

Cytogenetics is branch of biology devoted to the study of chromosomes and their implications in genetics.

CHROMOSOMAL ABERRATIONS: Occasionally, spontaneous (without any known causal factor, Natural occurrence) variations in the structure and number of chromosomes have been observed in nature. These variations are called chromosomal aberrations and can be due to either (a) structural changes or (b) numerical changes.

Origin of structural aberration

Chromosomes are structures with definite organization. However, through various means they may be broken and their normal structure disrupted. X-rays, atomic radiations and various chemicals are among the agents that can cause breaks in chromosomes. Breaks also sometimes occur under natural conditions, where in most instances the reason for breakage is not known.

Structural chromosomal aberrations: Structural chromosomal changes include those chromosomal aberrations which alter the chromosome structure i.e. the number of genes, the sequence or kind of genes present in the chromosome(s) and do not involve a change in chromosome number.

Types of structural chromosomal aberrations: These aberrations may be confined to a single chromosome or more than one chromosome. Hence they are of two types.

1. Intra-chromosomal aberrations
2. Inter-chromosomal aberrations

I. Intra -chromosomal aberrations: When aberrations remain confined to a single chromosome of a homologous pair, they are called intra -chromosomal aberrations. Includes deletions, deficiency and inversions.

II. Inter-chromosomal aberrations: When aberrations occur in non-homologous chromosomes and the resulting fragments are inter-changed by both the nonhomologous chromosomes, they are known as inter-chromosomal aberrations. Ex: Translocations.

I. Intra-chromosomal aberrations: They may be of the following types :

1. Deletions or deficiencies: Deletion is due to the loss of a part of a chromosome. In a deletion, a chromosome lacks either a terminal or an interstitial segment which may include only a single gene or a part of a gene. Hence it is of two types.

i) **Terminal deletion:** If a break occurs near the end of chromosome and a small piece of terminal chromosome is lost, it is called terminal deletion.

ii) **Interstitial or intercalary deletion:** Sometimes two breaks may occur at any two points and the broken ends of the original chromosome get fused or reunited and as a result, an interstitial deletion is formed. The deleted fragment is acentric. Consequently the acentric fragment is immobile and will be lost during cell division.

Both types of deletions can be observed during pachytene stage of meiosis or in the polytene chromosomes. However, in majority of the cases, terminal deficiencies are more frequent than intercalary deletion because single breaks are required whereas intercalary deletions require two breaks.

Origin and occurrence of Deletions

1. **Production of deletions through irradiation (X rays and neutrons):** Deficiencies can be artificially induced using radiations such as X-rays or fast neutrons. An effective way for artificial induction of deficiencies is achieved by irradiation of pollen used for pollination (as in tomato and Maize) or irradiation of developing seeds after pollination (as in Maize). Irradiation is an effective method because the deleted segment remains in the pollen or cell so that viability is not affected. X-rays mainly induce breaks in the heterochromatin region while fast neutrons induce breaks in the euchromatin region.
2. **Production of deficiency due to a gametocidal chromosome:** Endo developed a genetic system for isolation of several deletion lines in common wheat. A monosomic alien addition lines in wheat were produced by backcross programme involving *Aegilops cylindrica* that provides a gametocidal chromosome. This *Aegilops cylindrica* chromosome induces terminal deletions of chromosomes in wheat as identified by C-banding. These deletions are used to map genes on chromosomes. Monosomic addition lines can be defined as the original diploid plants or plants having normal somatic complement plus a single alien chromosome of another species ($2n + 1$ where the extra one chromosome is a gametocidal chromosome of *Aegilops cylindrica*).

Meiosis and Breeding behavior of deficiency heterozygote

Organisms with homozygous deletion do not survive to an adult stage because a complete set of genes is lacking (lethal effect). Small deficiencies, if present in heterozygous condition (deficiency heterozygote) can be tolerated by the organism. In such individuals during pachytene

stage of meiosis the unpaired segment of the normal chromosome of an intercalary deletion heterozygote produces a characteristic loop in a bivalent as seen in maize and tomato. In *Drosophila* loops or characteristic buckling and missing bands can be easily observed in salivary gland chromosomes which are found in a permanent state of pairing. Therefore even small deficiencies could be detected in these chromosomes. In case of terminal deletion heterozygotes, the segment towards one end of the normal chromosome appears as unpaired segment or univalent portion. Sometimes this univalent portion may fold back and pair non-homologously with the recipient chromosome. Generally deficiencies are usually lethal to pollen and ovules. If a deficiency is transmitted only through female gametes, a 1: 1 ratio of normal to deficiency heterozygote is observed in the progeny. The deficiency heterozygote is identified by loops seen at pachytene stage of meiosis.

Genetics of deficiency: Deficiencies have an effect on the inheritance also. In presence of deficiency a recessive allele will behave like a dominant allele. When an organism heterozygous for a pair of alleles Aa loses a portion of the chromosome bearing the dominant allele 'A', the recessive allele being in the hemizygous condition will be expressed phenotypically. This phenomenon is known as pseudo-dominance. Pseudo –dominance technique has been utilized for location of genes on specific chromosomes in *Drosophila*, maize, tomato and other organisms (that is, chromosome mapping).

In *Drosophila*, deletions are used for chromosome mapping (that is, locating genes on specific chromosome). If a female *Drosophila* heterozygous for a deficiency and carries a dominant marker is crossed to male fly having recessive marker, then the progeny will be 50% females having recessive phenotype instead of 100% dominant. This would mean that the concerned gene falls within the region of deficiency, so that the location of deficiency will determine the location of genes on that particular chromosome.

In maize, when pollen are irradiated with X rays they function normally and transmission of deleted segment will not be impaired. When such pollen is used as male source and crossed to females having recessive marker, the F1 seeds will express female recessive markers genes in case deletions are induced in the irradiated pollen. Here the technique of pseudodominance is exploited for locating genes in the broken segment cytologically. G. S. Khush and Rick carried out extensive studies using pseudodominance technique in tomato to locate genes on chromosome arms. Here the irradiated pollen carrying dominant alleles from RED CHERRY

variety of tomato is crossed to female parent having recessive marker allele at corresponding locus. Only the recessive pseudodominant stocks were retained for pachytene chromosome analysis and discarded dominant plants. Khush and Rick could able to assign 35 genes on 18 of the 24 arms of the chromosome complement. When this pseudodominance technique combined with aneuploidy, 1) almost all the genes can be located on chromosomes, 2) orientation of linkage groups are prepared 3) establish position of centromere on chromosomes.

2. Duplications or Repeats: Duplication occurs when a segment of chromosome is represented two or more times in a chromosome of a homologous pair. The extra segment may be a free fragment with a centromere or a chromosomal segment of the normal complement. As a result, in one chromosome of the homologous pair, there will be deletion, while in other there will be a duplication. Duplication was first reported in *Drosophila* by C.B. Bridges in 1919. Duplications generally result due to unequal crossing over at pachytene stage.

Duplications are of four types:

1. **Tandem or repeat duplication:** The extra chromosome segment may be located immediately after the normal segment in precisely the same gene sequence.
2. **Reverse tandem or reverse repeat:** The gene sequence in the extra segment of tandem duplication is in the reverse order i.e. is inverted. (eg . cb in place of bc)
3. **Displaced:** The extra segment may be located in the same chromosome but away from the normal segment and with same sequence.
4. **Reverse displaced:** The gene sequence in the extra segment of a displaced duplication is in the reverse order i.e. is inverted (eg. ed in place of de)

Duplication in one of the two homologous chromosomes can be seen at pachytene stage of meiosis, cytological observations characteristic of deficiency will be obtained in duplication also.

Origin, occurrence and production of duplications

1) Duplications can originate naturally or spontaneously as seen in dominant phenotypic marker called *Bar* locus in *Drosophila* (first reported by Tice in 1914). One of the classical examples of duplication in *Drosophila* is that of bar eye. Bar eye is a character where the eyes are narrower as compared to normal eye shape. This phenotypic character is due to the duplication for a part of chromosome. By the study of giant salivary gland chromosomes of *Drosophila melanogaster*, it could be demonstrated that 'Bar' character was due to duplication in the region 16A of x

chromosome. Barred individuals (16A 16A) gave rise to ultra bar (16A 16A 16A) and normal wild type (16A) due to unequal crossing over.

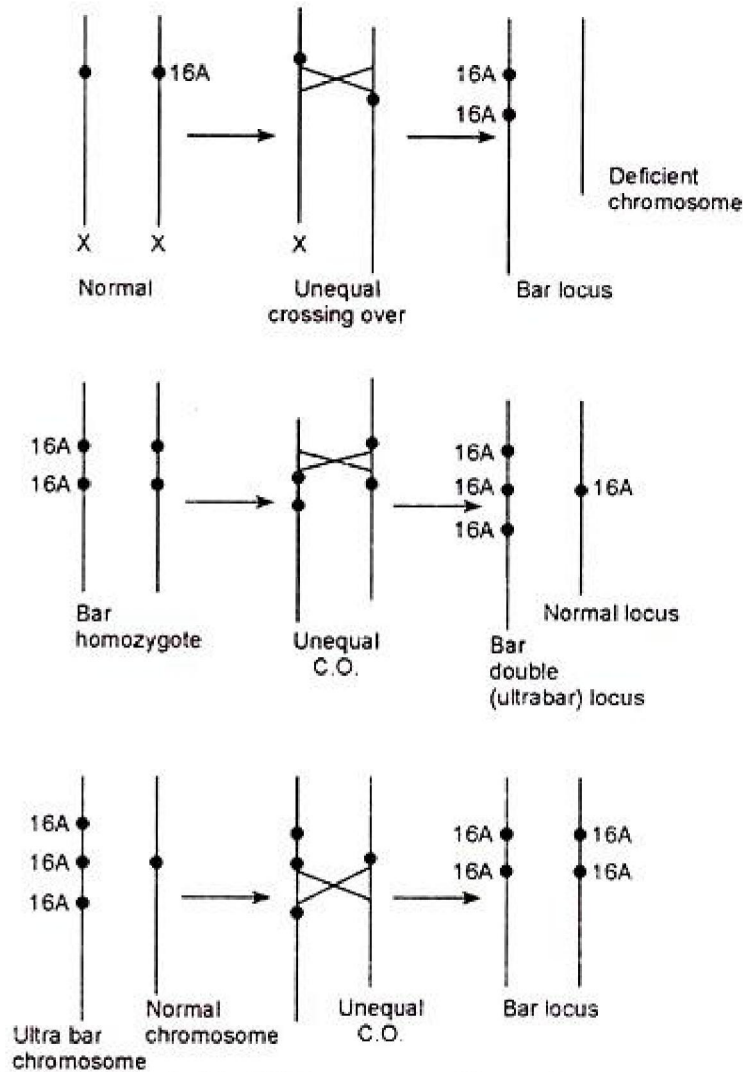


Fig. 13.2. Unequal crossing over in the X chromosome of *Drosophila* resulting in a duplication of 16A region; this duplication produces the Bar eye phenotype.

2) **Crossing over within inversion:** Crossing over within an inversion produces chromosomes showing deficiency-duplication.

3) **Translocation heterozygote:** Deficiency-duplication gametes are produced by translocation heterozygotes, but these gametes are sterile.

3) In minor cases Irradition treatments also cause duplications.

Chromosome Pairing at meiosis in duplication heterozygote:

The duplicated segment forms a loop during pachytene in duplication heterozygotes (Fig. 13.3). Unequal crossing over may occur in duplication heterozygotes leading further duplications of the concerned segment. For example, Bar eye locus of *Drosophila* gives rise to the double-Bar (ultra bar) eye following unequal crossing over (Fig. 13.2).

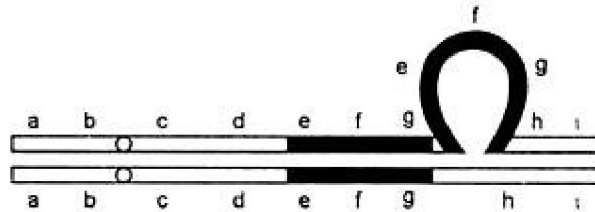


Fig. 13.3. Pachytene configuration in a duplication heterozygote. The duplicated region forms a loop.

If the duplication is carried on the other arm of the same chromosome, the two arms of a chromosome pair to form ring univalents. Duplications can be identified by molecular markers such as RFLP to distinguish loops of deletions and duplications. RFLPs give more than one fragments in case of duplications and one fragment in deletions.

Breakage-fusion-bridge Cycle: Extensive studies on broken chromosome-9 in corn have been made by Barbara Mc Clintock. In the gametophyte (pollen) and endosperm of corn, ends of chromosome that are recently broken tend to be “sticky,” as is shown by their tendency to adhere to one another. She found that following reduplication of a broken chromosome the two sister chromatids may fuse at the point of previous breakage. The fused sister chromatids would be unable to separate readily. In effect, they constitute a single chromatid with two centromeres, a dicentric chromatid. As the centromeres move to opposite poles at anaphase I or anaphase-II, the dicentric chromatid stretches out, forming a chromatin bridge from one pole toward the other. This bridge eventually breaks, but the break does not always occur at the point of previous fusion. The break usually occurs near one of the two poles resulting two daughter cell with one cell having duplication and the other cell has deletion. Therefore, chromosomes may be formed that show structural aberrations such as duplications and deficiencies if compared with an original type.

Thus, if the original chromosome is **C B A**
the type **C B A A**
is a duplication type, since region *A* is represented twice.

The type ***CB***

is a deficiency, since region *A* is absent.

Now two new broken ends of chromosomes are also sticky and these sticky broken ends do not heal in gametophyte or endosperm B. This situation permits repetition of more similar events as described above, in cyclic series. Spontaneous production of chromosome aberrations through breakage-fusion-bridge cycle may occur in this manner for some time. But when a broken chromosome is introduced into the sporophytic generation such cycles cease, as the broken ends heal in the zygote. Breakage-fusion-bridge cycle has phenotypic effects on maize endosperm such as colourless spots in the seed due to deletion of genes.