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MORPHOLOGICAL STRUCTURES OF MICROORGANISMS AND THE SYSTEMATICS OF PROKARYOTES: ORGANIZATIONAL STRUCTURE AND VIEWS

Xalilova Nigora Ixtiyorovna
Bukhara State Pedagogical Institute
Department of Biology, Lecturer
E mail: xalilova_nigora@buxdpi.uz
Phone: +998 (91) 4454994

Abstract
This article analyzes the morphological types of microorganisms, their shapes, structures, and functional significance in broad scope. The morphology of bacteria, fungi, viruses, archaea, and protozoa, their ecological adaptation, pathogenicity levels, and evolutionary importance are highlighted. The microscopic analysis methods and the role of morphological differences in diagnostics are discussed in detail. Microorganisms include bacteria, actinomycetes, yeasts, viruses, mold fungi, microscopic algae, and others. Microorganisms are divided into prokaryotes (organisms lacking a nucleus and chromosomal apparatus within the cell) and eukaryotes (organisms with a cytoplasm and a membrane-enclosed nucleus). For a long time, all prokaryotes were classified into a single domain (the largest taxonomic group). However, research by microbiologist Carl Woese in the 1970s demonstrated that prokaryotes are divided into two distinct lineages: Bacteria and Archaea. Currently, these groups are considered to constitute two of the three domains of life. The third domain (Eukarya) includes all eukaryotes such as plants, animals, and fungi.

Keywords: microorganisms, morphology, bacteria, viruses, fungi, archaea, protozoa, microscopy, shape, structure.

Introduction

Microorganisms are considered the most ancient and the most abundant representatives of living organisms. They have adapted to various ecological environments and possess diverse morphological features. Morphology refers to the external shape and internal structure of microorganisms. These characteristics directly influence their way of life, movement, reproduction, pathogenicity, and resistance to external conditions. The shape and structural features of microorganisms play a crucial role in their identification.

1. Main morphological forms of microorganisms

1.1 Bacteria Bacteria are prokaryotic cells with a unicellular structure. They can take the following shapes:

- Cocci – spherical bacteria (e.g., *Staphylococcus*, *Streptococcus*).
- Bacilli – rod-shaped bacteria (e.g., *Escherichia coli*, *Bacillus anthracis*).
- Spirilla – spiral-shaped bacteria (e.g., *Spirillum*).
- Vibrios – curved rod-shaped bacteria (e.g., *Vibrio cholerae*).

• Filamentous form – thread-like, chain-like structure.

The bacterial cell wall is composed of peptidoglycan, which determines whether the bacteria are gram-positive or gram-negative. This characteristic allows for differentiation using staining methods.

1.2 Archaea

Archaea are prokaryotic microorganisms that have adapted to extreme environments such as high temperatures, acidity, or salinity. They may have shapes similar to bacteria, but their cell wall composition and lipid membranes are distinctive. Morphologically, archaea can be spherical (cocci), rod-shaped (bacilli), or spiral.

1.3 Fungi

Microscopic fungi are eukaryotic microorganisms, with main representatives being molds, yeasts, and dimorphic fungi. Yeasts are usually oval or round and reproduce through budding. Mold fungi develop through hyphae (thread-like structures) and produce spores. Dimorphic fungi can adopt either yeast or hyphal forms depending on the temperature.

1.4 Viruses

Viruses are simple biological particles that lack a cellular structure and are composed only of a capsid and genetic material. Morphologically, they can have the following shapes:

• Icosahedral

• Spiral

• Complex forms (such as bacteriophages)

Their external structure depends on the type of host cell they infect and their replication mechanisms.

1.5 protozoa (unicellular animals)

Protozoa are complex, eukaryotic organisms with various morphological features based on their locomotor organelles (cilia, flagella, pseudopodia). They usually live in aquatic environments or as parasites.

2. The functional significance of morphological structure

Morphological features significantly influence the vital processes of microorganisms, their pathogenicity, and ecological adaptation. For example, bacteria with capsules are protected from phagocytosis. Microorganisms possessing motile organelles can actively move, allowing them to reach nutrients or host organisms more quickly.

3. Methods for studying morphology

The following microscopic techniques are widely used to study the morphology of microorganisms:

• Light microscopy (with stained and unstained preparations)

• Phase-contrast microscopy

• Fluorescence microscopy

• Electron microscopy (transmission and scanning)

Microscopic analysis plays a crucial role in identifying microorganisms, determining their species, and assessing their physiological state.

4. The role of morphological differences in diagnostics

In microbiological diagnostics, morphological characteristics — such as cell shape, size, motile elements, presence of capsule or spores — are of great importance. Methods like Gram staining, Ziehl-Neelsen staining, and detection of capsules and spores enable rapid and accurate identification of pathogenic microorganisms.

Most microorganisms are unicellular. Bacterial cells are surrounded by a cell wall from outside, sometimes only separated by a cytoplasmic membrane. Inside the cell, various structures are present. Based on cell structure, organisms are classified into two types: eukaryotic and prokaryotic cells. If a microorganism has a true (genuine) nucleus, such cells are called eukaryotic cells. (In Greek, *eu* means true or genuine, and *karyon* means nucleus).

Microorganisms with a simple nucleus (diffused nuclear structure) are called prokaryotes. Examples of eukaryotes include fungi, protozoa, and simple animals (protists), while bacteria and cyanobacteria (blue-green algae) are prokaryotes. In eukaryotic cells, there is a nucleus and 1-2 nucleoli, chromosomes (DNA, proteins), mitochondria, and in organisms carrying out photosynthesis, chloroplasts and the Golgi apparatus are present. Their ribosomes are of 80S size. In prokaryotic cells, there is no clear boundary between the nucleus and cytoplasm; the nuclear membrane is absent. They do not have a defined structure of DNA, and therefore, processes like mitosis and meiosis do not occur. Prokaryotes lack mitochondria and chloroplasts.

Bacteria are simple, uncomplicated, and can have various shapes such as spherical, rod-shaped, or curved. Spherical bacteria are called cocci (plural of coccus, from Latin *don*).

They can have various shapes such as spherical, elliptical, rod-shaped, and other forms. Based on the arrangement of bacterial cells relative to each other, they are classified with different names. Spherical bacteria that divide and remain attached to each other are called monocytes (monococci). When the cells divide and form clusters or irregular groups, these are called staphylococci.

Bacteria that divide and remain in pairs are called diplococci, while those forming chains after division are called streptococci. When they form groups of four, they are called tetracocci, and if they are arranged in a cube shape, they are called sarcina. Rod-shaped bacteria are known as streptobacteria (or streptobatsilla).

Sometimes, rounded or spiral-shaped bacteria are also found; these are called spirilla (from Latin *spiral*, meaning coil). Spirilla can be bent or curved. Bacteria with a short, curved shape are called vibrio (from Latin *vibrio*, meaning to bend or quiver).

Bacteria can also have filamentous forms, and many are multicellular, with cells forming various structures. Their shapes can be triangular, rod-shaped, open or closed rings, spherical, and other forms.

Due to their small size, bacteria are measured in micrometers, while their fine structures are measured in nanometers.

The sizes of cocci range from 0.5 to 1.5 micrometers (μm). The rod-shaped bacteria have a width of approximately 0.55 μm and a length of several micrometers (2–10 μm). Small rods are usually 0.22–0.4 × 0.7–1.5 μm in size. Among bacteria, there are some that reach sizes of several hundred micrometers. If a bacterial cell is cultivated on solid nutrient media, it can

multiply over a few hours and form colonies that are visible to the naked eye. The appearance, color, and other properties of colonies depend on the bacterial species and are specific to each type. The bacterial cell has a complex structure. The development of electron microscopy, the preparation of ultra-thin sections, and advances in microbiological techniques have made it possible to study the external and internal structures of bacterial cells in great detail.

A schematic diagram of a bacterial cell includes: from the outside: capsule, cell wall, fimbriae, pili; inside: cytoplasm, nucleoid, ribosomes, membrane structures, inclusions, and appendages; some bacteria also have spores.

Most bacteria are encased in a capsule. These capsules are made of slimy substances and can be either microcapsules or macro-capsules. The thickness of the macro-capsule is about 0.2 µm, while microcapsules are smaller than 0.2 µm.Inside both macro- and micro-capsules is a mucous layer, with a soluble mucous layer present internally.The capsule is a heteropolysaccharide composed of about 90% water,

polysaccharides, polypeptides, and lipids (in *Mycobacterium tuberculosis* bacteria).

Types of bacterial appendages:

- Monotrichous: a single flagellum at one end of the cell.
- Lophotrichous: a cluster of flagella at one end of the cell.
- Amphitrichous: a flagellum at each end of the cell.
- Peritrichous: flagella covering all sides of the cell, known as peritrichous flagella.

The number of flagella varies: spirilla have 5 to 30 flagella, while vibrios have 1, 2, or 3 flagella positioned on the cell surface. Fimbriae are made of protein. Several types of fimbriae are found in bacteria and vary based on function. Two types are the most well-studied:

The first type is common among many bacteria and is called general fimbriae. These fimbriae help bacteria attach to surfaces, other cells, or inert substrates, and they also participate in forming a layer on the liquid surface. Consequently, they can be referred to as adhesion organelles.

Tip 2: The type of fimbriae are called pili (F), and they consist of a hollow channel. This channel allows the bacteria to transfer genetic material to other bacteria involved in conjugation. Another function of pili is their role in helping pathogenic bacteria adhere to animal and human cells.

Prokaryotes, which include bacteria and archaea, are found almost everywhere — in every ecosystem, on every surface in our homes, and on the human body! Some of them live in environments that are extremely harsh for other organisms, such as hot springs at the bottom of the ocean.

Although prokaryotes are present in nearly every environment around us, identifying, counting, and classifying these microorganisms can be very challenging. The prokaryotic species we know today represent only a small fraction of all existing prokaryotic species. In fact, the concept of "species" presents some difficulties in the world of prokaryotes.

The "Tree of life" for prokaryotes for a long time, all prokaryotes were classified within a single domain (the largest taxonomic group). However, the work of microbiologist Carl Woese in the 1970s showed that prokaryotes are divided into two distinct lineages: bacteria and

archaea. Today, these groups are considered to constitute two of the three domains of life. The third domain, *Eukarya*, includes all eukaryotes such as plants, animals, and fungi.

The two domains of prokaryotes—Bacteria and Archaea—diverged early in evolution. Bacteria are highly diverse, ranging from pathogenic bacteria that cause diseases to beneficial bacteria involved in photosynthesis and symbiosis. Archaea are also very diverse, but they are not pathogenic, and most of them live in extremely harsh environments.

Metagenomic approaches to DNA sequencing have enabled scientists to discover new types of bacteria and archaea, including many that cannot be cultivated in laboratory conditions.

Many beneficial, symbiotic bacteria belong to the Gamma Proteobacteria; they live in the human intestines. Additionally, some pathogenic bacteria from this group are well known to humans. Some species within this small group oxidize sulfur compounds. Members of this group include *Escherichia coli*, which is considered a beneficial microbe in the human gut, although some strains can cause disease; some strains of *Salmonella* cause food poisoning and diarrhea; *Yersinia pestis* is the causative agent of bubonic plague; *Pseudomonas aeruginosa* causes lung infections; *Vibrio cholerae* is the causative agent of cholera; and *Chromatium* is a sulfur bacterium that oxidizes sulfur to produce H_2S.

A microphotograph shows a curved rod-shaped *Vibrio cholerae*, approximately 1 micron in size.Some species of Delta Proteobacteria form endospores in unfavorable conditions. Others can reduce sulfate and sulfur. Members of this group include *Desulfovibrio vulgaris*, an anaerobic bacterium that forms spores in harsh environments and reduces sulfur compounds. The microphotograph depicts a bent rod-shaped *Desulfovibrio vulgaris* with a flagellum.

Many members of the *Spirochaeta* taxonomic group have spiral-shaped cells. Most of these are free-living anaerobes, but some are pathogenic. They reside in the periplasmic space between the inner and outer membranes. Representatives of this group include *Treponema pallidum*, the causative agent of syphilis, and *Borrelia burgdorferi*, the causative agent of Lyme disease. A microphotograph depicts *Treponema pallidum*, which has a shape resembling a corkscrew and is approximately 1 micron in size.

Cyanobacteria (also known as blue-green algae) are bacteria that obtain energy through photosynthesis. They can be found in various environments—on land, in the ocean, and in freshwater bodies. The eukaryotic cell's chloroplast is thought to have originated from these bacteria. *Prochlorococcus* is the most widespread photosynthetic organism on Earth, responsible for producing about half of the oxygen in the atmosphere. A microphotograph shows *Phormidium*, a long, thin filamentous species.

Gram-positive bacteria have a thick cell wall and lack an outer membrane. Members of this small group inhabit the soil, where they decompose organic matter. Some species are pathogenic. Examples include *Bacillus anthracis*, which causes anthrax; *Clostridium botulinum*, responsible for botulism; *Clostridium difficile*, which can cause diarrhea during antibiotic therapy; *Streptomyces*, which produce many antibiotics including streptomycin; and *Mycoplasma*, the smallest bacteria that lack a cell wall. A microphotograph depicts *Clostridium* difficile, an elongated filament approximately 3 microns in length.

Chlamydiae: All members of this group are obligate intracellular parasites of animal cells. They lack peptidoglycan in their cell walls. One representative is *Chlamydia trachomatis*, which causes sexually transmitted infections and blindness. The microphotograph shows *Chlamydia trachomatis* as pinkish dots inside host cells.Epsilon Proteobacteria include numerous species that live as symbionts or pathogens in the digestive tracts of animals. These bacteria inhabit hydrothermal vents in the deep ocean and cold-water environments.

The next taxonomic group is Chlamydiae. All members of this group are obligate intracellular parasites of animal cells. Their cell walls lack peptidoglycan. A microphotograph shows tissue cells infected with *Chlamydia trachomatis*. *Chlamydia* infections are among the most common sexually transmitted diseases and can lead to blindness.

Conclusion

The morphology of microorganisms is one of the main factors in understanding their life processes, their interactions with the external environment, and their ability to cause disease. This information is important not only in the field of scientific research but also in practical medicine and agricultural microbiology. Microorganisms include bacteria, actinomycetes, fungi (including molds and yeasts), viruses, microscopic algae, and others. Microorganisms are divided into prokaryotes (organisms without a nucleus and chromosomal apparatus in their cells) and eukaryotes (organisms with a nucleus separated by a membrane and containing cytoplasm, either unicellular or multicellular). For a long time, all prokaryotes were classified within a single domain (the largest taxonomic group). However, the works of microbiologist Carl Woese in the 1970s showed that prokaryotes are divided into two distinct lineages: bacteria and archaea. Today, these groups are considered to constitute two of the three domains of life. The third domain (*Eukarya*) includes all eukaryotes, such as plants, animals, and fungi.

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