Bacterial Genetics

Genetics:

Genetics is the science of heredity, which means the study of inheritance of the different characteristics from parents to offsprings that have the same characters as parents.

In bacteria genetics means that the daughter cells inherit the same characters as the parent cell.

Gene:

Gene is the unit of heredity, which is defined as a segment of chromosome DNA or a segment of nucleotides (DNA that carries the information for a specific structure or a specific character)

Bacteria differ from fungi, protozoa and humans because, bacterial **reproduction** occurs asexually as a result of **binary fission** rather than sexually with corresponding fusion. Note that bacteria are haploid which may have a single chromosome .

Elements of the genes

The Gene elements are divided into the following**:**

1- Chromosomal elements of the genes

2- Non-chromosomal elements of the genes.

1- Chromosomal elements of the genes

1- Bacterial chromosome[DNA]

The bacterial chromosome which contains all genes essential for viability, exist as adouble strand DNA molecule which is closed circular and around on itself to form the nuclear mass.

II- RNA

- It is a nucleic acid which is different in chemical composition from DNA, and is rarely exists as a double stranded molecule.
- It differentiates into three major types that all play an important role in gene expression.
- Messenger RNA (mRNA)
- Transrer RNA (tRNA)
- Ribosomal RNA(rRNA).

Gene expression

It is a protein synthesis which occurs as:

1- Transcription

2- Translation

1- Transcription:

- When the two strands of the chromosome are separated, one acts as a temple for the synthesis of a complementary strand of RNA (mRNA) by the RNA polymerase enzyme.
- Each amino acid has specific tRNA which attaches to it at one end, where at its other end has a triplet of bases (anti-codon) of complement to the triplet of bases on mRNA.
- The triplet of base on mRNA is called the 'codon' for that amino acid.

2- Translation:

- On the surface of the ribosome the mRNA and tRNA come together from which each tRNA finds its complementry nucleotide triplet on mRNA and the amino acid is linked with the adjacent one to form a polypeptide chain.
- The entire mRNA is translated into a corresponding sequence of amino acids linked to form polypeptide chains and hence proteins are synthesized.

Chromosomal (DNA) replication

- Before cell division the 2 strands of the chromosome separate and each one is attached to a mesosome from which acts as a template on which a complementry strand is formed by the action of DNA polymerase enzyme,
- After the completion of chromosomal replication cell division occurs by the formation of transverse septum between the attachment sites.

2- Non-chromosomal elements of the genes

1- Plasmids

2- Transposable elements .

1- Plasmid

- It is a small extrachromosomal double strand, self replicating, closed, circular DNA molecule.

- Each plasmid is composed of several genes which some of these genes encode products that mediate plasmid replication and transfer between bacterial cells (conjugative plasmids).

Classification of plasmids

1- Virulence plasmid (virulence factor)

- It involves in the pathogenicity by the production of toxins .
- It is responsible for colonization by the production of factors which allow bacteria to adhere to cells.

2- Colicinogenic plasmid (col factor)

- It encodes small protein (colicin) that kill some bacteria related to the producing organism .
- It also encodes an immunity protein.

3- F-factor (fertility) plasmid

- It contains genes that codes for factors essential for **conjugation** (gene exchange). i e ,
- F-factor (E.coli) is responsible for sex pili production.

4- Dissimilation plasmid

- It has gene coding for enzymes that catalyze unusual hydrocarbons and sugars (species of pseudomonas) .
- Use these substances as primary carbon and energy source.

5- Drug-resistance (R) plasmid (R factor)

- All the drug resistance genes clustered on one region called the r-determinant while the genes involved in conjugational transfer located at the other region called the resistance transfer factor .
- The **r-determinant (r-gene)** is a complex collection of mobile genetic elements that enable the spread of the encoded antibiotic resistance properties throughout the bacterial population.

Transposable elements (jumping genes)

- These elements are sometimes called transposons
- These genetic elements are pieces of DNA that move externally readily (transpose) from plasmid to plasmid or from plasmid to chromosome and vice verse .
- Unlike plasmids they do not exist as separate entities within the microbial cell but they are incorporated into plasmid or chromosome.
- Transposable elements are divided into two types:

i- Insertion sequence (or simple transposons)

They contain genes that carry the genetic information for moving between plasmids and chromosomes.

ii- Transposon (complex transposons)

They contain genes for movement and to carry genes for antibiotic resistance or toxin production.

- Two types of bacterial variation are recognized
- the phenotype which is dependent on the growth conditions and is not inherited.
- the genotype which is due to charges in genetic constitution and is inherited by future generation.

1- Phenotypic variations

- These variations are due to changes in bacterial characters under the influence of the surrounding environment without any genetic changes.
- They are not heritable, but are reversible when the cause is removed.

2- Genotypic variations

- Genotypic variations are due to changes in genetic constitution .
- They are heritable and irreversible variations.
- They occur in one of the following ways:

A-Mutation

1- Spontaneously

2- Induced by the environment

B-Gene transfer (genetic exchange)

1- Transformation

2- Transduction

3- Conjugation

Mutation

It is a heritable, irreversible alteration in a gene which is due to change in the base sequence of DNA (double helix) leading to the production of a protein that has an altered amino acid sequence.

This change may be due to three types :

- Substitution of one base pair for another. **(Point mutation).**

- Deletion of bases. **(Frame shift mutation).**
- Insertion of new bases. **(Transposons).**

Types of mutation

1-Base substitution (point mutation)

It is the simplest type of mutation in which one base (nucleotide in DNA) is inserted in place of another.

a- Missense mutation: it occurs when the base substitution results in a codon which causes a different amino acid to be inserted.

b- Nonsense mutation: it occurs when the substitution generates a termination codon which stops protein synthesis prematurely .

c- Silent mutation: it occurs when the mutation results in no change in the amino acid sequence.

2- Deletion and addition (frame shift mutation)

It occurs if one or few base pairs are deleted or added to DNA. Which shifts the reading frame to the ribosome and results in the production of an inactive “downstream” from the mutation.

3- Insertion sequence (transposons)

This type of mutation is also called transposable-elements, mutagenesis or insertion of new bases.

The newly inserted pieces of DNA can cause changes in the genes (interfere with transcription of the gene) into which they insert.

Classification of mutation

According to the mutational events, mutation can be classified into:

- Spontaneous mutations
- Induced mutations.

I- Spontaneous mutations

- These mutations arise in the absence of a known mutagen.
- They occur without known intervention of mutation-causing agents during DNA replication .
- The most likely mechanism for spontaneous mutation include:

1-Errors in pairing at DNA replication.
2-Loss of segment of DNA.
3-Production of mutagens from normal metabolites.
4-Alteration in activity or synthesis of enzymes involved in DNA replication or repair.

II- Induced mutations

- These mutations are also called mutagens or variation induced by the environment.
- Mutagens are agents in the environment such as radiation or chemicals that cause mutation.
- They can be classified into those caused by: 1- Light energy .

2- Chemical energy .

1- Light energy

- Ionizing radiation.

At lower levels x-rays are powerful mutagens which can cause a considerable increase in the rate of mutation of living cells.

- Non-ionizing radiation or Ultraviolet (UV) light radiation.

This type of radiation may cause chromosomal aberrations that result in point mutations.

2- Chemical energy

Examples of this category are :

- Base analogues.
- Nitrous acid.
- Alkalizing agents.
- Acridine dyes.

Gene transfer (Genetic exchange)

- In bacteria, gene transfer occurs, as the genetic material from one parent is transferred to the other.
- For this process a recombinant chromosome is formed from genetic material of two different parental cells.
- During transfer, part of the donor cell genetic material is transferred to the recipient making it partial diploid.
- The **donor DNA** is called ‘exogenote’ while the original genome of the recipient is called endogenote .

Some generalizations about gene transfer

1. The transfers are unidirectional from DNA donor to DNA recipient.

2. The transfer of genetic is usually incomplete and only one part of the donor DNA is transferred .

3. Not all organisms are capable of all of the genetic transfer mechanisms .

4. The successful completion of transfer requires some positive level of DNA homology.

- Transfer may occur by,:

i- Transformation

ii- Conjugation

iii-Transduction.

Transformation

- In transformation: a single-stranded piece of the donor DNA replaces a strand of the recipient DNA
- It occurs when a recipient cell takes up a fragment of free DNA present in the surrounding medium.
- The transformation process can be divided into :

1- Competence development
2- The cells develop a state of 'competence' which means the ability to take up DNA.
3- DNA binding
4- The DNA binds to the cells.
5- DNA uptake (absorption)
6- The DNA is taken up by the cells.

Conjugation

- In conjugation: the donor DNA is transferred between cells that are in direct contact.
- It involves cell-to-cell contact in which DNA is transferred from the cell that contain **F- factor plasmid** (F+) [donor cell] to

the cell that contain receptor sites which binds pili (F-) [recipient cell] .

- Conjugation is controlled by an F (fertility) plasmid and code for formation of **sex pili**(conjugation tube) that bridge between cells.
- Conjugation may occur either by plasmid or chromosomal transfer.

Transduction

- In transduction: a small fragment of donor DNA is transferred to the recipient by a bacteriophage.
- It is the transfer of fragments of chromosomal DNA from one bacterium to a second bacterium by means of bacterial viruses (bacteriophage).
- The types of transduction are :

1-Generalized Type :

When viral DNA is integrated into bacterial DNA , this viral DNA is then cut from the bacterial DNA and packed within the protein coat . The viruses are subsequently released when the infected cell lyses. In other words generalized transduction occurs when the virus carries a segment from any part of the bacterial chromosome .

2-Specialized Type :

It occurs only when bacterial DNA that was adjacent to viral DNA in the bacterial chromosome is packaged . This means that when the bacterial virus DNA that has integrated into the cell DNA is excised (cut) and carries with it an adjacent part of the cell DNA

Transduction occurs as follows:

- A bacteriophage infects a bacterium and phage DNA enters the cell .
- The phage DNA replicates and the bacterial DNA fragments .
- The progeny cells- progeny phage assembles and are released .
- A second bacterium is infected by a phage containing bacterial DNA.
- Bacterial DNA integrates into the host and the host acquires a new trait.

Table1:comparison of conjugation, transduction and transformation

Transfer Procedure	Process	Type of Cells Involved	Nature of DNA Transferred
Conjugation	DNA transferred from one bacterium to another	Prokaryotic	Chromosomal or plasmid
Transduction	DNA transferred by a virus from one cell to another	Prokaryotic	Any gene in generalized transduction; only certain genes in specialized transduction
Transformation	Purified DNA taken up by a cell	Prokaryotic or eukaryotic (e.g., human)	Any DNA

Genetic recombination

In this process , once the donor's DNA is transferred to the recipient cell by transformation , conjugation or by transduction it can integrates into the host cell chromosome by recombination .

Genetic recombination , recombinant DNA technology , DNA cloning or genetic engineering is a branch of science which has very important application in medical field.

The technique of genetic recombination requires separation of DNA fragment by restriction endonucleases . This DNA fragment is carried on a vector (used to carry and introduce foreign DNA fragments into a host cell e.g plasmid bacteriophage or cosmid) which is introduced into a host cell by transformation where it is applied .

Recombination may occur by the following types :

1- Homologous recombination

In this type of recombination two pieces of DNA that extensive homologous regions pair up or similarities in their nucleotide sequences and exchange pieces by the processes of breakage and reunion .

2- Non-homologous recombination

In this type of recombination only little of homology is needed,

Application of Molecular Genetics

Gene Probes

- Each well classified species has a unique DNA sequence on its chromosome, which distinguish it from other species.
- If this sequence is identified a specific labeled **DNA probe** is used in a hybridization reaction to recognize pathogen-specific DNA released from specimens.
- DNA probes can be used to not easily cultured in vitro species.
- DNA probes can be used to recognize specific antibiotic resistance genes.