

An Extensive Report on the Fundamentals of Cell Biology

Chapter 1: Comprehensive Briefing Document on Cellular Biology

1.1. Executive Summary

The cell is universally recognized as the basic structural, functional, and biological unit of all known forms of life. First described by Robert Hooke in 1665, our understanding has culminated in the modern cell theory, which holds that all living things are composed of cells, and all cells arise from pre-existing cells. Life is broadly categorized into two primary cell types: the structurally simple prokaryotes (bacteria and archaea), which lack a nucleus, and the more complex eukaryotes (animals, plants, fungi, and protists), which are defined by a membrane-bound nucleus and extensive internal compartmentalization through organelles. This organization allows eukaryotic cells to perform specialized, concurrent biochemical processes with high efficiency. This document provides a detailed examination of these core concepts, from the foundational principles of cell theory to the intricate anatomy of the eukaryotic cell, its dynamic processes, and the clinical significance of cellular changes.

1.2. The Cell: The Fundamental Unit of Life

Introduction

The cell is the smallest functional unit within a living organism capable of independent function. It serves as the foundational building block for everything from single-celled bacteria to complex multicellular organisms like humans. Establishing a firm understanding of the cell and the scientific principles that govern it is the essential first step before exploring the vast diversity of cell types and the intricate molecular machinery that defines them.

Core Principles

The term "cell" originates from the Latin word *cellula*, meaning 'small room'. It was coined by Robert Hooke in 1665 after he observed the cell walls in a slice of cork under a microscope, which reminded him of the small rooms, or cells, inhabited by monks in a monastery. This initial discovery laid the groundwork for the formal articulation of the cell theory.

The original cell theory, developed by Matthias Jakob Schleiden and Theodor Schwann in 1839 and later refined by Rudolf Virchow, is based on three foundational tenets:

- All organisms are composed of one or more cells.
- The cell is the fundamental unit of structure and function in all living things.
- All cells come from pre-existing cells by cell division (*omnis cellula e cellula*).

Building upon this classical foundation, modern cell theory has expanded to incorporate discoveries in molecular biology and genetics. The six tenets of modern cell theory are:

- All known living things are made up of cells.
- The cell is the structural and functional unit of all living things.
- All cells come from pre-existing cells by division.



- Cells contain hereditary information (DNA), which is passed from cell to cell during division.
- All cells are basically the same in chemical composition.
- All energy flow (metabolism and biochemistry) of life occurs within cells.

Conclusion

These principles underscore the cell's central role in biology, a role that is expressed through two major evolutionary designs: the prokaryotic and eukaryotic cell types.

1.3. A Tale of Two Cells: Prokaryotes vs. Eukaryotes

Introduction

All life on Earth can be classified into two fundamental types based on cellular structure: prokaryotic and eukaryotic. The distinction between these two cell types is the most significant division in the biological world, reflecting billions of years of evolutionary history. Analyzing the structural and functional differences between prokaryotes and eukaryotes is crucial for understanding the trajectory of life from its simplest origins to its most complex forms.

Comparative Analysis

The following table outlines the key distinctions between prokaryotic and eukaryotic cells, based on data compiled from the source material.

Feature	Prokaryote	Eukaryote
Typical Organisms	Bacteria, Archaea	Protists, Slime moulds, Fungi, Plants, Animals
Typical Size	~0.1–5 μm	~10–100 μm
Nucleus	Absent; genetic material is in a nucleoid region	Present; enclosed by a double membrane
DNA Form	Often a single, circular chromosome; some have linear or multiple	Multiple, paired linear chromosomes with histone proteins
Membrane-Bound Organelles	Absent	Present (e.g., mitochondria, ER, Golgi apparatus)
Ribosomes¹	50S and 30S subunits	60S and 40S subunits
Cell Structure	Unicellular	Mostly multicellular; some unicellular
Cell Division	Binary fission (simple division)	Mitosis, Meiosis

¹S refers to Svedberg units, a measure of sedimentation rate during centrifugation.

Prokaryotic Cells



Prokaryotes, which include the domains Bacteria and Archaea, are the simplest and most ancient forms of life, believed to have first emerged on Earth around 4 billion years ago. Their defining characteristic is their lack of a membrane-bound nucleus and other organelles. Their genetic material is located in a region of the cytoplasm known as the nucleoid. While most prokaryotes have a single circular chromosome, some have been found to contain multiple circular or even linear chromosomes, demonstrating a greater genetic complexity than once assumed.

Eukaryotic Cells

Eukaryotic cells are the building blocks of animals, plants, fungi, slime moulds, and protists. Their defining feature is the presence of a true nucleus, an organelle that houses the cell's DNA and coordinates its activities. This compartmentalization extends to numerous other membrane-bound organelles, which create specialized micro-environments for specific biochemical reactions. This structural complexity allows eukaryotes to achieve a much larger size and organize into the complex tissues and organs of multicellular organisms.

Conclusion

The sophisticated internal organization of the eukaryotic cell is the key to its functional diversity and evolutionary success, warranting a closer look at its individual components.

1.4. Anatomy of the Eukaryotic Cell: Subcellular Components and Organelles

Introduction

The hallmark of the eukaryotic cell is its sophisticated internal organization, a feature known as compartmentalization. The cell is subdivided by membranes into distinct functional units called organelles. These organelles function like miniature organs, each specialized for a specific task, such as energy generation, protein synthesis, or waste disposal. This division of labor allows for complex biochemical processes to occur simultaneously and efficiently within the cell, enabling a level of complexity impossible in their prokaryotic counterparts.

Core Cellular Structures

The Cell Membrane The plasma membrane is a dynamic, semi-permeable barrier that envelops the cell, separating its internal environment from the outside world. It is composed of a phospholipid bilayer, with hydrophilic (water-loving) phosphate heads facing outward and inward, and hydrophobic (water-fearing) lipid tails forming a core. This structure, often called a "fluid mosaic," is interspersed with cholesterol molecules that maintain its consistency and various proteins that serve as channels, carriers, and receptors to regulate the passage of substances and receive external signals.

The Cytoskeleton The cytoskeleton is a complex network of protein filaments that provides structural support, maintains cell shape, and facilitates movement. It is composed of three primary components:

- **Microfilaments:** The thinnest fibers, made of actin, which are crucial for cell movement and muscle contraction.
- **Microtubules:** Hollow tubes made of tubulin, which act as tracks for organelle transport and form the mitotic spindle during cell division.



- **Intermediate Filaments:** Rope-like fibers that provide mechanical strength and anchor organelles in place.

Genetic Material Eukaryotic genetic information is encoded in deoxyribonucleic acid (DNA). This DNA is organized into multiple linear molecules called chromosomes. Each chromosome consists of DNA tightly coiled around scaffold proteins called histones, a packaging strategy that allows an immense amount of genetic material to fit inside the nucleus. While the vast majority of a cell's DNA resides in the nucleus (the nuclear genome), a small, distinct circular chromosome is also found within the mitochondria. This mitochondrial genome codes for 13 proteins involved in mitochondrial energy production and specific tRNAs.

Key Organelles and Their Functions

Cell Nucleus The nucleus is the most conspicuous organelle and serves as the cell's information and control center. Enclosed by a double membrane called the nuclear envelope, it houses the cell's chromosomes. It is the site of DNA replication and transcription—the process of copying a gene's DNA sequence into messenger RNA (mRNA). The nucleus also contains the nucleolus, a specialized region where ribosome subunits are assembled.

Ribosomes Ribosomes are the cellular machinery responsible for protein synthesis, a process known as translation. Composed of ribosomal RNA (rRNA) and proteins, they read the instructions carried by mRNA and assemble amino acids into polypeptide chains. The ribosome mediates the formation of a polypeptide sequence by binding to transfer RNA (tRNA) adapter molecules, which deliver the correct amino acids corresponding to the mRNA code. Ribosomes can be found floating freely in the cytoplasm or bound to the endoplasmic reticulum.

Endoplasmic Reticulum (ER) The ER is a vast network of membrane-enclosed sacs and tubules that functions in protein and lipid synthesis.

- **Rough ER (RER):** Studded with ribosomes, the RER is the site where proteins destined for secretion or for insertion into membranes are synthesized and modified.
- **Smooth ER (SER):** Lacking ribosomes, the SER is involved in the synthesis of lipids, phospholipids, and steroids. It also plays a critical role in detoxification and calcium sequestration.

Golgi Apparatus Also known as the Golgi complex, this organelle receives proteins and lipids from the ER. It then further modifies, sorts, and packages these macromolecules into membrane-bound vesicles for delivery to other destinations within or outside the cell, acting as the cell's primary processing and distribution hub.

Mitochondria Often called the "powerhouse" of the cell, the mitochondrion is the primary site of cellular respiration. This double-membraned organelle generates most of the cell's supply of adenosine triphosphate (ATP), the main source of chemical energy, through the process of oxidative phosphorylation. Mitochondria contain their own DNA and can replicate independently.

Lysosomes and Peroxisomes These are small, membrane-bound vesicles containing digestive and detoxifying enzymes. Lysosomes break down worn-out organelles, food particles, and engulfed pathogens. Peroxisomes are responsible for breaking down toxic substances, such as hydrogen peroxide, and are also involved in lipid metabolism.



Vacuoles Vacuoles are membrane-bound sacs that primarily function in storage and waste sequestration. In plant cells, a large central vacuole is a defining feature, storing water to maintain turgor pressure against the cell wall. In animal cells, vacuoles are typically smaller and more numerous.

Conclusion

The coordinated action of these organelles underpins the dynamic processes that define cellular life.

1.5. The Living Cell: Core Cellular Processes

Introduction

A cell is far more than a static collection of organelles; it is a bustling, dynamic system defined by a set of core processes that collectively constitute life. These processes are not abstract; they are the direct work of the organelles and structures detailed previously, with the ribosome acting as the factory, the ER as the finishing line, and the Golgi as the distribution hub. These fundamental activities, from creating copies of itself to synthesizing proteins and managing energy, are governed by the genetic information encoded in its DNA and carried out by its intricate molecular machinery.

Analysis of Processes

Replication and Division Cell division is the process by which a parent cell divides into two or more daughter cells. Prokaryotes divide through a simple process called binary fission. Eukaryotes undergo a more complex process of nuclear division called mitosis, followed by the division of the cytoplasm (cytokinesis). The prerequisite for any form of cell division is DNA replication, where the cell's entire genome is precisely duplicated to ensure each daughter cell receives a complete copy.

Protein Synthesis Proteins are the workhorses of the cell, carrying out a vast array of functions. This process occurs in two major steps:

1. **Transcription:** Inside the nucleus, the information from a specific gene in the DNA is copied into a complementary messenger RNA (mRNA) molecule.
2. **Translation:** The mRNA molecule travels from the nucleus to a ribosome in the cytoplasm. Here, the ribosome reads the mRNA sequence and, with the help of transfer RNA (tRNA), assembles the corresponding amino acids into a polypeptide chain, which then folds into a functional protein.

Growth and Metabolism Cell metabolism encompasses all the chemical reactions that occur within a cell to maintain life. These reactions are broadly divided into two categories:

- **Catabolism:** The breakdown of complex molecules (like glucose) into simpler ones to release energy, which is captured in the form of ATP.
- **Anabolism:** The use of energy and simple building blocks to construct complex molecules, such as proteins and nucleic acids, necessary for cell growth and function.

Multicellularity and Differentiation In complex multicellular organisms, cells specialize to perform distinct functions, a process known as differentiation. Though nearly all cells in an organism are genetically identical, they differentiate into hundreds of distinct cell types—such



as neurons, muscle cells, and skin cells—by selectively expressing different sets of genes. This process begins with a single totipotent cell, the zygote, which divides and differentiates in a highly regulated manner.

Conclusion

The precise execution of these cellular processes is a testament to the elegant solutions that evolution has crafted over billions of years, built upon the foundational principles discovered over centuries.

1.6. Clinical Significance of Cellular Changes

Introduction

A thorough understanding of normal cellular structure and function provides the essential foundation for diagnosing and treating disease. Pathological conditions frequently arise from disruptions to core cellular processes or from a cell's abnormal adaptation to stress. By recognizing how cells respond to injury and noxious stimuli, we can better comprehend the mechanisms underlying a wide range of human ailments.

Key Pathological Concepts

Cells can undergo several adaptive or terminal changes in response to environmental stimuli or internal damage. Key concepts in cellular pathology include:

- **Apoptosis:** This is a form of programmed, controlled cell death. It is a natural, orderly process in which a cell is systematically dismantled to remove damaged or worn-out cells without harming adjacent tissues.
- **Necrosis:** This is an unplanned and uncontrolled form of cell death that results from acute injury caused by external agents such as trauma, infections, or toxins. It often leads to inflammation and damage to surrounding cells.
- **Hyperplasia:** An increase in the size of an organ or tissue due to an increase in the *number* of its constituent cells. A common clinical example is benign prostatic hyperplasia.
- **Hypertrophy:** An increase in the size of an organ or tissue due to an increase in the *size* of its individual cells, while the number of cells remains the same. This is often seen in muscle tissue, such as in left ventricular hypertrophy of the heart.
- **Metaplasia:** A reversible process where one mature, differentiated cell type is replaced by another mature cell type better suited to a new environmental stress. For instance, in Barrett's esophagus, the normal squamous epithelium is replaced by more robust columnar cells in response to chronic acid reflux.
- **Dysplasia:** The proliferation of immature cells within a tissue, often accompanied by a decrease in the number of mature cells. It is considered a pre-malignant condition and can be a precursor to cancer.

Conclusion



These pathological deviations underscore the third tenet of cell theory—*omnis cellula e cellula*—reminding us that diseases are not external forces but often the result of pre-existing cells behaving, dividing, or dying incorrectly.

Chapter 2: Study Guide for Cellular Biology

2.1. Introduction

Welcome to your study guide! As your research assistant, I've designed this section to help you actively engage with the material from the briefing. We'll start with a quiz to lock in the key facts, move to some challenging essay questions to get you thinking critically, and finish with a glossary you can use as a quick reference. Let's get started.

2.2. Knowledge Review Quiz

Instructions: Please answer the following questions in 2-3 sentences each, based on the information provided in Chapter 1.

1. What are the three main tenets of the original Cell Theory as formulated by Schleiden, Schwann, and Virchow?
2. What is the primary structural difference between a prokaryotic and a eukaryotic cell?
3. What is the primary function of mitochondria within a eukaryotic cell?
4. Describe the key functional difference between the Rough Endoplasmic Reticulum (RER) and the Smooth Endoplasmic Reticulum (SER).
5. What are the two main steps of protein synthesis, and where does each step occur in a eukaryotic cell?
6. What was Robert Hooke's contribution to the field of cell biology?
7. Define the process of apoptosis.
8. What is the role of the Golgi apparatus in the cell?
9. Briefly describe the composition of the cell's plasma membrane.
10. What is the key difference between hyperplasia and hypertrophy as forms of cellular change?

2.3. Answer Key

1. The three main tenets of the original Cell Theory are: 1) All organisms are composed of one or more cells; 2) The cell is the fundamental unit of structure and function in all organisms; and 3) All cells come from pre-existing cells.
2. The primary structural difference is that a eukaryotic cell has a membrane-bound nucleus that contains its genetic material, whereas a prokaryotic cell lacks a nucleus and its DNA is located in a cytoplasmic region called the nucleoid. Eukaryotic cells also contain other membrane-bound organelles, which prokaryotes lack.



3. Mitochondria are the "powerhouses" of the cell, responsible for generating most of the cell's energy in the form of ATP through the process of cellular respiration.
4. The Rough ER, which is studded with ribosomes, is primarily involved in the synthesis and modification of proteins that are destined for secretion or for membranes. The Smooth ER lacks ribosomes and is primarily involved in lipid synthesis, detoxification, and calcium storage.
5. The two main steps are transcription and translation. In eukaryotes, transcription (copying DNA to mRNA) occurs in the nucleus, and translation (synthesizing protein from mRNA) occurs at the ribosomes in the cytoplasm.
6. In 1665, Robert Hooke was the first person to discover and name cells. He observed the dead cell walls of cork under a microscope and coined the term "cell" because their structure reminded him of the small rooms in a monastery.
7. Apoptosis is programmed, controlled cell death. It is a natural, orderly process by which damaged or worn-out cells are systematically broken down and removed without causing inflammation or damage to neighboring cells.
8. The Golgi apparatus functions as the cell's processing, packaging, and distribution center. It modifies, sorts, and packages macromolecules like proteins and lipids that it receives from the endoplasmic reticulum into vesicles for delivery elsewhere.
9. The plasma membrane is a phospholipid bilayer, often described as a "fluid mosaic." It is composed of two layers of phospholipids with embedded proteins (which act as channels and receptors) and cholesterol (which helps maintain consistency).
10. Hyperplasia is an increase in organ size due to an increase in the *number* of cells. Hypertrophy is an increase in organ size due to an increase in the *size* of the individual cells, while the number of cells remains the same.

2.4. Essay Questions for Deeper Analysis

1. Compare and contrast the organization and location of genetic material in prokaryotic and eukaryotic cells. Discuss the functional implications of these differences, including how they affect processes like transcription and translation.
2. Trace the historical development of the Cell Theory, from Robert Hooke's initial observations to Rudolf Virchow's "omnis cellula e cellula." Explain how each major discovery built upon the last to form our modern understanding.
3. Explain the concept of organelle compartmentalization in eukaryotic cells. Choose three different organelles (e.g., nucleus, mitochondrion, lysosome) and analyze how their specialized structures and functions contribute to the overall efficiency and complexity of the cell.
4. Describe the journey of a protein destined for export from the cell, starting from the genetic instructions in the DNA. Detail the roles of the nucleus, ribosome, rough endoplasmic reticulum, and Golgi apparatus in this "secretory pathway."



5. Using the concepts of metaplasia and dysplasia, explain how cells can adapt to environmental stress and how these adaptations can sometimes be precursors to disease like cancer. Use the examples provided in the text to support your explanation.

2.5. Glossary of Key Terms

- **Apoptosis:** Programmed, controlled cell death; a natural process to remove damaged or worn-out cells without harming adjacent tissues.
- **Cell Theory:** The scientific theory stating that all organisms are composed of cells, that cells are the fundamental unit of structure and function, and that all cells come from pre-existing cells.
- **Chromosome:** Linear molecules of DNA coiled around histone proteins that store the genetic material of eukaryotic cells.
- **Cytoplasm:** The semi-solid medium that fills the cell and suspends the organelles.
- **Cytoskeleton:** A network of microtubules, microfilaments, and intermediate filaments that organizes and maintains the cell's shape and facilitates movement.
- **DNA (Deoxyribonucleic acid):** The hereditary material in all cells, used for long-term information storage.
- **Eukaryote:** An organism whose cells contain a membrane-bound nucleus and other organelles. Includes animals, plants, fungi, and protists.
- **Golgi Apparatus:** An organelle that functions to further modify, sort, and package macromolecules such as proteins and lipids into vesicles.
- **Hyperplasia:** An increase in the size of an organ as a result of an increase in the number of its cells.
- **Hypertrophy:** An increase in the size of an organ resulting from an increase in the size of its constituent cells.
- **Lysosome:** An organelle containing digestive enzymes that breaks down excess organelles, food particles, and engulfed pathogens.
- **Metaplasia:** A reversible process in which one mature cell type is replaced by another mature cell type.
- **Mitochondrion:** A double-membraned organelle responsible for generating most of the cell's energy (ATP) through cellular respiration.
- **Nucleoid:** The region within the cytoplasm of a prokaryotic cell where the genetic material is concentrated.
- **Nucleus:** A large, membrane-bound organelle in eukaryotic cells that houses the chromosomes and serves as the cell's information and control center.
- **Organelle:** A specialized subunit within a cell that has a specific function, analogous to an organ in the body.



- **Phospholipid Bilayer:** The double layer of phospholipid molecules that forms the primary structure of the cell membrane.
 - **Prokaryote:** A unicellular organism that lacks a nucleus and other membrane-bound organelles. Includes bacteria and archaea.
 - **Ribosome:** A complex of RNA and protein molecules that is the site of protein synthesis.
 - **Transcription:** The process where the genetic information in DNA is used to produce a complementary RNA strand.
 - **Translation:** The process where a ribosome mediates the formation of a polypeptide sequence based on an mRNA sequence.
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Chapter 3: Frequently Asked Questions (FAQs)

1. **What is the most fundamental difference between a simple bacterium and a complex animal cell?** The most fundamental difference is that an animal cell (a eukaryote) has a membrane-bound nucleus to store its DNA, while a bacterium (a prokaryote) does not. The bacterium's DNA floats in a region called the nucleoid. Animal cells also have many other membrane-bound compartments called organelles, which bacteria lack.
2. **Why is the nucleus often called the "brain" of the cell?** The nucleus is called the "brain" or "control center" because it houses the cell's genetic material (DNA on chromosomes). This genetic information contains the instructions for nearly all cellular activities, including protein synthesis, metabolism, growth, and division. The nucleus controls these activities by regulating which genes are expressed and when.
3. **If cells are so small, how did scientists first discover them?** Scientists first discovered cells in 1665 when Robert Hooke used an early compound microscope to examine a thin slice of cork. He saw a structure of tiny, room-like compartments, which he named "cells." A few years later, Anton van Leeuwenhoek used his own powerful single-lensed microscopes to become the first person to observe living cells, such as protozoa and bacteria.
4. **What does it mean that all cells come from pre-existing cells?** This principle, stated by Rudolf Virchow as *omnis cellula e cellula*, means that cells cannot be created spontaneously from non-living matter. Life continues because existing cells divide to create new cells. This process ensures the continuity of life and the passing of hereditary information from one generation of cells to the next.
5. **How do cells get the energy they need to function?** Cells get energy by breaking down nutrient molecules through a process called metabolism. In eukaryotes, the mitochondria are the primary sites of energy production. They perform cellular respiration, using oxygen to break down molecules like glucose to produce ATP (adenosine triphosphate), which is the main energy currency of the cell.
6. **What is the purpose of the cell membrane?** The cell membrane acts as a protective, semi-permeable barrier that separates the cell's internal environment from the outside world. It regulates what enters and leaves the cell, ensuring that necessary nutrients can



get in and waste products can get out. It also contains receptor proteins that allow the cell to communicate and respond to signals from its environment.

7. **Do all cells have a rigid wall around them?** No, not all cells have a rigid wall. A cell wall is found in many prokaryotic (bacterial) and eukaryotic (plant, fungi) cells, where it provides structural support and protection outside the cell membrane. However, animal cells do not have a cell wall; their outermost boundary is the flexible plasma membrane.
8. **How does a cell make the proteins it needs?** A cell makes proteins in a two-step process. First, in the nucleus, a gene's DNA sequence is copied into a messenger RNA (mRNA) molecule in a process called transcription. Second, the mRNA molecule travels out to a ribosome in the cytoplasm, where the genetic code is read and used to assemble amino acids into a protein, a process called translation.
9. **What is the difference between healthy cell death (apoptosis) and unhealthy cell death (necrosis)?** Apoptosis is a clean, programmed, and controlled process where the cell systematically dismantles itself without causing inflammation or harm to its neighbors. Necrosis is a messy, uncontrolled death caused by external injury like trauma or toxins, which often leads to the cell bursting and causing inflammation and damage to the surrounding tissue.
10. **Are viruses considered cells?** Based on the core tenets of cell theory, viruses are not considered cells. They are not the fundamental unit of life, cannot replicate independently (*omnis cellula e cellula* does not apply), and lack their own metabolic machinery, requiring a host cell to perform these functions.

Chapter 4: Historical Timeline of Cell Biology

Year(s)	Key Discovery or Event	Scientist(s) / Institution
1595	Credited with inventing the first compound microscope.	Jansen
1665	Discovered and described 'cells' in cork using a microscope.	Robert Hooke
1674	First to discover and describe live protozoa.	Anton van Leeuwenhoek
1833	Described the cell nucleus in cells of the orchid.	Robert Brown
1838	Formally articulated the cell theory.	Matthias Schleiden & Theodor Schwann
1840	Realized that sperm cells and egg cells are also cells.	Albrecht von Roelliker
1857	Described mitochondria within cells.	Kolliker
1858	Stated that all cells arise from pre-existing cells (<i>omnis cellula e cellula</i>).	Rudolf Virchow



1879	Described chromosome behavior during mitosis.	Walther Flemming
1898	Described the Golgi apparatus.	Camillo Golgi
1931	Built the first transmission electron microscope (TEM).	Ernst Ruska
1939	Produced the first commercial transmission electron microscope.	Siemens
1952	Established a continuous human cell line (HeLa cells).	George Otto Gey and coworkers
1955	Systematically defined the nutritional needs of animal cells in culture.	Eagle
1957	Developed density gradient centrifugation for separating nucleic acids.	Meselson, Stahl, and Vinograd
1965	Produced the first commercial scanning electron microscope.	Cambridge Instruments
1981	Published <i>Symbiosis in Cell Evolution</i> , detailing symbiogenesis.	Lynn Margulis
1998	Cloned mice from somatic cells.	<i>Not specified in source</i>
2006	Identified factors required to create induced pluripotent stem cells (iPSCs).	<i>Not specified in source</i>
2012	CRISPR gene editing technology was developed.	<i>Not specified in source</i>

Chapter 5: List of Sources

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