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LINKAGE AND CROSSING OVER

Dr. Amrutha Gopan
Assistant Professor
School of Fisheries
Centurion University of Technology and Management
Odisha



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- ❖ The number of *genes* in an organism far exceeds the number of *chromosome*.
- ❖ 850 genes are known in the fruit fly, *Drosophila melanogaster* which has only 4 pairs of chromosomes.
- ❖ A single chromosome bears several genes.



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LINKED GENES

- ❖ Genes present at the same locus have the tendency to be linked together from one generation to the other and are not disturbed by the meiotic recombination.
- ❖ Linkage is defined as “the tendency of genes to remain together during the process of inheritance”.
- ❖ When two loci were linked genetically on the same chromosome they did not segregate.
- ❖ Extent of linkage - closer the genes, stronger the linkage and vice versa.
- ❖ Linkage of genes is in the linear fashion in the chromosomes.



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LINKAGE

- ❖ The genes that show linkage are located on the same chromosome.
- ❖ A linkage group is formed by all the linked genes in a chromosome.
- ❖ The strength of linkage between two genes is directly proportional to the distance between them.



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TYPES OF LINKAGE

i) Complete Linkage

- When two or more genes tend to remain together on the same chromosome and are inherited together for many generations, the phenomenon is known as **complete linkage**.
- Rare, found in male *Drosophila*.
- Happen when chromosomes do not undergo any breakage by accident during gametogenesis.



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Incomplete Linkage

When the linked genes tend to separate on some occasions during the course of inheritance, the phenomenon is known as ***incomplete linkage***.

- Occurs in the process of crossing over during gametogenesis.
- The genes present on the homologous part of sex chromosomes exhibit the phenomenon of incomplete linkage.



AUTOSOMAL & SEX LINKAGE

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❖ **Autosomal linkage**- the linked genes are present on the autosomes.

Sex linkage- the linked genes are present on the sex chromosomes.

- ❖ Linkage groups in fish-detected by Winge (1923).
- ❖ E.g., the **Xvi** and **Xel** genes in the guppy are linked on the X chromosome.
- ❖ Although both genes may cross over to the Y chromosome, it is assumed that they are located only on the X chromosome.



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CROSSING-OVER

- ❖ The physical exchange of parts of non-sister chromatids of homologous chromosomes following synapsis at meiosis is known as ***crossing-over***.
- ❖ Results in the recombination of genes.
- ❖ 1, or 2, or more fragments may be interchanged during crossing-over.



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❖ Frequency of crossing over of a given pair of genes is not constant.

❖ Crossing over frequencies are higher in the female sex than in males.

❖ Temperature, nutrition, sex, age, etc. influence crossing over.

❖ It is a part of meiotic mechanism during gametogenesis.

❖ Brings about variation and leads to evolution through natural selection.



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1. SINGLE CROSSING-OVER

- ❖ Only one chiasma is formed resulting in the formation of single-cross-over gametes.
- ❖ Only one chromatid of each chromosome is involved in single crossing over.
- ❖ Single crossing over is of most frequent occurrence.



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2. DOUBLE CROSSING-OVER

- ❖ Two chiasmata are formed.
- ❖ Both the chiasmata may be between the same chromatids or between different chromatids.
- ❖ Two, or three, or all the four chromatids of the homologous pairs of chromosomes are involved in the process of double crossing-over.
- ❖ Double cross-over gametes are produced.
- ❖ This is of less frequent occurrence.



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3. MULTIPLE CROSSING-OVER

- ❖ More than two chiasmata are formed.
- ❖ Corresponding to the number of chiasmata formed, it is called triple (3 chiasmata), quadruple (4 chiasmata), and so on.
- ❖ Multiple crossing-over does not occur frequently.



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SIGNIFICANCE

- ✦ Provides a direct evidence of the linear arrangement of genes in the chromosomes.
- ❖ Chromosome maps can be constructed.
- ❖ Gives rise to new combinations of genes, and hence, variations in offspring.



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CHROMOSOME MAPPING

- ❖ Sturtevant, (1913) constructed first chromosome map showing the position of 5 genes on the X chromosome of *Drosophila*.
- ❖ Genetic maps of chromosomes are also known as *chromosome maps*.



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GENE MAPPING

❖ Refers to the analysis of loci on the genome revealing the linear order of different genes on the chromosomes.

❖ Two types of gene maps.

1) Physical maps

2) Genetic maps



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PHYSICAL MAPS

- ❖ Based on the assignment of loci to chromosomes.
- ❖ Accomplished by the methods
 - 1) somatic cell hybrid panels,
 - 2) *in situ* hybridization,
 - 3) comparative mapping.
- ❖ In physical maps the coordinates are the chromosome regions or bands.
- ❖ The distance between two loci are measured in kilobases.



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GENETIC MAPS

- ❖ Constructed by studying the meiotic recombination between two or more loci through linkage analysis.
- ❖ A new locus are assigned to a chromosome following the inheritance of the new locus and of an already mapped locus.
- ❖ Do not provide an absolute location of loci but they reveal the genetic distance of the loci as a function of the frequency of crossing-overs occurring during recombination.
- ❖ Provides an ordered array or sequence tagged sites along the chromosome.



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GENETIC DISTANCE

- ❖ Expressed in units of crossing over or centimorgan (cM).
- ❖ One CM equals 1% crossing over and contains approximately 1000 kb.
- ❖ i.e, two loci which show 1% recombination are 1 CM apart on a genetic map.
- ❖ In a linkage a new locus is assigned based on an already known locus.
- ❖ It shows that a reference locus is a prerequisite for the purpose.



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➤ One map unit is defined as the linkage distance that yields 1% recombination.

When a large number of genes are mapped in any given species, the genes are observed to occur in linkage groups, with one linkage group corresponding to each pair of chromosomes.



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FISH – (Fluorescent *In Situ* Hybridization)

- ❖ Highly effective, rapid technique for use in gene mapping.
- ❖ Probes are labeled with fluorochrome dyes which fluoresce in different colours when excited by UV–light.
- ❖ Location of the probes are visualized under Epifluorescence microscope.



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❖ Fluorochromes used are,

- 1) Fluorescein isothiocyanate-fluoresces green.
- 2) Rhodamine and Texas red-fluoresces red.
- 3) 7-amino-4-methyl cocemarin –3- acetic acid-fluoresces blue.

❖ Three dimensional architecture of chromatin in interphase nuclei, gene expression and chromosome aberration can be studied.



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CHROMOSOME PAINTING

❖ This is one of the application of FISH techniques.

- ❖ The direct visualization of specific chromosomes by fluorescent detection by hybridized labeled whole chromosome probes is called *Chromosomes painting*.
- ❖ Used to improve the accuracy of cytogenetic studies, closing the gap between cytogenetic and molecular analysis.



❖ Whole chromosomes specific probes are called '*paints*'.

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❖ Used in identification of species specific chromosomes among somatic cell hybrids.

❖ Used in detection of Chromosomal rearrangements or abnormalities for which no locus-specific probes are available.



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