WHAT IS THE COEFFICIENT OF INBREEDING AND WHAT DOES IT MEAN?

by Barbara E. Beynon

INTRODUCTION

Recent discussion in the American Eskimo Dog community has centered on the hypothesis that the AED has a "high" coefficient of inbreeding ("COI"), although "high" is not defined. Nevertheless, the argument is that a "high" COI has caused or will cause a higher rate(s) of incidence of disease(s) (diabetes mellitus is the current concern) and/or a decline in genetic diversity.

This paper is designed to define and illustrate the term "COI", what it means to Eskie breeders, and present a preliminary value for the average COI for the American Eskimo Dog breed as a whole. To date:

- No one has published any study of the calculation of the "average" COI in the American Eskimo Dog;
- No one has published any study documenting a link between a "high" COI and an increase in rate(s) of incidence of genetic disease(s) in the AED; and
- No one has published any study documenting a link between a "high" COI and the loss of genetic diversity in the AED.

DEFINITION OF COI

Wright's Coefficient of Inbreeding (Wright, 1922) was created to give animal breeders a means to estimate the probability of one offspring inheriting identical copies of the two alleles which make up any gene. A low COI will have low risk, and a high COI indicates a greater likelihood that the pair of alleles is identical. The consequence of a low COI indicates that a given Eskie will have only a modest benefit in terms of consistent and predictable traits in their offspring. Over a long period of time and many generations, a high COI will produce more consistency and prepotency in the offspring, but also can also result in a loss of vigor and health (Willis, 1989).

The COI is the probability of inheriting two copies of the same allele from an ancestor that occurs ***on both sides*** of the pedigree; and therefore, the fraction of all of the genes of an animal that are homozygous (two copies of the same allele). For example, a mating that would result in offspring with a COI of 10%, means that the mating has a one in 10 chance that any particular locus would have two copies of the same allele, and 10% of all of the genes in an animal will be homozygous (Beuchat, 2015).

In the case above, the 10% could be the genes that make a dog a dog (instead of a cat); or an American Eskimo Dog an Eskie (instead of a Chihuahua). What breeders want are dogs and bitches of excellent quality who pass their excellent traits to their offspring, and the resulting litter of "cookie-cutter" future Champions.

However, the COI does not give the breeder information on which genes will be homozygous. It also does not indicate anything about the desirability of those homozygous genes. A litter could be uniformly "ugly" or uniformly "desirable". Experienced breeders warn novices that when performing a close line-breeding that they be equally prepared for either a "beautiful" litter or a "disaster" litter.

Also, the COI does not indicate the quality or breeding potential of an Eskie. Every breeding decision must be made based on the traits, characteristics, and pedigrees of each of the parents. Different breeders will have different breeding strategies***, and that fact keeps the AED genetically diverse.***

CALCULATING COI DATA

According to Willis (1989), the modern formula for calculating Wright's COI is:

$$Fx = \sum[(½)^{n1+n2+1}(1 + F_A)]$$

Where

Fx is the COI of the Eskie in question;
F_A is the COI of the common ancestor; and
n 1 + n 2 are the intervening generations between the sire and the common ancestor and between the dog and dam, respectively.

COI is typically expressed in terms of percent (%). COIs for some common relationships include:

Full Sibling (Brother- Sister) - 25%
Parent- Offspring (Father-Daughter or Mother-Son) - 25%
Half Siblings (One Common Parent) - 12.5%
Grandparent- Grandkid (Grandfather-Granddaughter or Grandmother-Grandson) - 12.5%

The COI formula can get extremely complicated quickly with increasing generations. The number of ancestors in each generation increases exponentially starting with 2 in the first generation. The number of ancestors in the second generation is 4; the third is 8; the fourth is 16; etc. With more generations, the greater number of ancestors, and the greater accuracy of the resulting COI value . Consider that the 15th generation has 32,768 ancestors, and the 20th has 1,048,596! Fortunately, modern pedigree programs calculate these large numbers in just a few seconds.

USING COI DATA

Some breeders correctly point out that with the exception of registries such as AKC, no one has pedigree data which can fill in *all* of those blank spaces in the higher generations of a pedigree. They are right…. no *one* breeder has that data. However, the AEDCA is in the process of creating a pedigree database whereby members can share their pedigree data and perhaps fill in most of the gaps.

But because breeders don't have a complete set of pedigree data is no reason that they cannot use the data that they presently have. Present calculations of COI should be used as a minimum number, and the "real" number will be higher when all of the missing ancestors are found. By the time this paper is published, the included data set will be out-of-date as more Eskies are added into the database. As the AEDCA pedigree data become more complete through the additions and corrections of data, the COIs will change.

Experts advise that breeders should consider what is the "average" or "typical" COI for their breed. Until now, no one has determined an "average" COI for the AED. To say any breed-average COI is "too high" is wrong because all breeds developed differently.

Another complication when discussing COI is the question of how many generations will be used in the determination. The more generations which are included in the COI calculation, the more likely that the calculated COI will be correct. As an example, one of my Eskies, Sunfall's Smoke Gets In Your Eyes, has calculated COIs of 4.69% (4-gen); 5.35% (6-gen); 8.23% (10-gen); 10.08% (15-gen); and 10.09% (20-gen). All are correct, but 10.09% is more 100% greater than 4.69%- a significant difference.

Jerold Bell, DVM, a Gordon Setter breeder, has an excellent article on pedigree analysis written in plain English which is available at the url found in *Sources* at the end of this paper. Eskie breeders are strongly encouraged to study his methods of pedigree analysis using both COIs and "percentage of blood". Bell demonstrates that repeated ancestors in the higher generations will have an influence on the COI for an individual. The Gordon Setter show the influence of foundation sires because the Gordon Setter was imported from Great Britain. While the AED as a whole likely did not have a true "founders effect" influence, some individual AEDs could be considered "foundation stock". We will know more as the database becomes a reality.

MISCONCEPTIONS OF COI DATA

Breeders must take care when studying and using COI data. Consider the following questions:

- ***What is "inbred" and is it really "bad"?*** The UKC used to place an "INBRED" watermark on an Eskie's pedigree to indicate a close mating, specifically either parent-offspring (father-daughter and mother-son) or full siblings (full brother and sister). The COI from both of these types of matings is 25%. The obvious intent was to discourage breeders from producing puppies from such closely line-bred matings; however, the UKC still registered those puppies as well as their resulting offspring in succeeding generations.

But consider the COI of a now-deceased, one-time top-winning AKC-registered AED dog whom we will call "Winner" (*not* his real name): His 4-gen COI is calculated at 27.65%, which is certainly greater than the 25% COI which was a source of concern for the UKC. Winner's parents did not appear to be particularly closely related in Winner's four-generation pedigree. But his parent's 4-gen COIs, which looks at Winner's 5th generation, were 30.47% (sire) and 39.31% (dam), both higher than Winner's.

Upon closer inspection, Winner had one common great-grandparent on both his sire's and his dam's side. Additionally the dam's grandsire appears in the fourth generation twice (once on each the sire's and the dam's side). Both of the dam's parents were half-siblings; and one of them was produced by a grandsire-granddaughter breeding.

Confusing? You bet! Breeders must forget the UKC's definition of "Inbred" which can cause a "high" COI. Instead, breeders must begin to use the terms "out-crossed" for the mating of two AEDs with no common ancestors and "line-bred" for those which have common ancestors. Willis (1989) states that breeders can further classify a line-bred matings as "close" when *the relationship is more closely related than the average dog of that breed.* That definition brings us back to the question: What is the average COI for the AED?

● ***Does a higher average COI mean that a breed has a low genetic diversity?*** **NO.** A survey of available literature in the American Eskimo Dog ***does not*** document any correlation between COI and genetic diversity. Bell (on-line paper) states that when breeders develop their own lines, genetic diversity is maintained. Additionally, the AED is unique from the typical American dog breed because of the three sizes which breeders tend to keep separated. While some breeders may cross Toys to Minis or Standards to Minis, they also continue to use Eskies from their line or related lines. These are the primary reasons that health researchers continue to say that the AED has one of the higher genetic diversities of all AKC breeds. A challenge for breeders will be continuing to protect this diversity in the future.

● ***If two Eskies have a "high" COI, can they be bred together?*** **YES!** Just because two Eskies have high COIs does not mean that their offspring will have a high COI. If the two Eskies have no common ancestors, the resulting COI will be 0% despite the high COI of each parent.

Breeders should also remember that COI data are simply a tool used in pedigree analysis. Two Eskies can be from similar lines but may be line-bred on different ancestors. Breeders and stud owners must determine who is the dominant ancestor(s) in the pedigrees and look at what those ancestors produced in different branches of the lines.

● ***Does a higher COI mean that the AED is more likely to have disease-causing genes?*** **NO.** A survey of available literature in the American Eskimo Dog ***does not*** document any correlation between COI and rate(s) of incidence of genetic disease(s). A higher COI simply means that a given Eskie has a greater chance of passing along his/her traits; ***but it does not predict which traits will be passed to the next generation.***

Many diseases such as hip dysplasia and diabetes mellitus are "old" mutations and are the result of multiple genes acting together. Presently the best method for controlling these diseases is for breeders to openly share all health information pertaining to which individuals AEDs develop these diseases and maintain the information in a pedigree database.

● ***Did the AED prior to AKC recognition have a "high" COI ? Or is are today's COIs a result of breeding practices in the past 20 years since AKC recognition?.*** As stated above, two Eskies which were the product of a parent-offspring and full sibling matings were still registered by the UKC and bred. Exactly how many of these early Eskies were used in producing today's AKC stock is not fully known because of a lack of data and pedigrees in public sources behind some of the earliest Eskies.

However, some of the early Eskies are included in the data set analyzed below, and some of them were produced by parent-offspring matings, and matings of even more closely related AEDs. The Eskie with the maximum COI of approximately 64% (4-gen) to 66% (20-gen) was a bitch with a UKC number consistent with registration in the 1960s.

In order to better understand any changes in breed-average COI in the AED through time, more pedigree data are needed.

PRELIMINARY COI STUDY

The author maintains a pedigree file using Breedmate Pedigree Explorer for personal use. The pedigree material is secured from several sources:

- Breeders who provided UKC pedigrees and handwritten pedigrees when the author was researching material for the book *The Complete American Eskimo* in the late 1980s.
- Show catalogs from AKC and AEDCA shows.
- AKC *Awards* listings from the 1990s and early 2000s.
- Pedigrees on AEDs with health clearances on the OFA webpage.
- The list provided by AKC of all of the original 1,793 Foundation Stock AEDs issued AKC registration numbers in 1993.

The individual Eskie name was entered into the program along with sire and dam information, date of birth, and AKC and/or UKC registration number(s), if known. A total of over 7,416 randomly-collected records was included at the time of the study.

These public data sources may result in duplicate entries and incorrect ancestral links, including:

- Public data found in show catalogs are based on information submitted by the owner or agent, and typed by the Show Secretary or Superintendent; therefore, entries may contain misspellings and incorrect registration numbers.
- Public data found in the OFA databases are based on information submitted by the owner or agent, and then typed by the OFA personnel; therefore, the entries may contain misspellings and incorrect registration numbers.
- Old UKC pedigrees prior to computerization were hand-typed and may contain misspellings.
- Old UKC pedigrees did not utilize apostrophes in some kennel names.
- The UKC formerly allowed the changing of an AED's registered name.
- The AKC Foundation Stock data were initially inputted into the AKC's database by hand and may have included in misspellings.

Pedigree Explorer calculates the COI for all Eskies in the database using a selected number of generations from 4 to 20. The number "0.00%" is the default result when no parentage data or insufficient parentage data are present. Therefore, a manual check of each Eskie was made to ensure at least three or four generations to confirm the 0.0% result. The number of AEDs with a valid COI of 0.0% was 1,047 (4-gen) and 185 (20-gen).

The data were exported to Quattro Pro to calculate descriptive statistics. At the time of this study, a total of 7,416 AEDs were included. Of these, 3,641 had sufficient data to make COI calculations using a varying number of generations- 4, 6, 8, 10, 15, and 20. The resulting data are:

COI	4-GEN	6-GEN	8-GEN	10-GEN	15-GEN	20-GEN
Population (*n*)	3,641	3,641	3,641	3,641	3,641	3,641
Minimum Value	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Maximum Value	64.06%	65.69%	65.69%	65.73%	65.87%	65.87%
Average (Mean)	**7.62%**	**9.81%**	**10.60%**	**11.66%**	**11.66%**	**11.66%**
25th Percentile	0.31%	0.95%	1.84%	2.47%	2.66%	2.67%
50th Percentile (Median)	3.52%	5.70%	6.58%	7.22%	7.69%	7.69%
75th Percentile	12.50%	15.65%	16.54%	17.28%	17.77%	17.77%
Mode (most common value)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Standard Deviation (*s*)	9.82%	10.95%	11.04%	11.11%	11.39%	11.39%
Variance (s^2)	0.97%	1.20%	1.22%	1.23%	1.30%	1.30%

Because COI is expressed in percentages, the statistical calculations for the average, selected percentiles, mode, standard deviation (*s*) values, and variance (s^2) values are also expressed in percentages. Since the sample size (*n*) is large (3,641) , the Central Limit Theorem allows the assumption that the data are distributed normally (Rumsey, 2011). On a plot of COI frequency (histogram), the data set is skewed to the right.

The average COI for these 3,641 AEDs increases with an increase in the number of generations studied. However, with the present limitations in the pedigree data, little difference can be seen between 15 generations and 20 generations. After the AEDCA pedigree database comes on-line and owners enter their information, "holes" in more pedigrees will be closed which may result in a greater difference in the COI values for 15 and 20 generations.

The average COI for the AED appears to range from 7.62% (4-gen) to 11.66% (10-, 15-, and 20-gen). The 75th-percentile COI, meaning that 75% of AEDs have a COI at or below this value, ranges from 12.50% (4-gen) to 17.77% (15- and 20-gen).

CONCLUSIONS

- A survey of available literature in the American Eskimo Dog ***does not*** document any correlation between COI and genetic diversity.

- Different breeders have different breeding strategies which maintains the genetic diversity of the AED.

- A survey of available literature in the American Eskimo Dog ***does not*** document any correlation between COI and rate(s) of incidence of genetic disease(s).

- Breeders should use the term *outcross breeding* to describe a mating which has no common ancestors on the sire's and the dam's side of the pedigree, and use the term *line-breeding* to designate a mating where common ancestors are on both the sire's side and the dam's side.

- Additionally, breeders should use the term *close line-breeding* when describing a mating which results in offspring which have COIs greater than the average COI for the AED breed.

- From this preliminary study of 3,641 AEDs, the average COI for the AED is calculated to be between 7.62% (4-gen) to 11.6% (10-, 15-, and 20-gen). The more generations used to calculate COI, the greater accuracy in the result.

- Some Eskies registered with the UKC prior to AKC recognition had higher-than-average COIs, up to 65%. In order to better understand any changes in breed-average COI in the AED through time, more pedigree data are needed.

- To assist in determining whether their Eskie's COI is "too high", breeders can use the 75th-percentile as a guide. Using the current data set, a COI greater than 17.77% (15-and 20-gen) is higher than 75% of the 3,641 AEDs included in the study. However, the question of "too-high" will ultimately be answered by individual owners and breeders.

- The value of these COIs may change over time as more Eskies are added into the database. Since the population of AEDs in this study is large, the COIs can be used by breeders as a minimum number. This means that while the present calculated COI may not be the absolute number, the true COI will be higher.

- Breeders today must continue to be vigilant for the increase of the rates of incidence of diseases in the American Eskimo Dog. This can be done by testing all breeding stock according to AEDCA recommendations and openly sharing all information pertaining to any disease(s) of concern, whether a screening test is available or not.

SOURCES

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