Genetic Inheritance Patterns
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Genetics has been the subject of fascination throughout the centuries, and continues to lead the news in debate and controversy. From the discovery of the double helix structure of DNA by Watson and Crick in 1953 to the cloning of a sheep called Dolly announced in 1997, genetics is a field which is exploding with information and discoveries. This article will describe the simple genetic inheritance patterns published by Gregor Mendel (called Mendelian inheritance) as well as more complicated patterns including partial expression, and polygenic inheritance.

Mendelian inheritance is based on unit characters (alleles) which are described as either dominant or recessive. A pair of alleles combine to make a gene, or a character trait which is expressed physically. A dominant allele is a trait that statistically meets the following criteria: 1) the trait does not skip generations, 2) on average a large number of offspring carry and express the gene (affected), 3) there are no "hidden" carriers, 4) a dominant allele can come from either the sire or dam, resulting in expression of the trait. For example, if we use the capital letter 'B' to stand for a dominant allele and the lower case letter 'b' to represent a recessive allele, then 'BB' would be a completely dominant individual, 'Bb' would contain a dominant and recessive allele, and 'bb' would be a completely recessive individual.
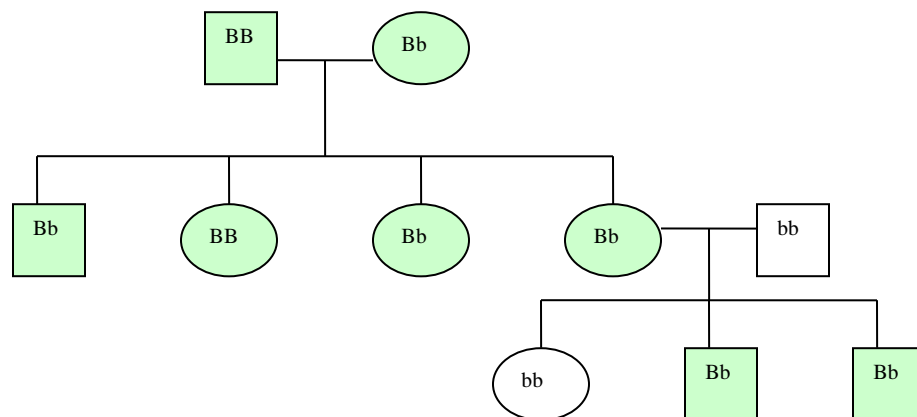

Figure 1: Inheritance pattern for a dominant genetic disease. The circles represent females and the squares represent males. The lines between circles and squares represent a breeding and the resulting generation. The letters inside the shapes represent the actual genotype of the animal with BB and Bb equaling affected and bb equaling clear. The solid color shapes represent animals which physically express the gene, or the affecteds. Note that the expression of the gene is in every generation and is present in large numbers in general.

Conversely, a recessive allele is a trait that meets a different criteria: 1) the trait may skip one or more generations, 2) on average a small number of offspring express the gene, 3) only those offspring which inherit two recessive copies of the gene express the trait, 4) there are "hidden" carriers, 5) both the sire and dam have to contribute a recessive allele to result in expression of the trait.
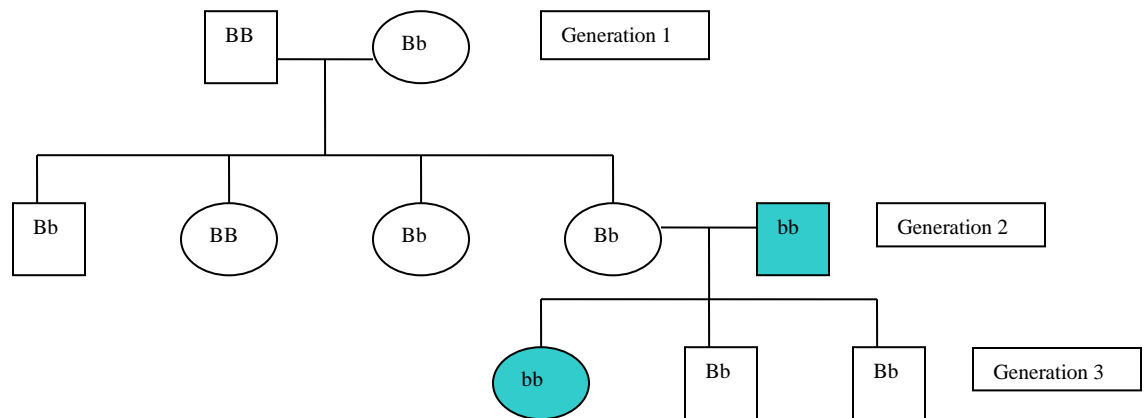

Figure 2: Inheritance pattern for a recessive genetic disease. The circles represent females and the squares represent males. The letters inside the shapes represent the actual genotype of the animal with BB equaling clear, Bb equaling carrier and bb equaling affected. The solid color shapes represent animals which physically express the gene, or the affecteds. Note that the expression of the gene skips generations and is present in small numbers overall.

In the poodle, we can use the inheritance of progressive retinal atrophy (PRA) as an example of a recessive trait. If a trait is recessive, then the "normal" allele is dominant, and expression of the trait requires two copies of the recessive allele. A 'BB' individual therefore would neither express nor carry the trait. This individual could be bred to any other individual and his offspring will never express the trait (see Figure 2, Generation 2 – the only solid color individual is the unrelated male bred to the second generation female to produce Generation 3). A 'Bb' individual does not express the trait, but does carry it. The Bb individual can pass the trait to his offspring if bred to another carrier (Bb) or an affected individual (bb) [refer to Figure 2 generation 3 – the dam of this generation is a carrier and the sire is an affected individual]. A 'bb' individual both expresses and carries the trait. This individual will pass the trait to all of his offspring, who will be either carries or affecteds depending on the genetic characteristic of the other parent. Two 'bb' individuals bred together will produce 100% affected puppies.

Tables 1 and 2 describes various pairings in a box format. Table 1 focuses on breedings between dominant individuals, none of which will physically express the trait, i.e. all individuals appear normal. Table 2 focuses on breedings between carriers who appear normal physically, and affecteds, who express the abnormal trait. The main focus of this exercise is to determine what breedings will result in affected puppies, and to show the percentage of affected puppies one could statistically expect depending on the genetic status of the parents (clear, carrier, affected).

Below are various breedings of genotypes containing dominant and recessive alleles. The tables reflect percentages of clear, carrier, and affected breedings for a genetic trait which is considered recessive in the population.

	B	B
B	BB	BB
B	BB	BB

a) breeding 2 dominant (BB) individuals

	B	B
b	Bb	Bb
b	Bb	Bb

b) breeding a dominant (BB) and recessive (bb) individual

	B	B
B	BB	BB
b	Bb	Bb

c) breeding a dominant (BB) and a carrier (Bb)

	B	b
B	BB	Bb
b	Bb	bb

d) breeding 2 carriers (Bb)

Table 1

(a) In breeding two dominant individuals it can be seen that 100% of the offspring inherit dominant alleles from both parents, these offspring are considered "clear" and will not pass on the trait to their progeny.
(b) The offspring from this breeding will not express PRA, but 100% will be carriers and can pass PRA on to their progeny.
(c) These offspring will result in 50% clear (BB) and 50% carriers (Bb)
(d) In breeding two carriers, 25 % of progeny will be clear (BB), 50% carriers (Bb) and 25 % affected (bb).

	b	b
b	bb	bb
b	bb	bb

a) breeding 2 recessive individuals

	B	b
b	Bb	bb
b	Bb	bb

b) breeding a recessive and a carrier individual

Table 2

(a) In breeding two recessive individuals it can be seen that 100% of the offspring will inherent recessive alleles from both parents, these offspring are considered "affected" and will both express and pass on the trait to their progeny.
(b) The offspring from this breeding will result in 50% carriers (Bb) and 50 % affected (bb). The remaining two combinations – carrier to carrier and recessive to dominant can be seen in Table 1.

The bottom line is, if the breeder knows the exact genetic status of the sire or dam, matings can be planned such that affected individuals are not produced. This does not mean that the gene itself will be eradicated from the population, merely that the disease will not be seen as often because litters are being planned which will only produce either clear (BB) or carrier (Bb) puppies. In the case of a dominant trait, such as black coat color, the opposite is true – the BB and Bb individuals will express the gene, and the bb individuals will be a different color depending on the parents (white, for example).

The next form of inheritance to be discussed is polygenic inheritance. When the expression of a trait depends upon the influence of several different genes it is considered to be "polygenic." For example, it has been hypothesized that both sebaceous adenitis (SA) and Addison's disease may be polygenic in that more than one pair of defective alleles must be inherited in order to express the disease. At this time, researchers are working on the inheritance patterns of both of these diseases, and it will be interesting to see their genetic pattern and whether it is a simple recessive, as previously suggested, or a polygenic pattern. If it is polygenic then it will still be possible to develop markers to test for the trait, however multiple markers may be required. In determining which dogs to breed in order to avoid producing affected pups, the breeder will have to be knowledgeable about how the disease is inherited and which combinations of genes will produce affected puppies versus clear or carrier puppies.

Another example of polygenic inheritance in poodles is coat color. Colors in the poodle include black, blue, silver, cream, white, brown, red, and apricot. Black is completely dominant and white is completely recessive. The other colors can be obtained through a combination of dominant, recessive, partial dominance, and dilution factors. For example, the red color is proposed to be the combination of recessive genes that affects only the apricot color. If the recessive gene for red is expressed by a dog that inherited two copies of the apricot gene, then the dog is red. If it is a carrier or dominant combination, then the dog is apricot but can carry red if it contains one recessive allele. If the recessive gene for red is carried by a black or white dog, the dog will appear black or white but it will not express any of the red color. Therefore, black dogs can carry other coat colors but not express them. Black dogs can carry recessive alleles for more than one coat color including brown, cream, white, apricot and red. White dogs can carry dilution and pigmentation factors which may be expressed when bred to a dog with color. Breeding two white or cream poodles together will never produce a black or any other color other than white or cream, unless a point mutation occurs. The likelihood of a point mutation producing black or another color is much like winning the lottery – there is less than 1 out of more than a million chances of it occurring.

Lastly, in discussing coat color in poodles, it would be remiss not to mention the parti-color or piebald gene. The parti-color gene is recessive to the complete color seen in all the other colors. A parti-color dog must inherit two copies of the recessive allele in order to be parti-colored. Any of the solid colors can carry a recessive allele for parti-color. Oftentimes breeders can go for many generations without any parti-color puppies and then one suddenly appears. This is not a mutation of the "normal" color genes, it is in fact a recessive allele that is present in small numbers within the poodle population. Chance breedings can result in parti-color puppies when both parents are solid color. In

this case, both parents must carry the recessive allele for piebald or parti-color. The parti-color gene will break up the solid color in the coat resulting in patches of color and white. The patches of color will be determined by the color of the parents and what they may carry. For instance, two silver dogs who carry piebald and white can be bred together to produce silver, white, and parti-color silver puppies.

Understanding basic genetics such as the inheritance of PRA or coat color is important for any breeder who wishes to have a successful breeding program. Planning breedings to avoid certain diseases as well as obtaining consistency in structure, temperament, coat color, etc. will only be successful if the breeder understands how those characteristics are inherited. Currently, there are genetic tests available for coat color inheritance, and DNA tests for PRA and von Willebrand's disease in the poodle. Researchers are studying genetic inheritance for sebaceous adenitis, epilepsy, juvenile renal disease, and Addison's disease, among others. In addition to understanding how specific characteristics (including diseases) are inherited the breeder must research to determine how prevalent those genes are in her line as well as any line she wishes to breed into her kennel. Genetics is the science of the future, and each year brings more and more exciting information for breeders to utilize.