppressor Genes, and DNA Repair Genes

The main types of genes that play a role in cancer are oncogenes, tumor suppressor genes, and DNA repair genes. Learn more here.

Cancer-related Genomic Testing and Genetic Testing

Genetics focuses on individual genes and their effects, while genomics is the study of a person's entire set of genes (their genome). Learn about what genomic and genetic testing can show.

## Related Topics

Genetics and Cancer Risk

Some types of cancer run in certain families, but most cancers are not clearly linked to the genes we inherit from our parents. Gene changes that start in a single cell over the course of a person's life cause most cancers.

Biomarker Tests and Cancer Treatment

Finding certain genes or mutations can help diagnose and treat cancer. Learn more here.

Precision or Personalized Medicine

Precision medicine is a way health care providers can offer and plan specific care for their patients, based on the particular genes, proteins, and other substances in a person's body. Learn more here.

# Gene Changes and Cancer

The human body is made up of trillions of cells - the basic building blocks of any complex animal.

These cells normally work together to form organs, such as the heart, liver, and skin. In order for cells to work together, they have to have certain traits or characteristics. For example, they need to be able to divide to make new cells at the right time, stay where they're needed, and not crowd out nearby cells.

Cancer begins when cells in the body become abnormal and start to grow out of control. This is caused by certain changes in a cell's genes.



## What are genes?

**Genes** are pieces of DNA inside each cell. They tell the cell how to make the proteins it needs to function. Each gene contains the code (instructions) to make a certain protein, and each protein has a specific job. For example, some genes code for proteins that help the cell grow and divide to make new cells. Other genes code for proteins that help keep cell growth under control.

Genes are contained in **chromosomes**, which are long strands of DNA in each cell. Each chromosome has many different genes.

Most human cells have 23 pairs of chromosomes. One chromosome of each pair is inherited from a person's mother, and the other comes from their father. This is why children tend to look like their parents, and why certain diseases tend to run in families.

### Gene expression

All the cells in the body have the same genes, but each cell uses only the genes it needs. That is, it turns on (activates) the genes it needs at the right time and turns off other genes that it doesn't need. This is called **gene expression**. Turning on some genes and turning off others is how a cell becomes specialized, such as becoming a muscle cell or a bone cell, for example. Some genes stay active all the time to make proteins needed for basic cell functions. Other genes are shut down when their job is finished and can be turned on again later if needed.

## Changes in genes

While we all have basically the same set of genes, we also have differences in our genes that make each of us unique.

The ‘code’ or ‘blueprint’ for each gene is contained in chemicals called **nucleotides.** DNA is made up of 4 nucleotides (A, T, G, and C), which act like the letters of an alphabet. Each gene is made up of a long chain of nucleotides, the order of which tells the cell how to make a specific protein.

### Gene variants and mutations

Some people have changes in the nucleotides of a gene, which are known as **variants** (or **mutations**). For example, one nucleotide ‘letter’ might be switched for another, or one or more letters might be missing, when compared to most other people’s genes.

Gene variants can have different effects on the proteins they code for. For example:

- Some gene variants might not have any noticeable effect on the protein.
- Some variants might lead to very minor changes in the protein. For example, a variant might result in a protein that’s shaped a little differently and is therefore a bit less effective than the ‘normal’ version of the protein.
- Some variants might have larger effects. For example, a variant might result in a protein that doesn’t work at all.

Gene variants that lead to changes in proteins can affect all of the cells with that variant, which might even affect the whole body.

The overall effects of some gene variants might not necessarily be ‘good’ or ‘bad.’ For example, gene variants account for differences in people’s hair or eye color. On the other hand, some variants can lead to a disease (such as cancer) or increase the risk of a disease. These are referred to as **pathogenic variants**. (These are also what many people think of when they hear the term **mutation**.)

## When do genetic mutations occur?

Genetic mutations can be inherited from a parent (meaning a person has always had the mutation), but they can also happen at any time during a person's life.

### Inherited gene mutations and cancer

An **inherited gene mutation** is inherited from a parent, so it’s present in the very first cell (once the egg cell is fertilized by a sperm cell) that eventually becomes a person. Since all the cells in the body came from this first cell, this mutation is in every cell in the body, and can also be passed on to the next generation. This type of mutation is also called a **germline mutation** (because the cells that develop into eggs and sperm are called germ cells) or a **hereditary mutation**.

It typically takes more than one gene mutation for a cell to become a cancer cell. But when someone inherits an abnormal copy of a gene, their cells already start out with one mutation. This makes it easier (and quicker) for other mutations to happen, which can lead to a cell becoming a cancer cell. This is why cancers related to inherited mutations tend to occur earlier in life than cancers of the same type that are not inherited.

**Inherited gene mutations are not the main cause of most cancers.** To learn about some of the more common inherited gene mutations that can lead to cancer, see Family Cancer Syndromes[1].

### Acquired gene mutations and cancer

An **acquired gene mutation** is not inherited from a parent. Instead, it develops at some point during a person's life. Acquired mutations occur in one cell, and then are passed on to any new cells that come from that cell. This mutation cannot be passed on to a person's children, because it doesn’t affect their sperm or egg cells. This type of mutation is also called a **sporadic mutation** or a **somatic mutation**.

Acquired mutations can happen for different reasons. Sometimes they happen when a cell’s DNA is damaged, such as after being exposed to radiation or certain chemicals. But often these mutations occur randomly, without having an outside cause. For example, during the complex process when a cell divides to make 2 new cells, the cell must make another copy of all of its DNA, and sometimes mistakes (mutations) occur while this is happening. Every time a cell divides is another chance for gene mutations to occur. The number of mutations in our cells can build up over time, which is why we have a higher risk of cancer as we get older.

**Acquired gene mutations are a much more common cause of cancer than inherited mutations.**

## Other ways gene activity can be changed

Some of the changes inside cells that can lead to cancer don't involve gene variants or mutations. Cells can turn some of their genes on and off in other ways, and some of these might also affect how a cell grows and divides.

As mentioned earlier, different genes are more active in some cells than in others. Even within a certain cell, some genes are active at some times and inactive at others. Turning these genes on and off isn't done by changing the DNA sequence (as is the case with variants and mutations). Instead, the changes in gene activity occur by other means known as **epigenetic changes**. There are several types of these changes:

- **DNA methylation:** In this type of change, a small chemical group called a *methyl group* is attached to the DNA so that the gene can't start the process of making the protein it codes for. This basically turns off the gene. On the other hand, removing the methyl group (in a process called *demethylation*) can turn a gene on.
- **Histone acetylation/histone modification:** Chromosomes are made up of strands of DNA wrapped around proteins called *histones*. Histone proteins can be changed by adding (or subtracting) a small chemical group called an *acetyl group*. Adding acetyl groups (acetylation) can activate (turn on) that part of the chromosome, while taking them away (deacetylation) can deactivate it (turn it off). Drugs called *histone deacetylase (HDAC) inhibitors* can help in the treatment of some types of cancer by turning on genes that help control cell growth and division.
- **RNA interference:** Inside each cell, DNA acts as long-term storage for our genes. But DNA isn't in the same part of the cell where proteins are made. For a protein to be made, a copy of its genetic code (in the form of messenger RNA, or mRNA), needs to be made from the DNA first. This piece of mRNA can then bring the instructions to the part of the cell where proteins are made. mRNA is only used for a short time to make the protein, and then it's broken down. If the cell needs more of that protein, it makes more mRNA. RNA interference is another way cells can turn off genes. A cell can make other forms of RNA that stick to mRNA. This can cause the mRNA to break down or stop it from delivering its code. Drugs are being developed to target the forms of RNA involved in RNA interference. This might help

turn off specific genes that cause cancer.

## How changes in genes can affect cancer risk

Some genes normally help control when our cells grow, divide to make new cells, repair mistakes in DNA, or cause cells to die when they're supposed to. If these genes aren't working properly, it can affect cancer risk. For example:

### Gene mutations may cause oncogenes

Changes in genes that normally help cells grow, divide, or stay alive can lead to these genes being more active than they should be, causing them to become **oncogenes**. These genes can result in cells growing out of control.

### Gene mutations may turn off tumor suppressor genes

Genes that normally help keep cell division under control or cause cells to die at the right time are known as **tumor suppressor genes**. Changes that turn off these genes can result in cells growing out of control.

### Gene mutations may turn off DNA repair genes

Some genes normally help repair mistakes in a cell's DNA. Changes that turn off these **DNA repair genes** can result in the buildup of DNA changes within a cell, which might lead to them growing out of control.

### How these changes cause cancer

DNA changes that create oncogenes or that turn off tumor suppressor genes or DNA repair genes might lead to cancer, but typically it takes several gene changes before a cell becomes a cancer cell. To learn more, see Oncogenes, Tumor Suppressor Genes, and DNA Repair Genes.

Changes in some other genes don't lead to cancer directly, but they might still make someone more likely to get cancer. For example, some gene changes might make it harder for the body to break down toxins in tobacco smoke. Among people who smoke, people with these kinds of gene changes might be more likely to get lung and other smoking-related cancers.

Gene changes can also play a role in other conditions that might impact cancer risk. For example, some gene variants can affect body weight. People with extra body weight are more likely to get some types of cancer, so these variants might also indirectly affect cancer risk.

Gene variants and other changes are common. We all have them, and their effects can add up to influence our cancer risk.

## Hyperlinks

1. www.cancer.org/cancer/risk-prevention/genetics/family-cancer-syndromes.html

**References**

National Cancer Institute. Physician Data Query (PDQ). Cancer Genetics Overview. 2022. Accessed at https://www.cancer.gov/about-cancer/causes-prevention/genetics/overview-pdq on March 30, 2022.

National Cancer Institute. The Genetics of Cancer. 2017. Accessed at https://www.cancer.gov/about-cancer/causes-prevention/genetics on March 30, 2022.

National Library of Medicine. What is a gene variant and how do variants occur? 2021. Accessed at https://medlineplus.gov/genetics/understanding/mutationsanddisorders/genemutation/ on March 30, 2022.

The BT, Fearon ER. Chapter 14: Genetic and Epigenetic Alterations in Cancer. In: Niederhuber JE, Armitage JO, Doroshow JH, Kastan MB, Tepper JE, eds. *Abeloff's Clinical Oncology*. 6th ed. Philadelphia, Pa: Elsevier; 2020.

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# Oncogenes, Tumor Suppressor Genes,

# and DNA Repair Genes

Our bodies are made up of trillions of cells, which must work together to keep us healthy. Our cells need to be able to divide to make new cells to help the body grow, or to replace cells that have died. At the same time, cell growth and division need to be controlled, so the cells don't grow too much and crowd out the cells around them.

It may be helpful to think of a cell as a car. For it to work properly, there need to be ways to control how fast it goes – that is, ways to speed up cell growth and division if it's needed (like a gas pedal), and ways to keep this growth under control or slow it down (like a brake pedal). There also need to be ways to fix parts of the car if they break down.


- Oncogenes
- Tumor suppressor genes
- DNA repair genes


Cell growth is normally controlled by the actions of certain genes inside each cell. Cancer begins when cells in the body become abnormal and start to grow out of control. This happens where there are changes in genes that affect cell growth.

The main types of genes that play a role in cancer are:

- Oncogenes
- Tumor suppressor genes
- DNA repair genes

Cancer is often the result of changes in more than one of these types of genes within a cell.

## Oncogenes

**Proto-oncogenes** are genes that normally help cells grow and divide to make new cells, or to help cells stay alive. When a proto-oncogene mutates (changes) or there are too many copies of it, it can become turned on (activated) when it is not supposed to be, at which point it's now called an **oncogene**. When this happens, the cell can start to grow out of control, which might lead to cancer.

A proto-oncogene normally functions in a way much like the gas pedal on a car. It helps the cell grow and divide. An oncogene is like a gas pedal that is stuck down, which causes the cell to divide out of control.

Oncogenes can be turned on (activated) in cells in different ways. For example:

- **Gene variants/mutations:** Some people have differences in the 'code' of their genes that can cause an oncogene to be turned on all the time. These types of gene changes can be inherited from a parent, or they can occur during a person's life, when a mistake is made when copying the gene during cell division.
- **Epigenetic changes:** Cells normally have ways of turning genes on or off that don't involve changes in the genes themselves. Instead, different chemical groups can be attached to genetic material (DNA or RNA) that affect whether a gene is turned on. These types of epigenetic changes can sometimes lead to an oncogene being turned on. For more on epigenetic changes, see Gene Changes and Cancer.
- **Chromosome rearrangements:** Chromosomes are long strands of DNA in each cell that contain its genes. Sometimes when a cell is dividing, the sequence of the DNA in a chromosome can be changed. This might put a gene that functions as a type of 'on' switch next to a proto-oncogene, keeping this gene turned on even when it shouldn't be. This new oncogene can result in the cell growing out of control.
- **Gene duplication:** Some cells have extra copies of a gene, which might lead to them making too much of a certain protein.

A small number of family cancer syndromes[1] are linked to an inherited change in an oncogene. These types of changes can sometimes be the first step in a cell becoming a cancer cell. But most changes involving oncogenes are acquired during a person's lifetime, rather than being inherited.

## Tumor suppressor genes

**Tumor suppressor genes** are normal genes that slow down cell division or tell cells to die at the right time (a process known as *apoptosis* or *programmed cell death*). When tumor suppressor genes don't work properly, cells can grow out of control, which can lead to cancer.

A tumor suppressor gene is like the brake pedal on a car. It normally helps keep the cell from dividing too quickly, just as a brake keeps a car from going too fast. When something goes wrong with a tumor suppressor gene, such as a pathogenic variant (mutation) that stops it from working, cell division can get out of control.

Inherited changes in tumor suppressor genes have been found in some family cancer syndromes[2]. They cause certain types of cancer to run in families. But most tumor suppressor gene mutations are acquired during a person's lifetime, not inherited.

For example, *TP53* is an important tumor suppressor gene. It codes for the p53 protein, which helps keep cell division under control. Inherited changes in the *TP53* gene can lead to Li-Fraumeni syndrome. Family members with this syndrome have an increased risk of several types of cancer, because all of their cells have this *TP53* gene change.

Changes in the *TP53* gene are also very common in cancer cells in people *without* an inherited cancer syndrome. These *TP53* changes are acquired during the person's life. These changes can help the cancer cells grow, but they are found only in the cancer cells, not in other cells in the body, so they can't be passed on to a person's children.

## DNA repair genes

When a cell divides to make new cells, it needs to make a new copy of all of its DNA. This is a complex process, and sometimes it results in mistakes in the DNA.

Genes known as **DNA repair genes** act like a person who repairs a car. They help fix mistakes in the DNA, or if they can't fix them, they trigger the cell to die so the mistakes can't cause any further problems.

When something goes wrong with one of these DNA repair genes, it can allow more mistakes to build up inside the cell. Some of these might affect other genes, which could lead to the cell growing out of control.

As with other types of gene changes, changes in DNA repair genes can either be inherited from a parent or acquired during a person's lifetime.

Examples of DNA repair genes include the *BRCA1* and *BRCA2* genes. People who inherit a pathogenic variant (mutation) in one of these genes have a higher risk of some types of cancer, particularly breast and ovarian cancer among women. (For more information, see Family Cancer Syndromes[3].) But changes in these genes are also sometimes seen in tumor cells in people who did not inherit one of these mutations.

## Hyperlinks



EXHIBIT 1040.10

1. www.cancer.org/cancer/risk-prevention/genetics/family-cancer-syndromes.html
2. www.cancer.org/cancer/risk-prevention/genetics/family-cancer-syndromes.html
3. www.cancer.org/cancer/risk-prevention/genetics/family-cancer-syndromes.html

**References**

National Cancer Institute. What Is Cancer? 2021. Accessed at https://www.cancer.gov/about-cancer/understanding/what-is-cancer on April 6, 2022.

National Library of Medicine. How Genes Work. 2020. Accessed at https://medlineplus.gov/genetics/understanding/howgeneswork/ on April 6, 2022.

The BT, Fearon ER. Chapter 14: Genetic and Epigenetic Alterations in Cancer. In: Niederhuber JE, Armitage JO, Doroshow JH, Kastan MB, Tepper JE, eds. *Abeloff's Clinical Oncology*. 6th ed. Philadelphia, Pa: Elsevier; 2020.

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# Cancer-related Genomic Testing and Genetic Testing

Over the past few decades, researchers have learned a great deal about the thousands of different genes inside the cells in our bodies, how they interact with each other, and how many of these genes might be related to cancer.

You may have heard terms such as genomics (and genomic testing) and genetics (and genetic testing) and wondered what they mean. Here we'll talk about these terms, how they're related, and how they're different, especially in the context of cancer.

## What are genomics and genetics?

Genomics and genetics are related fields of study.

**Genetics** refers to the study of genes and their roles in inheritance – in other words, it's about how genes affect the way that certain traits or conditions are hereditary, or passed down from one generation to another. Genetics focuses mainly on the study of individual genes and their effects. **Genes** are pieces of DNA in our cells that carry the instructions for making proteins, which direct the activities of cells and functions of the body.

**Genomics** is the study of a person's entire set of genes (their **genome**), including how these genes interact with each other and with the person's environment.

On a broad level, genomics is helping researchers learn more about the gene and protein changes inside different cancer cells. This is being used to develop newer cancer treatments aimed at these gene and protein changes. You can learn more about how changes in a cell's genes can lead to cancer in Genes and Cancer.

Genomics is also becoming an important part of care for many people with cancer.

## What is genomic testing?

When it comes to cancer, **genomic testing** most often refers to tests done to look at the genome (or parts of the genome) inside a person's cancer cells to learn about the gene or protein changes in these cells that make them different from normal cells.

For people with cancer, genomic testing of the cancer cells can often provide important information, such as how quickly the cancer is likely to grow, as well as if certain treatments (such as targeted therapy or immunotherapy drugs) are likely to be helpful in treating their cancer.

Genomic testing can go by many other names, including:

- **Genomic profiling or genome sequencing**
- **Biomarker testing**
- **Tumor testing, tumor genetic testing, tumor marker testing, or tumor subtyping**
- **Molecular testing or molecular profiling**

- **Next generation sequencing**

Testing is often done on a sample of the tumor (from a biopsy or surgery) if possible, but it might also be done using a sample of blood, saliva, or other body fluids.

Genomic testing might be used in other situations as well. To learn more about how genomic testing can be important for people with cancer, see:

- Biomarker Tests and Cancer Treatment
- Precision or Personalized Medicine[1]

## How is genetic testing different from genomic testing?

The term **genetic testing** can have different meanings, but when talking about cancer it most often refers to ***predictive genetic testing.*** This type of testing looks for certain changes in a person's genes to see if they've inherited a change from a parent that affects their risk of cancer. These inherited gene changes are also called **germline mutations.**

Genetic testing is sometimes done in people with cancer. But unlike genomic testing, genetic testing is usually not done on cancer cells. It's done on other cells in the body (such as cells from a blood or saliva sample). This is because the purpose of genetic testing is to see if a person has inherited a gene change from a parent (and therefore has the change in all the cells in their body).

To learn more about genetic testing as it relates to cancer risk, see Genetic Testing for Cancer Risk[2].

## Hyperlinks

1. www.cancer.org/cancer/diagnosis-staging/tests/biomarker-tests.html
2. www.cancer.org/cancer/managing-cancer/treatment-types/precision-medicine.html
3. www.cancer.org/cancer/risk-prevention/genetics/genetic-testing-for-cancer-risk.html

### References

National Human Genome Research Institute. Genetics vs. Genomics Fact Sheet. 2018. Accessed at https://www.genome.gov/about-genomics/fact-sheets/Genetics-vs-Genomics on November 2, 2023.

National Institute of General Medical Sciences. Studying genes. 2017. Accessed at https://www.nigms.nih.gov/education/Documents/Studying_genes_final.pdf on November 2, 2023.

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