FROM PEAS TO PUPS

BASIC GENETICS FOR DOG BREEDERS

Claudia Waller Orlandi, Ph.D.

Claudia Waller Orlandi, Ph.D. has been in dogs for 40 years and is well known for her Topsfield Bassets. She was 2009 AKC Breeder of the Year. She has a background in education. She writes and lectures frequently.

From Tally Ho issues July-August 1997. September-October 1997 and January-February 1998

Part 1: Chromosomes and Genes

SCENARIO: ***You have just bred your best bitch to the top producing sire in the country with high expectations for a beautiful litter. Results, however, were a disaster. What went wrong?***

ANSWER: GENETICS!

It's difficult to understand why puppies may look different from each other as well as from their parents. Gregor Mendel's work with garden peas uncovered the mystery of this fascinating process and helps explain how genes function in the passing on of traits from one generation to another. The intelligent breeding of dogs requires an understanding of how chromosomes and genes work as well as the maintenance of a system of written records which charts the "genetic" progress of a breeding program. We will attempt to break down the potentially complex topic of genetics into easy-to-understand scenarios. Part 1 discusses the role that chromosomes and genes play in making every dog unique in outward appearance (phenotype) as well as genetic make-up (genotype). The process of "chromosome swapping" during reproduction is a phenomenon that every breeder should understand and helps explain the diverse physical appearance of littermates.

WHAT ARE DOGS MADE OF?

A dog is made up of innumerable cells, each containing a nucleus. Within the nucleus are tiny thread-like structures called chromosomes. In each species, the number of chromosomes is always constant and even. The nuceli of all dogs contain 78 chromosomes; man has 46, the cat, 38. Chromosomes come in different shapes and sizes, with every cell containing two of each particular kind. In this regard, instead of referring to 78 chromosomes in dogs, it is preferable to speak of 39 pairs of chromosomes, one member of each pair having come originally from the sire and one from the dam. Chromosomes which are members of the same pair are called homologous chromosomes. Strung out along the length of each chromosome, like beads on a string, are thousands of genes. Consisting primarily of DNA, genes are carriers of hereditary information which will ultimately determine an individual's size, temperament and conformation. As the chromosomes are paired, so are the genes along their length. Genes located in the same position (locus) in homologous chromosomes will influence the same trait or traits in the dog. With one member of the homologous chromosomes coming from the sire and one from the dam, it follows that one member of each gene pair also came from each parent.

HOW ARE GENES PASSED FROM ONE GENERATION TO THE NEXT?

Dawkins (1976) simplifies the discussion of how genes are passed from one generation to the next by viewing each nucleus as a ROOM which contains a BOOKCASE of architect's PLANS on how, in our case, to build a dog. In our discussion, the "volumes" in the bookcase (nucleus) will be the chromosomes and the "pages" will refer to genes, which are the carriers of heredity. Because each nucleus in the dog contains 39 pairs of chromosomes we could say that filed in the BOOKCASE of every cell nucleus of our dog are 2 alternative sets of 39 volumes of plans. Call them Volume 1a, Volume 2a and Volume 1b, Volume 2b down to Volume 39a and Volume 39b ("a" volumes came from the father; "b" volumes from the dam). The identifying number used for volumes, and later, pages, is purely arbitrary. From this point on, let's consider each volume (chromosome) to be of a loose-leaf binder type and its removable pages to be the genes. In the two sets of volumes in each cell, instructions for building any part of our Basset Hound would be on corresponding pages. For example, if the genetic instructions for making our dog's ears were on pages 500 to 700 in Volume 1a, ear instructions would also have to be on pages 500 to 700 in Volume 1b. The ears our dog actually inherited were based on the combined instructions from both volumes.

UNIQUE PLANS FOR EACH PUPPY!

In the reproductive process, which is called meiosis (pronounced my-o-sis), a specialized kind of cell division takes place in the testicles and ovaries. A sperm cell from the male (or an egg cell from the female) is made when a cell divides, going from two full sets of 39 chromosomes to a cell with only one full set of 39 chromosomes. Sperm and egg cells are collectively referred to as gametes. Using a sperm cell as an example and returning to our analogy of loose-leaf binders, each sperm would contain only one set of volumes 1 through 39. The most important point to be made here is that during the dividing process Volumes 1a through Volumes 39a and Volumes 1b through Volumes 39b do not stay neatly intact, with the "a" set going to one sperm cell and the "b" set going to another sperm cell. Rather a new and unique 39 volume set is produced for each sperm cell in which single pages, or rather multi-page chunks, are detached from the "a" volumes and swapped with corresponding chunks from the alternative "b" volumes. For example, in producing its unique 39 volume set a sperm cell might make up its "ear instructions" (contained in both volumes on pages 500 to700) by taking pages 500 to 575 from Volume 1a and pages 576 to 700 from Volume 1b. A different sperm cell's "ear instructions" may include pages 500 to 600 from Volume 1a and pages 601 to 700 from Volume 1b. In genetic terms, this process of swapping bits of chromosome (in our analogy, gene "pages") is called crossing-over. Our two sperm cells' other 38 volumes of building plans for all the other parts of the dog would be made up in a similar, one-of-a-kind way. Each gamete (sperm or egg) always ends up with one of each of the 39 volumes, with no duplications or omissions of a volume number.

Remember, our sire's "a" set of chromosomes came from his father and his "b" set of chromosomes from his mother. Due to a random swapping of genes between the two sets, any one of the "new" chromosomes that ends up in a sperm cell is therefore a patchwork or mosaic of his paternal and maternal genes. This chance arrangement of chromosomes and genes makes every sperm "genetically" unique. The same holds true for eggs produced by the dam.

When a sperm cell, with its newly formed set of 39 chromosomes, pokes its head into an egg cell, with its new set of 39 chromosomes, a fertilized cell or zygote is formed. A new puppy starts from this single cell, which now contains 39 chromosomes from the sire and 39 chromosomes from the dam. At this point, each puppy's conformation and temperament are going to result from a double set of plans or genetic instructions. The question is: "Which set of instructions will be followed?" This process, discussed in Part 2, deals with the effects of dominant and recessive genes.

REAL LIFE IMPLICATIONS

Traits are not transmitted through the blood of an animal but rather through its genes. The mating of our dogs is in reality a "pairing of two hosts of genes," (Onstott 1962) in which an element of randomness occurs. This chance factor takes place in the reproductive process where crossing-over occurs, resulting in any one chromosome in a sperm (or egg) ending up a one-of-a-kind patchwork or mosaic of maternal and paternal genes originally inherited from that individual's parents. The random swapping of chromosome material in the formation of a gamete negates the myth that 50% of a dog's total heritage comes from its parents and 25% from the 4 grandparents; it also explains why a sire, who received half his genes from his sire and and half from his dam, may pass along a concentration of genes from his parents. In such a case a puppy would be more closely related to its grandparents than to its sire. When we realize that gametes (sperm and eggs) do not have the same genetic content though they come from a single individual, it becomes clear why repeat breedings so often fail, why littermates are not identical and why breeders who use the brother or sister of an excellent dog and believe they are using the same genetic material are in error!

With the union of a sperm and egg, the physical and genetic make-up of a puppy will originate from two sets of genetic instructions. Which instructions are followed depends largely on the dominant and recessive nature of the genes involved. We will review this phenomenon in Part 2.

Part 2: Genes:
Dominant and Recessive —
Homozygous and Heterozygous —
Genotype and Phenotype

SCENARIO: Y*ou are especially fond of ticking in your breed, however, the "pick" puppy in your most recent litter is the only one of six puppies with no ticking. To what can this be attributed?*

ANSWER: The effect of dominant and recessive genes.

In Part 1: Chromosomes and Genes we learned the following:

1. Chromosomes are made up of genes, which provide the instructions for how a puppy will look and act.
2. Except in the case of twins, no two dogs are ever genetically the same because the genes a sire and dam pass on to each puppy are always a unique, one-of-a-kind composition of the genes they each received from their ancestors.
3. In the fertilized cell from which a new puppy will develop there are two sets of genetic instructions, one "building plan" provided by 39 chromosomes from the sire and the other by 39 chromosomes from the dam.

We are now ready to address the issue of which of the 2 sets of genetic instructions will be followed in the "building" of our new puppy. This brings us to the role of dominant and recessive genes.

GETTING A HANDLE ON MENDEL!

Successful breeders have long recognized the necessity of understanding how genes are involved in the passing of a trait from one generation to the next. The key to breeding better dogs lies in learning how to "arrange" genes, which are the carriers of heredity and which determine a dog's size, conformation and temperament. Gregor Mendel's work with garden peas and other plants laid the ground work for understanding this phenomenon. Mendel's work established that traits do not blend. Breeding tall plants to short ones did not produce medium-size plants. The lesson here: don't breed an overshot dog to an undershot one and expect to get a scissors bite!

DOMINANT AND RECESSIVE GENES

One of the major conclusions that emerged from Mendel's work that affects our breeding of dogs is that genes are inherited in related pairs, one from each parent. Mendel discovered some genes over-rule the activity of others. These are called DOMINANT genes and geneticists depict them with an upper case letter. For example, we know that the gene T for ticking (color spots in white patches) is dominant and over-rules the gene t for non-ticking. Genes that are over-ruled are called RECESSIVE genes and are represented by lower case letters. The alternative forms of a particular gene, in this case, T for ticking and t for non-ticking, are known as alleles.

Remember, one member of each gene pair comes from each parent. In our example, whether a puppy has ticking will depend on which two genes it inherits. If his sire passes on to him the T gene for ticking and his dam the t gene for non-ticking, the puppy will inherit the gene pair Tt. It will have ticking because the T gene is dominant and over-rules the activity of the t gene. If it inherits the gene pair TT it will also have ticking because both genes are dominant for ticking. If it inherits tt it will have non-ticking because there is no dominant T gene in the pair. In any gene pair there are only 3 possible combinations. Using our example they would be: TT, Tt and tt.

HOMOZYGOUS AND HETEROZYGOUS GENES

We need to understand two funny sounding words: HOMOZYGOUS and HETEROZYGOUS. When both genes in a pair are the same, either dominant (for example, TT) or recessive (for example, tt), we say the dog is HOMOZYGOUS or PURE for that trait or character and must pass this characteristic on to a puppy. If the genes in a pair are different (in our case, Tt) the dog is HETEROZYGOUS for that trait and could pass either the recessive or the dominant gene to offspring. As we learn more about genes we will see that the goal in breeding lies in trying to arrange desirable genes in homologous pairs. Having two "good" genes in the same pair in both the sire and the dam guarantees us that one "good" gene from each parent will always be inherited by a puppy.

GENOTYPE AND PHENOTYPE

The term genotype refers to the genetic make-up of an animal. It refers to the letter symbols describing the gene pair. The term phenotype is used to describe the external appearance resulting from a gene's action. Thus the genotype for dogs with ticking is either TT or Tt, while the genotype for non-ticking is always tt. Every breeder needs to understand that a dog is really two different entities: what we see on the outside (the phenotype) does not always predict what genes he is carrying on the inside (genotype). If a dog happens to carry the Tt gene pair he himself will have ticking. When bred to a female carrrying either TT or Tt, however, he is capable of producing puppies with non-ticking (see Figure 1).

THE PUNNETT SQUARE

Geneticists and breeders frequently use a diagram called a Punnett square to predict the expected outcome of individual breedings. Genes or traits that can be contributed by one parent are listed on the top of the diagram; at the left are listed genes that may be contributed by the other parent. Possible combinations that can be produced in the offspring are found in the squares formed by the intersection of the columns and rows. Figure 1 shows the mating of Emma to Joe and the expected outcome relative to ticking and non-ticking. Joe and Emma both carry the Tt gene pair; they can each contribute a T or a t to each puppy.

Figure 1

Possible Combinations In 4 Puppies			
		(Emma Tt)	
		Egg with T	Egg with t
(Joe Tt)	Sperm with T	Rover TT	Eddy Tt
	Sperm with t	Spot Tt	Jane tt

LET'S REVIEW!

Referring to the Punnett Square and the text, see if you can answer the following questions. Answers follow below.

1. Does Joe have ticking?
2. Does Emma have ticking?
3. Which of the four puppies will have ticking?
4. Which puppies will have non-ticking?
5. Of the two parents and 4 puppies, who is homozygous for these traits? Who is heterozygous?
6. Which puppies have the genotype for non-ticking? Which have the genotype for ticking?
7. Of the 4 puppies, which are capable of producing non-ticking in their offspring?

IF THINGS WERE ONLY THIS SIMPLE!

The above discussion has centered on single genes and how they are involved in the passing on of a trait.

In the Part 3 we will address the more complicated issue of traits that are controlled by multiple gene pairs.

ANSWERS

1. Joe has ticking.
2. Emma has ticking.
3. Rover, Eddy and Spot will have ticking.
4. Jane will have non-ticking.
5. Rover and Jane are homozygous. Joe, Emma, Eddy and Spot are heterozygous.
6. Jane has the genotype for non-ticking. Rover, Eddy and Spot have the genotype for ticking.
7. Eddy, Spot and Jane are capable of producing non-ticking in offspring mated to a Basset with the t gene.

Part 3:
Dominant and Recessive Traits

REVIEWING THE BASIC 4

In the first two parts of our series we covered the four major genetic concepts every breeder needs to understand: (1) Chromosomes and Genes, (2) Dominant and Recessive Genes, (3) Homozygous and Heterozygous gene pairs and (4) Genotype and Phenotype (Figure 1). Learning to "arrange" desirable genes in our breeding programs begins with understanding these four concepts.

Figure 1

EVERY DOG BREEDER'S "NEED TO KNOW" BASIC 4

CONCEPT	COMMENTS
1. CHROMOSOMES and GENES Hereditary components in every cell that determine how a dog will look and act.	▷ Chromosomes are made up of genes, which carry hereditary information ▷ Chromosomes and genes are inherited by a puppy in related pairs, one member of each pair coming from the sire, the other from the dam. ▷ Each parent passes on a random, chance assortment of chromosomes and genes inherited from his or her ancestors.

2. DOMINANT and RECESSIVE GENES Two types of genes whose interaction help determine which trait will be passed on to a new-born puppy.	▷ Dominant genes "win out" over recessive genes. ▷ Use capital letters for dominant genes (ex. **T** for ticking). ▷ Use lower case letters for recessive genes (ex. **t** for non-ticking). ▷ Example, a dog inheriting **T** from the sire and **t** from the dam will have the gene pair **Tt** and will have ticking.
3. HOMOZYGOUS and HETEROZYGOUS Refers to whether members of a gene pair are alike (homozygous) or dissimilar (heterozygous). In- (line) breeding within first 3 generations increases homozygosity.	▷ Heterozygous gene pair example: **Tt** (members are dissimilar) ▷ Homozygous gene pair examples: **TT** and **tt** (members are alike) ▷ Breeder's Goal: To "arrange" good genes in homozygous pairs to ensure that no matter which member of a gene pair a parent happens to pass on to a puppy, it will be a "desirable" gene.
4. PHENOTYPE and GENOTYPE How a dog looks on the outside is his phenotype. A dog's genetic make-up is his genotype.	▷ How a dog looks on the outside does not always predict what genes he is carrying and what he will produce. ▷ Example: A dog inheriting the gene pair **Tt** from his parents will have ticking, but because he "carries" the gene t for non-ticking he is capable of producing dogs with non-ticking when bred to a bitch carrying the **Tt** or **tt** gene pair. The non-ticking would occur in any puppy that by chance happens to inherit his sire's **t** gene and a **t** gene from the dam.

WHAT'S THE CATCH?

Breeding would be simpler if genes consistently played by the rules. Genes, however, are not always predictable. Several phenomena that can affect the action of genes include (1) Incomplete Dominance, where a gene does not totally mask a recessive version (usually relates to temperament, intelligence, body height and length of leg); (2) Incomplete Penetrance, generally occurring in a heterozygous gene pair such as Aa, where the dominant gene A does not always show itself in a dog's outward appearance; (3) Modifiying Genes which combine with other genes, accentuating the effect of a trait or changing it altogether (control polygenetic traits such as shoulders, stifles and sternum); (4) Lethal Genes, which result in death of the embryo when they are passed on by both parents; and (5) Mutations, which occur when a cell is not exactly duplicated, leading to a variation of the original gene. Most mutations are destroyed at birth but those such as the short legs of the Basset Hound and Dachshund were viewed as favorable and deliberately selected for.

IF ONLY PUPS WERE MORE LIKE PEAS!

Our job as breeders would be greatly simplified if traits like good shoulder layback, temperament and reaching gait were controlled by single pairs of genes, such as those in Mendel's plants. Unfortunately, this is not the case. Outside of straight-forward traits like coat color and length, which are determined for the most part by single gene pairs, most of the intricate traits we desire in our dogs are controlled by complexes of genes which are called polygenes. Polygenes usually combine mixed patterns of dominant and recessive genes. Although we do not know how many thousands of genes are involved in polygenetic traits such as skeletal structure and gait, geneticists feel that such traits follow a bell-shaped curve, with most animals falling in the middle (Willis, 1989). Based on this theory, two excellent individuals will usually produce slightly less outstanding offspring and vice-versa. Regarding size within a breed, most animals will be average sized, with excessively large or small animals being less common.

DOMINANT AND RECESSIVE TRAITS IN THE DOG

At this point it is necessary for dog breeders to understand two fundamental concepts: (1) aside from coat length and color, the traits of interest to us are for the most part polygenetic (controlled by many gene pairs), and (2) polygenetic traits are generally composed of a mixed bag of dominant and recessive genes. Although research in canine genetics lags behind that of other species, and some authorities disagree on whether certain traits are indeed dominant or recessive, Figure 2 lists those dominant and recessive traits agreed upon by a majority of geneticists and breeders (Willis, 1989; Seranne, 1980). Most of these traits are controlled by numerous gene pairs (polygenetic) and factors such as incomplete dominance and penetrance. For our purpose, the most important task is to familiarize yourself with the list in general and make note of traits you wish to improve in your breeding program.

Figure 2

Genetically DOMINANT and RECESSIVE Traits In The Dog Does not include disease, coat color or abnormal factors			
	HEAD	**BODY**	**MENTAL**
DOMINANT TRAITS	Low set ears Long ears Long head Wide ear leather Dewlap Dark eye Correct bite Black nose Short face	Sternum Deep chest Straight top line Straight tail High tail set Good spring of rib Heavy bone Achondroplastic: short leg with crook (correlates with big bone) Compact foot Short coat Weight Body height Poor shoulder angulation Poor stifle angulation Short, choppy gait	Intelligence Shy and/or vicious temperament

	HEAD	BODY	MENTAL
RECESSIVE TRAITS	Pronounced parietal crest and occiput Large skull size Short ears Fine skull Light eye Bulging eye Overshot/Undershot Bite	Good shoulder angulation Good stifle angulation Long, reaching gait Low tail set No feathering on tail Kinked tail Long coat Longer, straight leg (correlates with light bone)	Mild, non-aggressive temperament Lack of intelligence

A FINAL WORD ON ANGULATION AND TEMPERAMENT

Several traits in the above chart are worthy of a closing comment. These are good shoulder and stifle angulation and good temperament, all of which are considered genetically RECESSIVE traits by most authorities. The shy temperaments and poor angulation often in evidence in the show ring today seem to support the theory that these traits are genetically dominant. Once these faults rear their ugly heads in a breeding program, a breeder needs to understand the concept of dominant and recessive genes as well as the effect of linebreeding to start decreasing their occurrence.

REFERENCES Part 1:

Dawkins, R. 1976. The Selfish Gene. Oxford University Press, New York.

Onstott, K. 1980. The New Art of Breeding Better Dogs. Howell, New York.

Willis, M.B. 1989. Genetics of the Dog. Howell, New York.

REFERENCES Part 2:

Seranne, A. 1980. *The Joy of Breeding Your Own Show Dog*. Howell, New York.

Willis, M. B. 1989. *Genetics of the Dog.* Howell, New York