Topic overview:

The mechanism known as **recombination** is the process of exchanging genetic information between **chromosomes** and happens to take place in a variety of organisms. It plays a crucial role in many processes since it takes place in **evolution**, **inheritance**, **genetic variation**, etc.

In **molecular** terms this would involve the swapping, or exchange of segments of **DNA** molecules. During **copulation** in **eukaryotic** organisms, **meiosis** is what allows the exchange of segments of DNA between traits that share the same function and origin in chromosomes. This event creates significant genetic diversity by allowing offspring to have a chance of evolution and a change of **heritable characteristics**. However, unlike eukaryotes, **prokaryotes** (single-celled organisms) do not reproduce in the same manner as eukaryotes do. Instead, they follow several different mechanisms to promote their genetic exchange. These mechanisms involve having fragments of DNA recombined into the chromosome after entering it through a process of **conjugation**, **transformation**, or **transduction**. This results in recombination having an influence on the evolution of bacteria. It is important to note that in all cases involving recombination, pieces of DNA molecules are rejoined after being broken and thus they form a crossover. Recombination happens when two crossovers take place and allows a segment of DNA to be transferred from one molecule of DNA to another. Additionally, recombination can be categorized into two different examples: **homologous** and **nonhomologous**. In the homologous example, recombination occurs from two similar sequences while the nonhomologous example recombination occurs in short bases and no similarity is apparent.

1. Homologous Recombination

As stated previously, homologous recombination involves the occurrence of a **crossover** to take place from the recognition of two double-stranded DNA. The process requires the breaking of one strand of each DNA duplex and results in the formation of a **Holliday junction** which contains two **heteroduplex regions** where the two separate DNA molecules have paired.

Two products can be formed from the breakdown of the Holliday junction and the product that is obtained (from the two products that are able to be formed) is dependent on the composition of the junction when it is set on. In addition, the Holliday junction is able to migrate in a process called “**branch migration**” where it migrates along the DNA.

1.2 Chi Sites & Single-Strand Invasion

In the process of forming a **triple-stranded helix**, a single strand of DNA invades a second **DNA double helix**. This involves two stages and depends on **RecA** and **RecBCD** proteins. Specific sequences called **chi sites** are needed, but they're common in bacterial DNA.

First, RecBCD binds to DNA breaks, driven along by **RecB** and **RecD** helicase proteins, unwinding the double helix to create a single strand. RecA is recruited by **RecBC** as it passes chi sites, binding to single-stranded DNA. RecA then binds to the 3’ end of the chi site, forming a triple helix and stabilizing the single-stranded DNA. This displaces some strands, which pair with the residual single strand of DNA unwound by RecBCD.

2. Conservative Site-Specific Recombination

**Site specific-recombination** (also known as nonhomologous recombination) in single-celled organisms may occur in DNA molecules with slight sequence similarity. In this process, short identifiable sequences for particular proteins are utilized. The proteins then bind to DNA and the recombination event is initiated.

Site specific-recombination is critical and may be used in **genetic modification**. Some examples would include **CRISPR** (clustered regularly interspaced palindromic repeats), it is understood as a gene-editing technology in biomedical research and is able to correct known errors in the **genome** with ease (Redman, et al. 2016). Site specific-recombinases do however, differ. Some only require a set number of proteins while others only require a single one.

3. Recombination in Higher Organisms

During the early stages of **meiosis**, recombination takes place. Double-stranded breaks are introduced in order for crossover to occur between the pairs of homologous chromosomes. Double-stranded breaks occur in eukaryotic chromosomes during the first stage of meiosis (leptotene). In the following stage (zygotene) paired chromosomes are coupled to properly form hybrid junction structures that somewhat resemble those of bacteria (Holliday junctions). Following this, in the third stage (pachytene) resolution of the crossovers happens. Lastly,in the last stage of meiosis (diplotene) the crossovers disconnect and deliver recombinant chromosomes.

In recombination of higher organisms, **mitosis** focuses mainly on repairing double-stranded breaks and/or single-strand gaps. Chromosome rearrangements may increase if homologous recombination becomes defective in the persistence of mutations.

4. Gene Conversion

According to **Mendel’s law dominance** is seen in heredity and in other higher organisms such as animals and plants (Castle, 1903). As a result, crossing over must be symmetrical and have dissimilar **alleles** from two distinct parents. When copulation between two parents takes place, the different alleles from each individual parent should present equivalent frequency in the **offspring**. Nevertheless, there are exceptions for this. **Gene conversion** is that exception. It is able to involve a system that operates in the structures which are generated by recombination. Gene conversion occurs when one allele is transformed to another during the process of recombination.

Chapter Summary:

In conclusion, recombination is essential and is a process that expands to the contribution of genetic diversity which allows the survival of species. In addition to expanding genetic diversity, it also allows evolutionary adaptation in both the higher-order and single-cell organisms. Furthermore, and as stated previously, advances in genetic engineering have allowed scientists to further analyze techniques involving the recombination of genetic material. Additionally, recombination is crucial in a wide variety of organisms, involving the exchange of genetic information between chromosomes. In eukaryotic organisms during copulation, meiosis enables the exchange of DNA segments, leading to genetic diversity and evolutionary change. Prokaryotes, however, use different mechanisms such as conjugation, transformation, or transduction to promote genetic exchange. This influences bacterial evolution. Recombination involves DNA segment swapping and can be categorized into homologous and nonhomologous types. In all cases, pieces of DNA are rejoined to form crossovers, allowing DNA transfer between molecules.

Vocabulary:

**Recombination:** genetic material such as DNA, is substituted between chromosomes or among different areas of the equal chromosomes. Typically occurs in processes that are cellular like meiosis and other mechanisms that take place within prokaryotes. Also plays an important role in inheritance, genetic diversity, and evolution.

**Chromosomes:** Structures composed of DNA and proteins that are within cells, specifically the nucleus. Genetic information that is necessary for the functioning of an organism such as the development, growth, and purpose are contained within the chromosome. Different species have different characteristics as well as number of chromosomes, these are transpired from parents to the offspring during the process of copulation.

**Evolution:** This process involves populations of organisms that are modified within generations. These occur in many mechanisms such as genetic drift, natural selection, and genetic variation. The process also results in adaptation within species and their environment as well as the arrival of new organisms. This system is driven by many factors that include environmental changes, resources, competition, and genetic mutation which in turn results in a wider diversity within species. Thus, diversifying life.

**Inheritance:** The process of inheritance involves influencing genetic composition. It refers to characteristics that are passed from one generation to the next. This occurs when offspring acquire traits from their parents. These traits can range from behavior to physical features.

**Genetic Variation:** Involves the diversity of genetic sequence within a population of species. Genetic variation is important in evolution since it grants populations to adjust to evolving ecosystems. It can also appear as distinctions in multiple traits.

**Molecular:** Refers to the smallest level of biological structures such as DNA and proteins.

**DNA:** Also known as deoxyribonucleic acid, is a molecule found within cells of organisms. DNA dictates an organism's traits by carrying its genetic information. Crucial for helping organisms function.

**Copulation:** The mating of individuals of the same species in order for reproduction to occur.

**Eukaryotic:** These organisms have a defined nucleus within a membrane. Typically involve species such as animals, fungi, and plants.

**Meiosis:** Takes place during copulation (the mating of individuals) and has two divisions. An important part of reproduction since it ensures that offspring acquire singular traits from their parents. Also highly important for the production of gametes and genetic diversity. Throughout the course of meiosis, homologous chromosomes match and swap genetic sequences.

**Heritable characteristics:** Can also be called inherited traits and they’re passed down from the parents to the offspring. They’re inherited from one generation to the next.

Prokaryotes: Single-celled organisms that do not have a nucleus and are not enclosed by membrane organelles (unlike eukaryotes). Known as the simplest forms of organisms which include bacteria. They’re highly important in multiple ecological processes.

**Conjugation:** Process of genetic transfer in bacteria where DNA molecules are transferred between the cells of bacteria that are briefly attached together.

**Transformation:** Cell transformation is a process in which a cell faces changes which affect it by evolving into a distinct cell that develops abnormalities.

**Transduction:** Signals that lead to a cellular response. Important in cells in order for them to sense and react to changes in the environment as well as being able to accept signals from other cells.

**Homologous:** Can be defined as the likeness amidst two chromosomes in a wide variety of organisms that have a common lineage. These features have different functions in various life forms due to branching evolution.

**Nonhomologous:** Unlike homologous chromosomes, these do not share a common lineage. However, they also have different functions in various life forms.

**Crossover:** Also referred to as genetic recombination, the process involves the genetic exchange of material.

**Holliday junction:** Named after the discoverer Robin Holliday, the four-way DNA structure manifests during a crossover. Essential in the exchange of material amongst two homologous DNA molecules.

**Heteroduplex regions:** Areas where two DNA strands from the homologous chromosomes form pairs yet include mismatches in nucleotide sequences. In this process, the chromosomes align together for the exchange of genetic material. The heteroduplex regions are important in order for genetic recombination to take place. They serve as repair enzymes and also aid in genetic diversity.

**Branch migration:** Another process that occurs during genetic recombination, it occurs after the development of a holliday junction. During the process of branch migration, enzymes (also referred to as branch migration proteins) promote the movement of the junction by the side of DNA molecules.

**Triple-stranded helix:** Can also be referred to as ‘triple helix’ is a DNA structure that involves three strands of DNA to be bound together through the bonding of hydrogen. Thus, resulting in the form of the helical structure.

**DNA double helix:** Structure of DNA that consists of two complementary strands of DNA. These are twisted and thus are able to form a fixed helical structure.

**RecA protein:** Typically referred to as recombinase A, is an important protein that participates in the process of genetic recombination. Plays a role in homologous recombination (repairing of double-strand breaks and producing genetic diversity).

**RecBCD protein:** also known as RecBC protein is an enzyme complex that is found within bacteria, and is associated with the participation in DNA repair and recombination. The RecBCD protein is composed of three components: Firstly, RecB, which involves the unwinding of a double helix and the generation of a single-stranded DNA. Secondly, RecC, which is able to recognize sequences (chi sites) and interacts with RecB which in turn assists the direction of activity towards chi sites. Lastly, RecD, which works with RecB to unwind the duplex of the DNA. In conclusion, the enzyme complex (RecBCD protein) has multiple functions in DNA repair. Including, DSB repair, the processing of DNA ends, and chi recognition.

**Chi site:** Can also be referred to as chi sequence, is a DNA sequence that functions as a signal of recognition. It primarily does so for the beginning of homologous recombination in prokaryotes (they’re unique to prokaryotes {so they’re not found in eukaryotic organisms}). Chi sites increase the efficiency of homologous recombination by encouraging recombination gear to areas of DNA with high levels of homology. Chi sequences are also important in maintaining the diversity of bacterial populations.

**RecB protein:** One of the three subunits of the enzyme complex (RecBCD). RecB is multifunctional and unwinds the DNA duplex of the double helix and separates the DNA strands by creating a newly formed single-stranded DNA.

**RecD protein:** One of the three subunits of the enzyme complex (RecBCD). RecD protein is a DNA helicase and is also known to be responsible for the unwinding of the DNA duplex during recombination.

**Site specific-recombination:** Type of genetic recombination that takes place within exact DNA sequences (referred to as recognition sites within the genome). In this process, enzymes detect and link to specific DNA sequences, split DNA strands, and exchange DNA segments. This results in the insertion, deletion, and translocation of DNA segments.

**Genetic modification:** Involves the change of an individual's genetic material by using biotechnological processes. This process can involve many steps such as the identification of target genes, gene delivery, integration, expression, selection, and gene manipulation.

**CRISPR:** This is an example of genetic modification, more specifically gene delivery. For instance, the modification of genes requires the involvement of the introduction of a recipient's cells, like gene editing applications which take place in CRISPR.

**Genome:** The complete set of genetic substances (RNA or DNA) that is found within an organism.

**Meiosis:** Cell division that takes place within sexually reproducing species and produces gametes with only half of the chromosomes present in the parents cell. This process ensures the reduction in chromosomes and maintains the chromosome number across successive generations. Some key events of meiosis include: Prophase I, metaphase I, anaphase I, telophase I, cytokinesis, and meiosis II.

**Mitosis:** Type of cell division that takes place within eukaryotic organisms (it is primarily known for being responsible for the growth of multicellular organisms). Mitosis results in two daughter cells that are completely identical to the parent cells. In conclusion, mitosis is important for the repair of tissue, and for the growth of multicellular organisms. Key events for the process of mitosis include: Interphase, prophase, metaphase, anaphase, telophase, and cytokinesis.

**Mendel’s law dominance:** The law involves the recognition that a heterozygote will convey the dominant trait during the first set of offspring.

**Allele:** Two or more choice forms of a gene which arise from mutations in DNA sequences. This results in different traits and qualities.

**Offspring:** Produced during sexual reproduction. They inherit genetic substances from their parents. Resulting in a combination of qualities and traits.

**Gene conversion:** Engages in the one-way transfer of genomic data from either two completely different or similar DNA sequences.

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