7.21A: Chemotaxis

Chemotaxis is the phenomenon whereby bacterial cells direct their movements according to certain chemicals in their environment.

LEARNING OBJECTIVES

Explain how chemotaxis works in bacteria that have flagella

Key Takeaways

Key Points

- Chemoattractants and chemorepellents are inorganic or organic substances possessing chemotaxis -inducer effect in motile cells.
- Some bacteria, such as E. coli, have several flagella that can rotate to facilitate chemotaxis.
- The overall movement of a bacterium is the result of alternating tumble and swim phases.

Key Terms

- **chemotaxis**: Chemotaxis is the phenomenon whereby somatic cells, bacteria, and other single-cell or multicellular organisms direct their movements in response to certain chemicals in their environment.
- **flagella**: A flagellum is a lash-like appendage that protrudes from the cell body of certain prokaryotic and eukaryotic
cells.

- **movement**: Physical motion between points in space.

Chemotaxis is the phenomenon whereby somatic cells, bacteria, and other single-cell or multicellular organisms direct their movements according to certain chemicals in their environment. This is important for bacteria to find food (for example, glucose) by swimming towards the highest concentration of food molecules, or to flee from poisons (for example, phenol).

Positive chemotaxis occurs if the movement is toward a higher concentration of the chemical in question. Conversely, negative chemotaxis occurs if the movement is in the opposite direction.

Chemoattractants and chemorepellents are inorganic or organic substances possessing chemotaxis-inducer effect in motile cells. Effects of chemoattractants are elicited via described or hypothetic chemotaxis receptors; the chemoattractant moiety of a ligand is target cell specific and concentration dependent. Most frequently investigated chemoattractants are formyl peptides and chemokines. Responses to chemorepellents result in axial swimming and they are considered a basic motile phenomena in bacteria. The most frequently investigated chemorepellents are inorganic salts, amino acids and some chemokines.

Figure: **Chemoattractants and chemorepellents**: In response to chemoattractants, cells move toward the stimulant. In response to chemorepellents, cells move away from them.

Some bacteria, such as E. coli, have several flagella per cell (4–10 typically). These can rotate in two ways:
Figure: **Bacterial chemotaxis**: Correlation of swimming behavior and flagellar rotation in E. coli.

1. **Counter-clockwise rotation** – aligns the flagella into a single rotating bundle, causing the bacterium to swim in a straight line.

2. **Clockwise rotation** – breaks the flagella bundle apart such that each flagellum points in a different direction, causing the bacterium to tumble in place.

The directions of rotation are given for an observer outside the cell looking down the flagella toward the cell.

### Overall movements in bacterium

This is the result of alternating tumble and swim phases. If one watches a bacterium swimming in a uniform environment, its movement will look like a random walk with relatively straight swims interrupted by random tumbles that reorient it. Bacteria such as *E. coli* are unable to choose the direction in which they swim, and are unable to swim in a straight line for more than a few seconds due to rotational diffusion: they “forget” the direction in which they are going. By repeatedly evaluating their course, and adjusting if they are moving in the wrong direction, bacteria can direct their motion to find favorable locations with high concentrations of attractants (usually food) and avoid repellents (usually poisons).

In the presence of a chemical gradient bacteria will chemotax, or direct their overall motion based on the gradient. If the bacterium senses that it is moving in the correct direction (toward attractant/away from repellent), it will keep swimming in a straight line for a longer time before tumbling. If it is moving in the wrong direction, it will tumble sooner and try a new direction at random. In other words, bacteria like *E. coli* use temporal sensing to decide whether their situation is improving or not. In this way, it finds the location with the highest concentration of attractant (usually the source) quite well. Even under very high concentrations, it can still distinguish very small differences in concentration. Fleeing from a repellent works with the same efficiency.

### Purposeful random walk

This is a result of simply choosing between two methods of random movement; namely tumbling and straight swimming.
In fact, chemotactic responses such as forgetting direction and choosing movements resemble the decision-making abilities of higher life-forms with brains that process sensory data.

The helical nature of the individual flagellar filament is critical for this movement to occur. As such, the protein that makes up the flagellar filament, flagellin, is quite similar among all flagellated bacteria. Vertebrates seem to have taken advantage of this fact by possessing an immune receptor (TLR5) designed to recognize this conserved protein.

As in many instances in biology, there are bacteria that do not follow this rule. Many bacteria, such as *Vibrio*, are monoflagellated and have a single flagellum at one pole of the cell. Their method of chemotaxis is different. Others possess a single flagellum that is kept inside the cell wall. These bacteria move by spinning the whole cell, which is shaped like a corkscrew.

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**Signal transduction in bacteria**

The proteins CheW and CheA bind to the receptor. The activation of the receptor by an external stimulus causes autophosphorylation in the histidine kinase, CheA, at a single highly-conserved histidine residue. CheA in turn transfers phosphoryl groups to conserved aspartate residues in the response regulators CheB and CheY [note: CheA is a histidine kinase and it does not actively transfer the phosphoryl group. The response regulator CheB takes the phosphoryl group from CheA]. This mechanism of signal transduction is called a two-component system and is a common form of signal transduction in bacteria.

CheY induces tumbling by interacting with the flagellar switch protein FliM, inducing a change from counter-clockwise to clockwise rotation of the flagellum. Change in the rotation state of a single flagellum can disrupt the entire flagella bundle and cause a tumble.