Chapter 10 ~ Sex Chromosomes & Sex Linkage

Introductions

- Mendel worked w/ plants showed patterns of inheritance derived from gene loci on autosomal chromosomes.
  - One complication to this model of inheritance in animals is that loci present on sex chromosomes called SEX-LINKED loci, don't follow this pattern!

- Most of the chromosomes in humans are present in two copies.
  - Each copy has the same length, centromere location & banding pattern → called autosomes

- In mammals, males have on of each females have to x chromosomes

NOTE: Two of the chromosomes, the X & Y do NOT look alike. These are SEX CHROMOSOMES

Autosomes & Sex Chromosomes

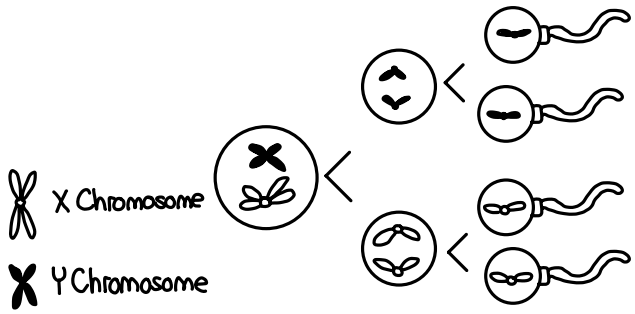
In diploids, most chromosomes exist in pairs (same length, centromere location & banding pattern) w/ 1 set coming from each parent.
These chromosomes are called autosomes.
However, many species have an additional pair of chromosomes that do NOT look alike.
These are sex chromosomes blw the sexes.
In humans, males have one of each while females have 2 x chromosomes.
Autosomes are those chromosomes present in the SAME number in males & females while sex chromosomes are those that are NOT.

When sex chromosomes were first discovered, their function was unknown & the name X was used to indicate this mystery.
The next ones were named Y, then Z, then W (depending on the species)

The combination of sex chromosomes within a species is associated w/ either male or female individuals.
In mammals, fruit flies & some dioecious plants those w/ two X chromosomes are females, while those w/ X & Y are males.
In birds, moths, & butterflies:
males = ZZ
females = ZW
Because sex chromosomes have arisen multiple times during evolution the molecular mechanism(s) through which they determine sex differs among those organisms
Ex: Humans & Drosophila both have X & Y sex chromosomes they have different mechanisms for determining sex

How do the sex chromosomes behave during meiosis?
In those individuals w/ two of the same chromosomes (ie homogametic sexes XX = females ZZ = males) the chromosomes & segregation during meiosis I, the same as autosomes.
During meiosis XY males or ZW males (heterogametic sexes) the sex chromosomes pair w/ each other

- In mammals (XX, XY) the consequence is all egg cells will carry an X chromosome while the sperm cells will carry either an X or a Y chromosome
  - Half of the offspring will receive two X chromosomes & become female, while half will receive an X & a Y & become male
- In species w/ ZZ males all sperm carry a Z chromosome, while in females ZW, half will have a Z & half a W
- It is a popular misconception that the X & Y chromosomes were named based upon their shapes; physically each looks like any other chromosome.
  - A Y chromosome doesn't look like a Y any more than a chromosome 4 looks like a 4.
  - The combination of sex chromosomes within a species is associated with either male or female.
- In mammals, fruit flies & some flowering plants
  XX = females
  XY = males

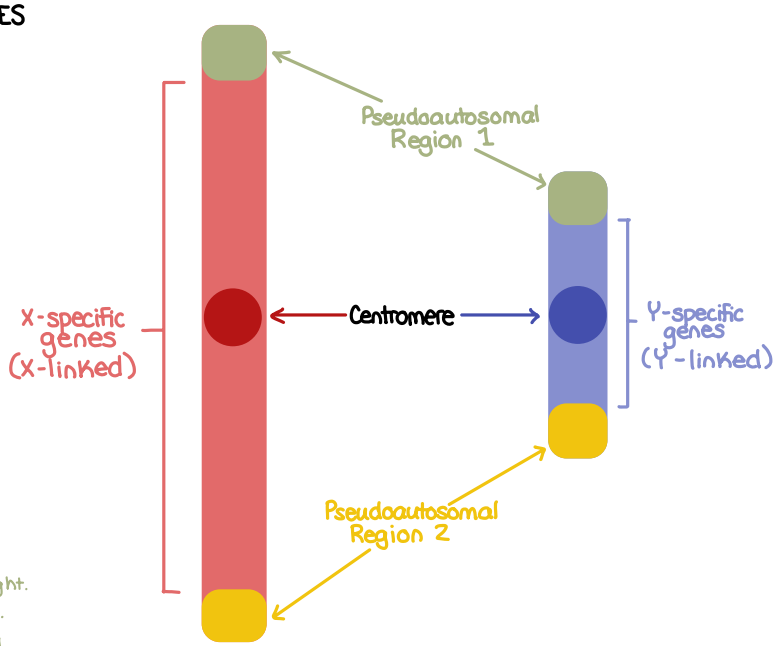


Pseudo-Autosomal Regions on the X & Y Chromosomes

- In evolution, before the X & Y chromosomes differentiated, they used to be equivalent homologs, like an autosome.
- Over time, the Y chromosome lost most of its genes (hence the reduced size), but the X chromosome retained all its genes
  - Thus, even though the Y chromosome has lost most of its genes, it still shares some regions w/ the X chromosome.
  - This is the reason why although X & Y chromosomes are heteromorphic (morphologically dissimilar), they are able to act as a homologous pair in meiosis & undergo crossover.
- These common regions, which contain similar genes, permits the X & Y to pair up & are called the "PSEUDO AUTOSOMAL REGIONS"
  - The name comes from the observation that genes in these regions behave like autosomes in their inheritance.
- Alleles of the genes in this region crossover just like those on the autosomes.
  - Thus genes in this region ARE NOT inherited in a sex-linked pattern, even though they are located on the X chromosome

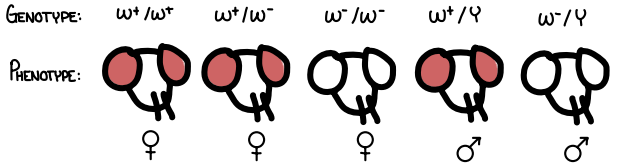
- The genes found in pseudo-autosomal region are represented in two copies in both XY males & XX females, and thus expressed from both active & inactive chromosomes.
- These genes may explain clinical features in sex chromosomes aneuploidy
  - Addition or subtraction of a sex chromosome
    ↳ex: XXY)
  - As gene products may be either under or over expressed in relation to normal females & males

- One of the genes in this region is called SHOX.
  - It makes a protein that promotes bone growth.
  - 46, XX & 46XY people have two functioning copies & have average age, height.
    ↳People w/ 47XYY & 47XXX genomes have 3 copies & are taller than avg.
    ↳And people w/ 45X have one copy & are short.
  - It is the single copy of SHOX & a few other genes in the pseudo-autosomal region that causes health problems for women w/ Turner Syndrome



Sex Linkage: An Exception to Mendel's 1st Law

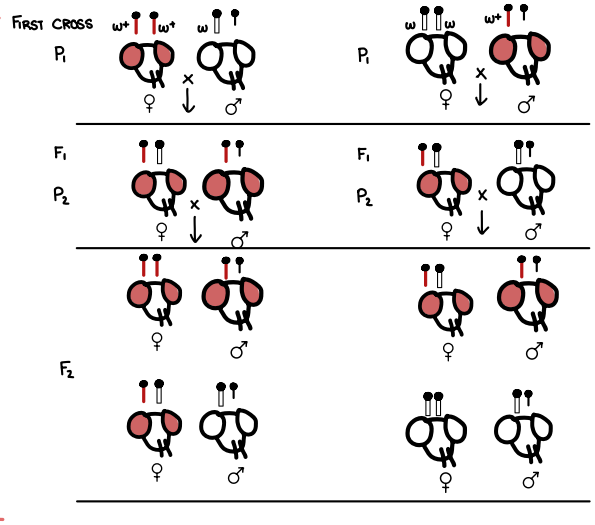
- We have introduced sex chromosomes & autosomes (non-sex-linked chromosomes)
- The loci on autosomes, the alleles follow the classic Mendelian inheritance.
  - However, for loci on the sex chromosomes this doesn't follow b/c most (not all) of the loci on the typical X-chromosome are absent on the Y chromosome, even though they act as a homologous pair during meiosis.
- Instead they follow a sex-linked pattern of inheritance
  - A X-linked allele in the father WILL ALWAYS be passed on to his daughters ONLY, X-linked allele in the mother will be passed on to both daughters & sons equally



X-Linked Genes: The White Gene in Drosophila Melanogaster

- Sex-linked gene → white gene on X chromosome of Drosophila melanogaster.
  - Normally flies have red eyes, but flies w/ a mutant allele for this gene called white- (w-) have white eyes b/c the red pigments are absent.
  - B/c this mutation is recessive to the wild type w+ allele, females that are heterozygous have normal red eyes.
- Female flies that are homozygous for the mutant allele have white eyes
  - B/c there is no white gene on the Y chromosome, male flies can only be hemizygous for the wild type allele or the mutant allele
- A researcher may not know beforehand whether a novel mutation is sex-linked

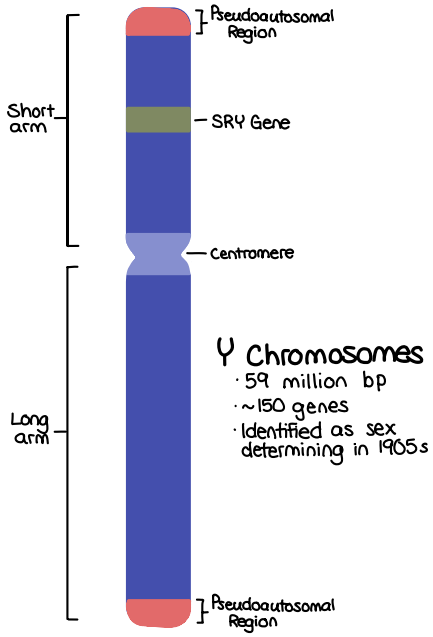
- The definitive method to test for sex-linkage is reciprocal crosses
- This means to cross a male & a female that have different phenotypes then conduct a second set of crosses, in which the phenotypes are reserved relative to the sex of the parents in the first cross.
  - Ex: If you were to set up reciprocal crosses w/ flies from pure-breeding w+ & w- strains the results would be...



- Whenever reciprocal crosses give different results in the F_1 & F_2 and whenever the male & female offspring have different phenotypes the usual explanation is sex-linkage.
- Remember, if the locus were autosomal the F_1 & F_2 progeny would be different from either of these crosses
- A similar pattern of sex-linked inheritance is seen for X-chromosome loci
- In other species w/ XX-XY sex chromosome system, including mammals & humans

Y-Linked Genes

In humans, the Y chromosome has been studied is known to contain approximately 200 genes which provide instructions for making protein.
B/c only males have the Y chromosome, the genes on this chromosome tend to be involved in male sex determination & development.
Sex is determined by the SRY gene which is the sex determining region of the Y chromosome



- Other genes on the Y chromosome are important for enabling men to father biological children (male fertility)
- Many genes are unique to the Y chromosome but genes in areas known as pseudoautosomal regions are present on both sex chromosomes.
  As a result, men & women each have two functional copies of these genes.
- Many genes in the pseudoautosomal regions are essential for normal development.
- Although the Y-chromosome is sex-determining in humans & some other species, not all genes that play a role in sex determination are Y-linked
  - Y-linked traits, while few in number, do exist.
    For instance, the Y-linked trait of "webbed toes" causes a web-like connection b/w second & third toes and "porcupine man" occurs when the skin thickens & gradually becomes darker scaly, rough & w/ bristle-like outgrowths.
  - Since Y-linked inheritance involves the Y chromosome Y-linked inheritance is passed on from father to son.
- Of course, Y-linked traits never occur in females & occur in all male descendants of an affected male.
- The concept of dominant & recessive do NOT apply to Y-linked traits, as only one allele (on the Y) is ever present in any one (male) individual
  - Ignors XYY syndrome (rare) which affects males
  - Caused by the presence of an extra Y chromosome
  - Males normally have one X & one Y
  - These individuals have one X & two Y's