17.1: Bacterial Growth

Skills to Develop

1. Briefly describe the process of binary fission in bacteria, stating the functions of Par proteins, the divisome, and FtsZ proteins.

2. Define the following:
   a. generation time
   b. geometric progression

3. Draw a generalized bacterial growth curve, label the phases, and briefly describe what is happening during each phase.

Bacterial Growth

Bacteria replicate by binary fission, a process by which one bacterium splits into two. Therefore, bacteria increase their numbers by geometric progression whereby their population doubles every generation time. Generation time is the time it takes for a population of bacteria to double in number. For many common bacteria, the generation time is quite short, 20-60 minutes under optimum conditions. For most common pathogens in the body, the generation time is probably closer to 5-10 hours. Because bacteria grow by geometric progression and most have a short generation time, they can astronomically increase their number in a short period of time.

The relationship between the number of bacteria in a population at a given time ($N_t$), the original number of bacterial cells in the population ($N_0$), and the number of divisions those bacteria have undergone during that time ($n$) can be expressed by the following equation:
\[ N_t = N_o \times 2^n \]

For example, *Escherichia coli*, under optimum conditions, has a generation time of 20 minutes. If one started with only $10$ *E. coli* ($N_o = 10$) and allowed them to grow for 12 hours ($n = 36$; with a generation time of 20 minutes they would divide 3 times in one hour and 36 times in 12 hours), then plugging the numbers in the formula, the number of bacteria after 12 hours ($N_t$) would be

\[ [10 \times 2^{36} = N_t = 687,194,767,360 \text{ } E. \text{ } coli] \]

In general it is thought that during DNA replication (discussed in Unit 6), each strand of the replicating bacterial DNA attaches to proteins at what will become the cell division plane. For example, Par proteins function to separate bacterial chromosomes to opposite poles of the cell during cell division. They bind to the origin of replication of the DNA and physically pull or push the chromosomes apart, similar to the mitotic apparatus of eukaryotic cells.

In the center of the bacterium, a group of proteins called Fts (filamentous temperature sensitive) proteins interact to form a ring at the cell division plane. These proteins form the cell division apparatus known as the divisome and are directly involved in bacterial cell division by binary fission (see Figure 1 and Figure 2).

- electron micrograph of a divisome: see under Bacterial Cell Division, Jon Beckwith’s Lab.

The divisome is responsible for directing the synthesis of new cytoplasmic membrane and new peptidoglycan to form the division septum. The function of a number of divisome proteins have been identified, including:

- **MinE**: Directs formation of the FtsZ ring and divisome complex at the bacterium’s division plane.
- **FtsZ**: Similar to tubulin in eukaryotic cells, FtsZ forms a constricting ring at the division site. As FtsZ depolymerizes, it directs an inward growth of the cell wall to form the division septum. It is found in both *Bacteria* and *Archaea*, as well as in mitochondria and chloroplasts.
- **ZipA**: A protein that connects the FtsZ ring to the bacterial cytoplasmic membrane.
- **FtsA**: An ATPase that breaks down ATP to provide energy for cell division and also helps connect the FtsZ ring to the bacterial cytoplasmic membrane.
- **FtsK**: Helps in separating the replicated bacterial chromosome.
- **FtsI**: Needed for peptidoglycan synthesis.

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**YouTube movie of binary fission in bacteria, #1.**

**YouTube movie of binary fission in bacteria, #2.**

**YouTube movie of fluorescing imaging of binary fission in bacteria.**

- Scanning electron micrograph of *dividing Escherichia coli*; courtesy of CDC.

- Scanning electron micrograph of *dividing Salmonella typhimurium*; courtesy of CDC.
The Population Growth Curve

Although bacteria are capable of replicating geometrically as a result of binary fission, in reality this only occurs as long as their is space to grow, sufficient nutrients, and a way to dispose of waste products. Because these factors limit the ability to replicate geometrically, over time in a closed growth system a bacterial population usually exhibits a predictable pattern of growth - its growth curve - that follows several stages or phases:

1. The lag phase

During the lag phase growth is relatively flat and the population appears either not to be growing or growing quite slowly (see Figure 3). During this phase the newly inoculated cells are adapting to their new environment and synthesizing the molecules they will need in order to grow rapidly.

2. The exponential growth phase (also called the logarithmic or log phase)

This is the phase where the population increases geometrically as long as there is sufficient food and space for growth (see Figure 3).

3. The stationary growth phase

Here the population grows slowly or stops growing (see Figure 3) because of decreasing food, increasing waste, and lack of space. The rate of replication is balanced out by the rate of inhibition or death.

4. The decline or death phase

Here the population dies exponentially from the accumulation of waste products (see Figure 3), although the rate of death depends on the degree of toxicity and the resistance of the species and viable cells may remain for weeks to months.

For more information: Lab 4, Enumeration of Microorganisms

Summary

1. Bacteria replicate by binary fission, a process by which one bacterium splits into two.

2. Generation time is the time it takes for a population of bacteria to double in number. For many bacteria the generation time ranges from minutes to hours.

3. Because of binary fission, bacteria increase their numbers by geometric progression whereby their population doubles every generation time.

4. Par proteins function to separate bacterial chromosomes to opposite poles of the cell during bacterial cell division.

5. The bacterial divisome is responsible for directing the synthesis of new cytoplasmic membrane and new peptidoglycan to form the division septum.

6. Although bacteria are capable of replicating geometrically as a result of binary fission, this only occurs as long as
their is space to grow, sufficient nutrients, and a way to dispose of waste products.

7. In a closed growth system, a bacterial population usually exhibits a predictable pattern of growth - its growth curve - that follows several stages or phases.

8. During the lag phase growth is relatively flat and the population appears either not to be growing or growing quite slowly as newly inoculated cells are adapt to their new environment.

9. During the exponential growth phase (log phase) the population increases geometrically as long as there is sufficient food and space for growth.

10. During the stationary phase the population grows slowly or stops growing because of decreasing food, increasing waste, and lack of space.

11. During the death (decline) phase the population dies exponentially from the accumulation of waste products.

Contributors

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