Genes for Cowboys

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This is pdf document/book was written to help ranchers and agriculture students understand genetics relevant to beef cattle. A set of webpages was originally mounted on Sept. 28, 2002. It was last updated in June, 2023.

The goal of this "book" is to help ranchers and agriculture students understand the “recent” developments in genetics as they relate to cattle. DNA studies and molecular genetics are the focus, as opposed to quantitative genetics. Several other books on quantitative genetics have been published and you are advised to seek out some of those for information of that nature.

Mendelian Inheritance

Gregor Mendel chose a small set of traits in peas to develop his principles of genetics. There has been considerable debate since whether he studied only these traits or chose to build his founding principles using the data from only these traits. His principles have now stood the test of time. However there are additional concepts about inheritance that need to be added to cover other traits. Some concepts will probably still be developed as our understanding continues to build on the foundation his principles set.

Autosomal Dominant Inheritance

Autosomal Dominant Traits are those in which a single copy of an allele is enough for the trait to be expressed or shown in the phenotype of the animal.

There is substantial evidence to suggest that some animals with dominant traits are the result of new mutations. Certain genes seem to be more prone to mutation than others. One common example is Polled or the lack of horns in cattle. Archaeological evidence suggests that all original cattle had horns and therefore Polled is a mutation that occurred later. For a further discussion of polled & horned, see a later section.

As males age, they continue to produce sperm but their DNA repair mechanism deteriorates. In humans there are several studies showing that men over 55 are more prone to having children with new dominant mutations. What age would that happen in cattle? 11? 12? No beef bulls would be in natural service at that age, but some famous dairy bulls are collected into that age range.

Some autosomal dominant traits cause deleterious effects when they occur in the homozygous state.....when a calf has 2 copies of the allele instead of just one. One example is dwarfism in Dexter cattle. Note that a red dwarf Dexter (note short legs) is in the foreground and a full height animal is in the background. The heterozygous dwarf carrier cattle are short-legged with normal size bodies but the homozygous dwarf fetuses die about the seventh month of gestation. The defect results in abnormal cartilage development. Sometimes such traits are called **Homozygous Lethals**.

Bulldog dwarfism in Dexter cattle is caused by mutations in ACAN.
Julie A L Cavanagh [1], Imke Tammen, Peter A Windsor, John F Bateman, Ravi Savarirayan, Frank W Nicholas, Herman W Raadsma Mamm Genome 2007 Nov;18(11):808-14.

Several dominant traits do not have absolutely equivalent phenotypic expression. This concept is called **variable expressivity**. An example of such a trait is the belt pattern in Belted Galloway cattle. The photos below show that not all belts are the same size or shape. To be registered as a Belted Galloway in Canada, the belt must be continuous around the entire animal but not overlap onto the legs.

The belted pattern was mapped to cattle chromosome 3 by the group of Tosso Leeb in Switzerland. They studied primarily Brown Swiss, but also included some belted Galloway in their study. In 2017, the found that this pattern is due to a mutation near the *TWIST2* gene.

Schmutz, S. M., T.G. Berryere, J. S. Moker, DJ Bradley. Jan. 17, 2001. Inheritance of the belt pattern in Belted Galloway cattle. Plant and Animal Genome IX, San Diego, CA.

- Droegemueller C, Engensteiner M, Moser S, Rieder S, Leeb T. (2009) Genetic mapping of the belt pattern in Brown Swiss cattle to BTA3. Anim Genet. 40:225-9.
- Awasthi Mishra N., Droegemüller C., Jagannathan V., Keller I., Wüthrich D., Bruggmann R., Beck J., Schütz E., Brenig B., Demmel S., Moser S., Signer-Hasler H., Pienkowska-Schelling A., Schelling C., Sande M., Rongen R., Rieder S., Kelsh R.N., Mercader N. & Leeb T. (2017) A structural variant in the 5' - flanking region of the TWIST2 gene affects melanocyte development in belted cattle. PLoS One 12, e0180170.

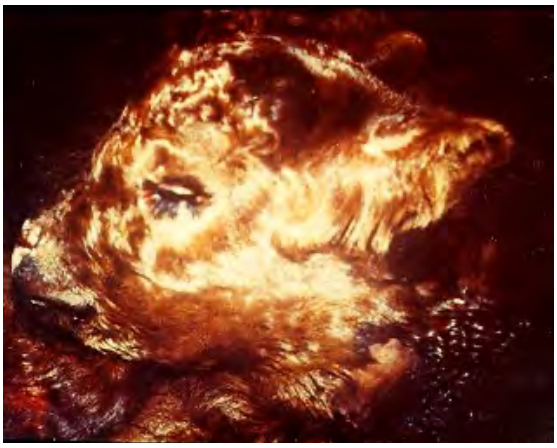
Autosomal Recessive Inheritance

Autosomal recessive traits require that the calf have 2 copies of the trait to express the phenotype. Since polled is dominant in cattle, horned is recessive. This gene has only 2 alleles.....horned or polled.

Other genes have multiple alleles. Alpha-mannosidosis is a disease in Angus and Galloway cattle. There are 2 different mutations that can cause this recessive disease. An animal that has one copy of each of the 2 different recessive deleterious alleles can be called a compound heterozygote. Such an affected calf is not strictly a homozygote because it has two different alleles but in this case, each allele leads to an improperly made alpha-mannosidase enzyme molecule and so the calf is still sick.

Autosomal recessive diseases are usually severe and more consistent in symptoms than are autosomal dominant diseases. Often such diseases are due to a lack of a critical enzyme or an improperly formed enzyme that can not perform its normal function.

Another example of such a recessive disease is Beta-mannosidosis. This disease occurred in Salers cattle but a concerted DNA testing program implemented by the Canadian Salers Association many years ago has virtually eradicated this problem in Canada. Calves with Beta-mannosidosis could not stand or suckle because they had no grey matter in their brains.



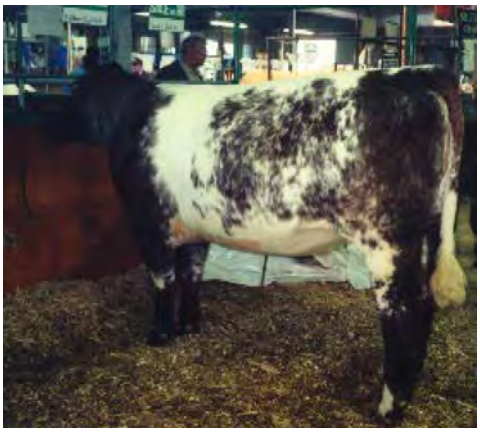
This calf shows a slightly domed forehead. Autosomal recessive diseases occur more frequently when there is inbreeding or linebreeding. Technically linebreeding is a special type of inbreeding in which a desired ancestor is re-introduced over and over to build a line. Many ranchers and farmers use the term linebreeding because they believe it has less negative connotations than inbreeding does. Any animal suspected of carrying an autosomal recessive disease should not be inbred.

- Berg, T., P. Healy, O. Tollersrud and O. Nilssen. 1997. Molecular heterogeneity for bovine a-mannosidosis: PCR based assays for detection of breed-specific mutations. Res. Vet. J. 63:279-282.
- Bryan, L., S. M. Schmutz, S. D. Hodges, and F. F. Snyder. 1993. Bovine beta-mannosidosis: pathological, genetic, and biochemical findings in Salers calves. Vet. Path. 30:130-139.
- Bryan, L., S. Schmutz, S. D. Hodges, and F. F. Snyder. 1990. Bovine b-mannosidase deficiency. Biochem. Biophys. Res. Comm. 173:491-495.

Co-dominant Inheritance

Occasionally a gene has two alleles and when the calf is a heterozygote a different phenotype is produced than that of either homozygote. This is often called co-dominant inheritance. The classic textbook example of this in cattle is roan. This roan Shorhorn heifer has 2 different alleles at the Mast Cell Growth Factor (*MGF* or *KITLG*) gene. One homozygote would be white and the other would be red in Shorthorn cattle. In Belgian Blue cattle the homozygotes would be white or black.

Seitz, J. J., S. M. Schmutz, T. D. Thue, F. C. Buchanan. 1999. A missense mutation in the bovine MGF gene is associated with the roan phenotype in Belgian Blue and Shorthorn cattle. Mamm. Genome 10: 710-712.




Roan Shorthorn (left) and roan Belgian Blue (right).

Sex-Linked Recessive Inheritance

Sex-linked recessive traits occur more commonly in males than females. Since males have only a single X chromosome, a recessive trait on the X chromosome has no normal allele on another X chromosome to produce a normal protein. In females, two copies of the deleterious allele, one of each X chromosome is required for the animal to be affected. This is rare because most males that have X linked diseases are not bred.

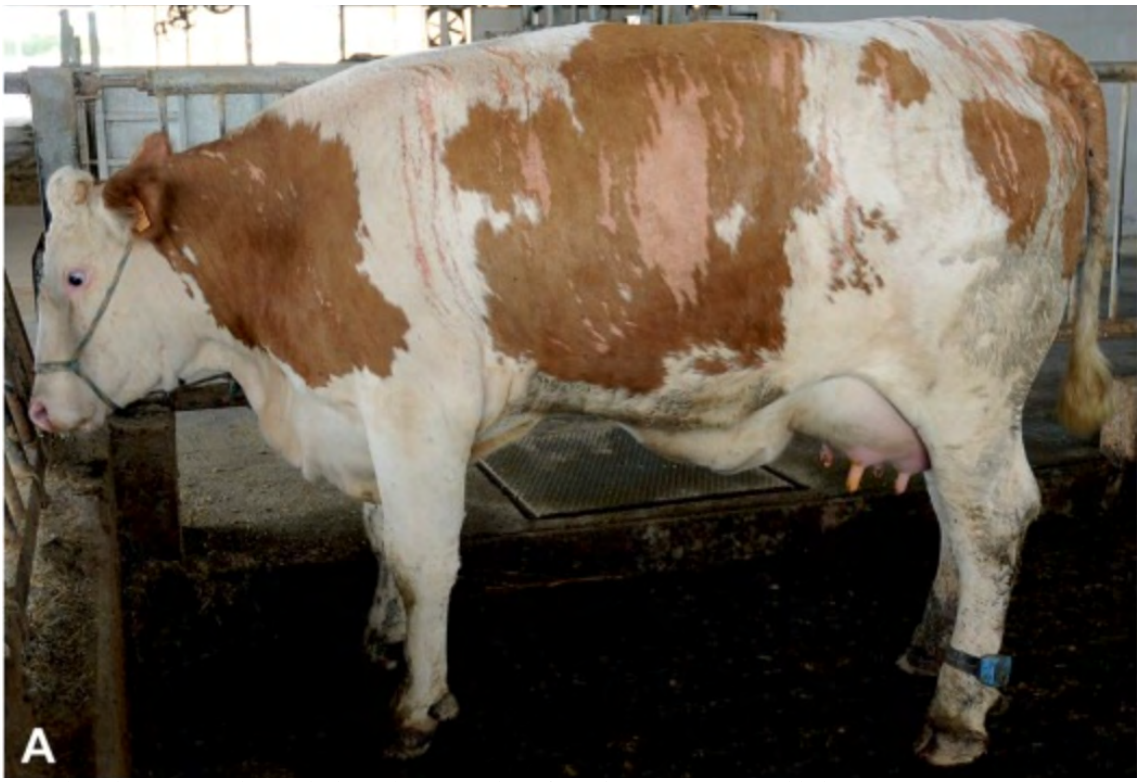
An example of an X-linked disease in cattle is a form of hairlessness with tooth problems, called "anhidrotic ectodermal dysplasia". Affected cattle have little hair, few sweat glands and no incisors as shown in the photo at the left. This disorder has been seen in male Holstein cattle primarily.

Photo courtesy of Tosso Leeb

Drogemuller, C, Distl O, Leeb T. Partial deletion of the bovine ED1 gene causes anhidrotic ectodermal dysplasia in cattle. Genome-Res. 2001 Oct; 11(10): 1699-705.

Sex-Linked Dominant Inheritance

Sex linked-dominant traits seem to be more rare than sex-linked recessive traits. They should be considered more deleterious because most are male lethal. An example of an x-linked dominant trait in cattle is Streaked Hairlessness in Holsteins. This disorder causes streaks of missing hair in females, especially on the flanks. Males which inherit this allele die in utero.



An Italian dairy cow with Streaked Hairlessness. Photo from the manuscript cited below.

Eldridge & Atkeson 1953 J. Heredity p. 265-271

Hairless Streaks in Cattle Implicate *TSR2* in Early Hair Follicle Formation.
Leonardo Murgiano,[1,2] Vera Shirokova,[3] Monika Maria Welle,[2,4] Vidhya Jagannathan,[1,2] Philippe Plattet,[5] Anna Oevermann,[5] Aldona Pienkowska-Schelling,[6] Daniele Gallo,[7] Arcangelo Gentile,[7] Marja Mikkola,[3] and Cord Drögemüller. PLoS Genet. 2015 Jul; 11(7): e1005427.

Holandric Inheritance

Holandric is the term used to describe genes carried on the Y chromosome in mammals. Since only males have a Y chromosome, the traits inherited in this manner will be exhibited only by males. The Y chromosome is a very small chromosome and some of it does not seem to harbor any genes. In cattle, the only genes that we know are carried on the Y are those relating to the primary sex characteristics. Although few, these are very important phenotypic features!

Sex-limited Inheritance

A few traits that are not caused by genes on the X or the Y chromosome occur in only one sex of animals. Antlers in deer in such a trait. Only bucks, never does have antlers. We could say that milk yield is a trait expressed by only cows. Milk yield was recently shown to be affected by the DGAT gene on cattle chromosome 14. Both bulls and cows carry the DGAT1 gene and therefore both contribute an allele to their daughters which affects the quantity of milk that daughter produces.

Grisart, B., W. Coppieters, F. Farnir, L. Karim, C. Ford, N. Cambisano, M. Mni, S. Reid, R. Spelman, M. Georges, R. Snell. 2002. Positional candidate cloning of a QTL in dairy cattle: identification of a missense mutation in the bovine DGAT1 gene with major effect on milk yield and composition. Genome Research 12:222-231.

Spelman, R. J., C. A. Ford, P. McElhinney, G. C. Gregory, R. G. Snell. 2002. Characterization of the DGAT1 gene in the New Zealand dairy population. J. Dairy Science 85:3514-3517.

Sex-Influenced Inheritance

Sex-influenced inheritance is a pattern of inheritance in which the sex hormones of the animal affect the expression of a trait by the heterozygotes. Both homozygotes are unaffected and express the trait irrelevant of the hormones produced.

Scurs are a sex-influenced trait. Scurs are further complicated because only heterozygous polled cattle (*Pp*) can have scurs. In females 2 copies of the scur allele (*Sc*) are needed for the cow or heifer to have scurs. In males a single copy of the scur allele is sufficient to produce scurs. Some people say a sex-influenced trait is dominant in males and recessive in females. I prefer not to use that expression because to me a sex-influenced trait is NOT dominant or recessive.....this is a separate inheritance pattern.

Genotype	Cows	Bulls
PP Sc/Sc	smooth polled	smooth polled
PP Sc/sc	smooth polled	smooth polled
PP sc/sc	smooth polled	smooth polled
Pp Sc/Sc	scurs	scurs
Pp Sc/sc	smooth polled	scurs
Pp sc/sc	smooth polled	smooth polled
pp Sc/Sc	horned	horned
pp Sc/sc	horned	horned
pp sc/sc	horned	horned

The crossbred bull below has scurs and through DNA testing has been shown to have a single scur allele. The gene for scurs in on cattle chromosome 19.

Long, C. R. and K. E. Gregory. 1978. Inheritance of the horned, scurred, and polled condition in cattle. J. Heredity. 69:395-400.

Asai, M. , T. G. Berryere, and S.M. Schmutz. 2004. The *scurs* locus in cattle maps to bovine chromosome 19. Animal Genetics 35: 34-39.

Gene Interaction, Beyond "Single Gene" Mendelian Inheritance

One form of gene interaction is when specific alleles at two or more alleles are required for a trait to be expressed. An example of this is dun brown coat color in Dexter cattle. Brown is a color produced by a type of eumelanin pigment. For eumelanin to be produced cattle must have at least one *ED* allele at the MC1R gene. Then for cattle to be dun brown, they must be homozygous for the b allele at the *TYRP1* gene. Therefore dun brown is a recessive trait but it requires a dominant allele at an interactive gene.

photo by John Potter

Berryere, T.G., S. M. Schmutz, R. J. Schimpf, C. Michael Cowan, John Potter. 2003. TYRP1 is associated with dun brown coat colour in Dexter cattle or how now brown cow?. Animal Genetics 34:169-175.

Epistasis

Sometimes one gene affects the expression of another gene by over-riding it. This is called epistasis. This could be because one epistatic gene makes or does not make a product essential for the function of other hypostatic genes. It could be because one gene causes a trait that would "mask" the expression of another trait.

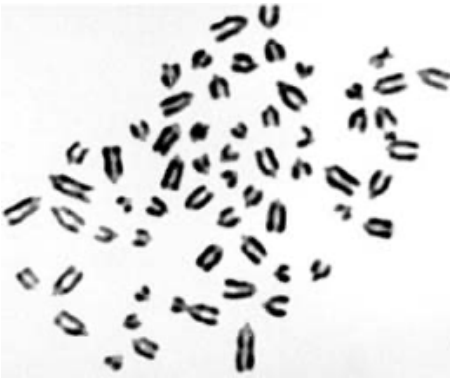
Albinism is the absence of pigment in an animal.....note Snowdrop's colorless hooves and pink nose and eyes. Braunvieh cattle have occasionally been albino since at least 1933. In 2002 the mutation causing albinsim was found in the tyrosinase gene, the same gene that causes albinism in many other animals (although not all albinism is caused by this gene). Calves, such as Snowdrop make only half of the tyrosinase enzyme and stop prematurely, instead of making the complete enzyme. Since this enzyme is required for other genes later in the pigmentation pathway to make pigment, none is made. Albinism is therefore an epistatic trait. The albino genotype is espistatic to the the *ED* allele of the *MC1R* gene which causes black pigment to be made. The albino genotype is also epistatic to the agouti allele that probably causes the normal pigmentation color and pattern in Braunvieh cattle.

Sheila M. Schmutz, and Tom G. Berryere, Daniel C. Ciobanu, Alan J. Mileham, Barbara H. Schmidtz, Merete Fredholm. A form of albinism in cattle is caused by a tyrosinase frameshift mutation. Mammalian Genome, 2004, 15:62-67.

Chromosome Considerations in Cattle .....Fertility

Normal Karyotype

Cattle have 60 chromosomes, 29 pair of autosomes and 1 pair of sex chromosomes. As in other mammals, males have an X and a Y chromosome and females have 2 X chromosomes. All of the autosomes are somewhat tear drop shaped, with the centromere at the end of the chromosome. The sex chromosomes have the centromere in the middle of the chromsome, with the X being much larger than the Y.



During gametogenesis the chromosomes undergo meiosis which results in each primary reproductive cell producing 4 sperm with 30 chromosomes each from a bull or 1 ovum plus 3 polar bodies from a cow.

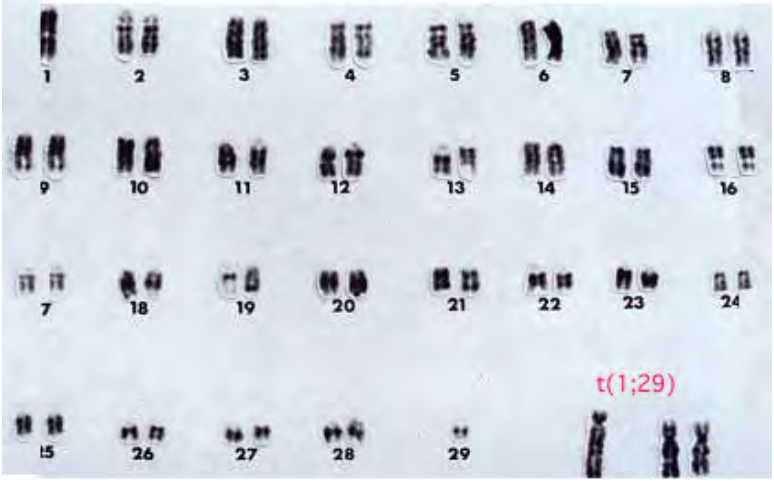
The bull can contribute either his X or Y chromosome to a sperm so it is the bull's contribution that determines the sex of the calf. The cow always contributes one of her X chromosomes.

Chromosome Abnormalities

Translocations

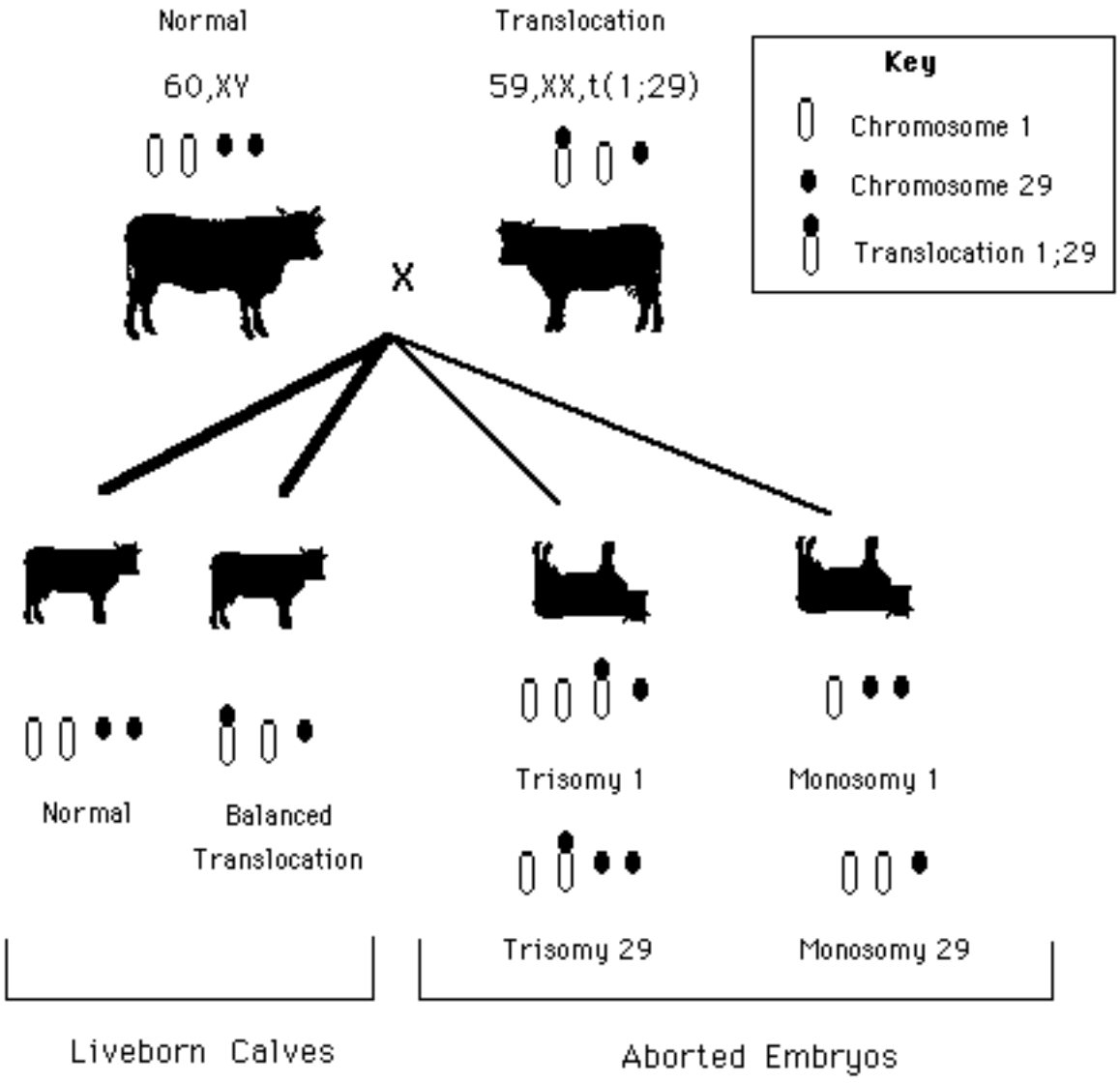
One of the anomalies that affects fertility in cattle is called a Robertsonian translocation. This type of translocation was named after a person called Robertson from Scotland. Because cattle autosomes always have their centromere at the end, two chromosomes can fuse at the centromere and result in 1 larger bi-armed chromosome with a Robertsonian translocation. This also changes the chromosome number in cattle with this to 59 instead of 60. This fusion or Robertsonian translocation does not alter any genes, just alters the position of such genes. Therefore carriers of such translocations look perfectly normal.

The most common type of Robertsonian translocation in cattle is the **t(1;29)** which is a fusion of a chromosome 1 (the largest of the autosomes) with a chromosome 29 (the smallest of the chromosomes). This translocation has been shown to occur in most beef breeds which came from the European continent. It therefore is either very old or arose many times or most likely, both.



The second most common Robertsonian translocation in cattle is the **t(14;20)** which has primarily been seen only in Simmental cattle. It is very rare, occuring in less than 1% of Simmentals.

Although cattle with Robertsonian translocations are phenotypically normal, they have **fertility "issues"**. One can imagine that dividing a cell with 59 chromosomes "in half" during meiosis will not work well for these animals. Instead of 30 chromosomes in every sperm or ovum, some will get only 29. The diagram below shows the various products of conception possible when one parent, shown as the cow in this case is carrying a t(1;29).



Unfortunately there is no easy way to look at a cow or bull and see a translocation in them. However one can have a chromosome test done, often called karyotyping, to determine if this problem exists. When more than 10% of the cows a bull services come in open or abort, it may be time to consider karyotyping the bull to see if he has a translocation. Most ranchers ship cows that abort or are open, but if this ever happens a second time, then it may be time to karyotype the cow.

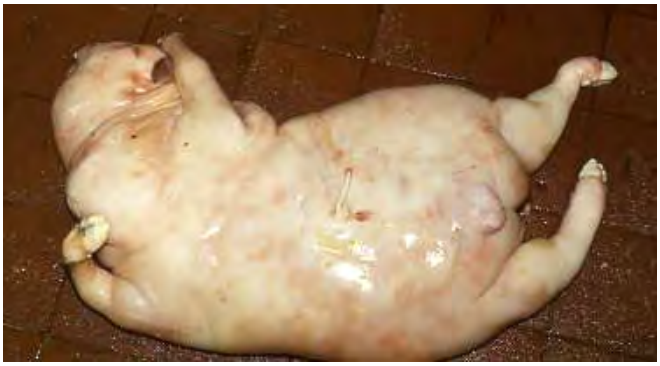
When purchasing expensive semen from an A.I. unit, it is worthwhile to ask if the bull has a normal karyotype. Many A.I. stations karyotype bulls and have this information on file. A few still sell semen from bulls with translocations so it is not "safe" to assume that because a bull's semen is sold, its karyotype is normal. Some countries and/or some breed associations within some countries demand that imported animals, semen or embryos have to have normal karyotypes before the calves born in that country can be registered.

There are fewer and fewer laboratories that offer commercial karyotyping. Your vet may know of the nearest lab where this can be done. Blood is drawn and couriered to the lab because viable cells capable of further division are needed for karyotyping.

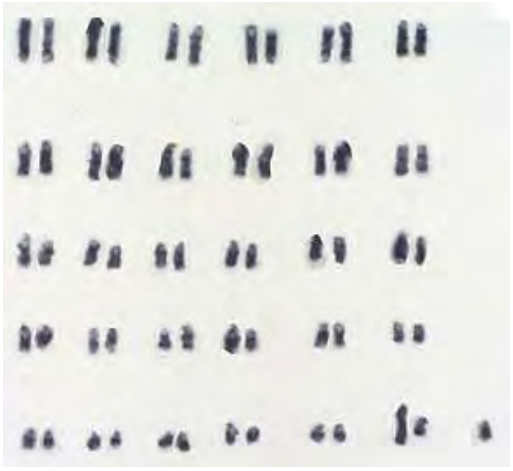
Numerical Errors

Autosomes

In addition to the **abortion** that results when cattle carry translocations, there are other types of chromosome errors that lead to loss during pregnancy. Studies in humans who also have a 9 month gestation, suggest that 50% of fetal loss occurs during the first trimester. Many cattle may resorb rather than physically abort such early pregnancy deaths. Therefore ranchers do not find these malformed products of conception unless they persist into late gestation. We have not received malformed fetuses for necropsy less than 5 months old. Many such pregnancy losses may be recorded as "open cow" during fall pregnancy testing by a visiting veterinarian, instead of an early abortion. Therefore the actual abortion rate experienced on a working ranch does not seem very high but is probably much higher than the records reflect.



Abnormal calf fetus detected at the abattoir



Karyotype of this fetus showing an extra chromosome

Spermatogenesis takes about 60 days in a bull and continues from puberty to relatively old age, although the absolute quantity of sperm may diminish. Oogenesis in a cow actually begins when she is a fetus herself and then is suspended until puberty. The process in not completed until fertilization when the 3rd polar body is shed. This long suspended meiotic process is probably what makes ova more prone to having numerical chromosome errors, than sperm. We think the

error rate begins to exponentially climb after a cow is about 9 years old (in women this climb begins at 35 years).

During meiosis the chromosomes are meant to pair and then one of each pair goes into each gamete. When this fails to happen correctly it is called **non-disjunction**. This results in one gamete receiving 31 chromosomes and the other receiving 29 chromosomes - both incorrect numerically. Both with many many genes in incorrect number because each chromosome has hundreds of genes. The calf who develops from a sperm or ovum with 29 chromosomes has "monosomy", a single copy of one of its chromosomes instead of the normal 2. The calf who develops from a gamete with 31 chromosomes has **"trisomy"**. Down Syndrome in humans is trisomy 21 - 3 copies of human chromosome 21. In cattle the calves with **monsomy** die very early in gestation and the calves with trisomy die a bit later in gestation. The calf at the right had an extra chromosome and was found in a cow sent for slaughter by the abattoir staff. Ranchers sometimes may see a very malformed calf abort and this is likely a fetus with trisomy.

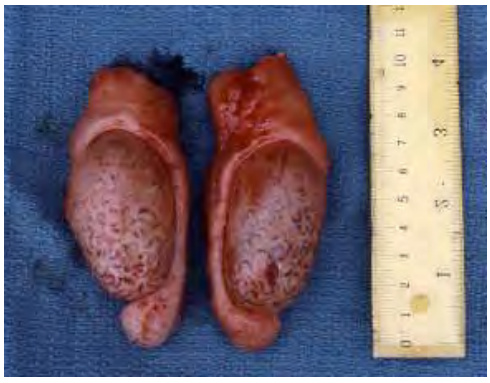
Therefore **cows over 9 years old** run a slightly higher risk of abortion because they are more prone to non-disjunction and numerical chromosome problems. All heifers and cows run a risk of about 1% of such an event. As non-intuitive as it may seem, the more malformed an aborted fetus is, the less reason there is to cull either the cow or the bull. Malformations that affect multiple systems in the body and therefore multiple organs are probably caused by multiple genes being out of sync.....and this is usually due to a numerical error of the chromosomes.

Sex Chromosomes

Numerical errors also occur with the sex chromosomes. Most of these are not lethal but do affect fertility. A bull fetus that inherits only a Y chromosome from the sire and no X from his dam aborts. The X chromosome is large and carries many essential genes.

A heifer fetus that inherits only an X from its dam and no chromosome from its sire lives. Such a heifer is sterile. She will develop only streak gonads, not proper ovaries and will never ovulate. This condition is called **Turner Syndrome**.

"Bull" with a Kleinfelter karyotype



Smaller than normal testes

A bull that inherits 2 X chromosomes and a Y from its sire is said to be 61,XXY and have **Klinefelter's Syndrome**. This bull with have small testicles and usually be sterile but is otherwise normal. The bull above left had this problem. A sperm check should indicate that he is producing no sperm at all.

A heifer fetus that inherits 3 X chromosomes is said to have trisomy X with the karyotype 61,XXX. Such females can reproduce and the bull calf at the left was hers. At least such cows two have had both normal calves and Klinefelter sons. It is possible that they abort more often than a normal cow but there are not enough documented cases to be sure about this.

Freemartins are heifers that are born co-twin to a bull. Twinning is discussed in more detail under the section on Teratogenic Inheritance. Both twins in unlike sex twin pairs in cattle have the karyotype 60,XX/60,XY meaning that each has some male cells and some female cells. The bull calf is fertile although he might have a slightly lower sperm count than would a normal bull. The freemartin heifer is sterile.

Articles on this Topic

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- Schmutz, S. M., A. D. Barth, and J. S. Moker. 1994. A Klinefelter bull with a 1;29 translocation born to a fertile 61,XXX cow. Can. Vet. J. 35:182-184.
- Plante, Y., S. M. Schmutz, K. D. M. Lang, and J. S. Moker. 1992. Detection of leukochimerism in bovine twins by DNA fingerprinting. Animal Genetics 23:295-302.

Teratogenic Inheritance

In terms of disease, teratogenic inheritance implies a genetic predisposition in the fetus and an environmental trigger during gestation. Sometimes the lactation period is included under this category because the triggers or teratogens are still under maternal influence.

- Few teratogenic effects last from prior to conceptions
- Most effects have a 2 week delay from time of exposure to teratogen
- "Preimplantation" is usually a "safe" period
- Most teratogenic defects are congenital

Since teratogenic inheritance is due to in utero exposure of a teratogen, it is a mammalian phenomenon. Gestation in cattle, like humans, is 9 months. Therefore the calf fetus is developing on approximately the same timescale as a human fetus.

If there is teratogenic exposure early in pregnancy up to the blastocyst stage, there is more likely abortion than a congenital defect. This is typically the first 7 days post-copulation in the cow. Organogenesis occurs during the first trimester of pregnancy and is the most critical period during which teratogens should be avoided. Histogenesis occurs during the middle trimester. Subtle changes in the the types of cells in the gut lining, etc. happen during this period. The third trimester is primarily growth of the fetus so teratogenic exposure at this time is more likely to lead to stunting than to specific congenital defects.

Teratogens fall into several categories and include fever, drugs, chemicals, viruses, specific plants, etc. Keep in mind that most cows are pregnant or lactating or they wouldn't be on your ranch. Avoiding drug treatments completely is therefore impossible but one must try to pick the least dangerous time to administer vaccinations, etc.

Most ranchers are very familiar with BVD or bovine virus diarhea. If a heifer contracts this disease early in pregnancy she is likely to abort. Later, the calf is often left with central nervous system damage.

Most medications and vaccines have warnings about use in pregnancy for a reason. Wormers such as parbenzol should not be used during pregnancy. Anury or tailessness is one of the defects that can result. The calf at the left has a shortened tail but also contracted vertebrae in its spine.

Pollutants can be teratogens to cattle also. These could be in dugouts from runoff and become especially concentrated in drought years. Conifer resin from the accumulation of pine needles in puddles can be toxic to cattle who drink this water source.

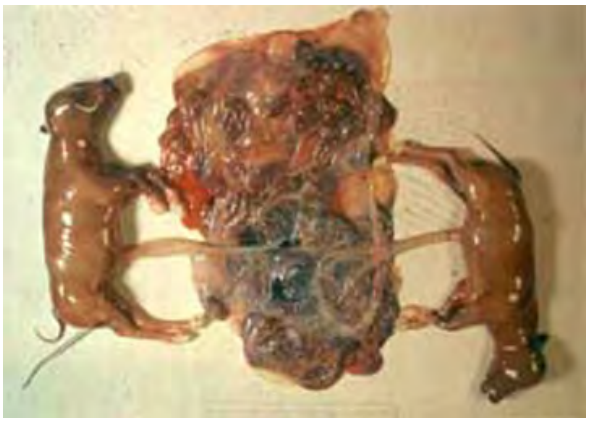
Sour gas wells near pastures can be teratogenic also. Sulfur occurs in high amounts near such wells and the plants growing nearby take up this sulfur and not the rarer selenium. Although plants do not need selenium, animals do. Calves who suckle cows grazing on selenium deficient pastures can develop white muscle disease.

The calf beloow has arthrogryposis or twisted legs. One teratogen that has been known to cause this type of defect is lupines. Lupines tend to bloom in years of relatively high moisture on the prairies and may attract cattle to graze them heavily during such blooms. Loco weed is another prairie plant that can be a teratogen for cattle.

Twinning in cattle and humans usually puts the pregnancy into the "high risk" category. About 5% or less or pregnancies in cattle result in twins. 30-40% of twin pregnancies in cattle result in abortion. Twins are usually born about 2 weeks premature and should not be expected to be more than 75% of the birthweight of a single born calf.

Position defects, such as arthrogryposis, are higher in twins than singleton calves. The other problem with twins of unlike sex is that the heifer calf is a **freemartin**. Both twins exchange cells due to placental anastomosis as is shown in early (left) and late pregnancy (right). These cells and the hormonal exchange, cause the gonads and genitalia of the female to not develop properly. The fertility of the bull co-twin may be subtlely lowered, but this is not usually noticable.

All cattle twins potentially harbor cells of the other twin. It is possible that a bull might literally sire his brother's calves! Parentage testing and other DNA testing can reveal more than 2 alleles in twins.



Placental Anastamosis

About 2 weeks gestation About 3 months gestation

Twins require extra management during the pregnancy and thereafter but they are desired by some ranchers. Dr. Brian Kirkpatrick, at the University of Wisconsin in Madison, publishes a newsletter about twinning in cattle which offers advice on how to select for and manage twins.

References

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Multifactorial Inheritance

In terms of disease, multifactorial inheritance implies a genetic predisposition or susceptibility and an environmental trigger. Often the genetic predisposition is polygenic or due to several genes.

Many multifactorial disorders are of late onset, such as cancer. However some are congenital defects.

Cancer eye in a Hereford

The most common congenital defect in cattle is cleft lip. Cleft lip is usually considered a multifactorial disorder when it is the only anomaly but it is often one of several anomalies when cytogenetic abnormalities occur. Cleft lip can occur unilaterally as in this calf or bilaterally or in combination with a cleft palate. In early fetal development the face of all mammals looks quite similar to a fish with several slits. These gradually close between week 7 to 9 of gestation in cattle. Consider that all sheep have a cleft lip and that all dogs have open nostril slits on each side of their nose.

Development in utero is proceeding along a timecourse of a biological clock. When that timecourse is delayed by a virus or fever, the dam is unable to divert the normal amount of energy to fetal development and so it temporarily slows. When the "normal" time period for facial development is over, the face simply halts in whatever stage of completion it has reached and other parts of the fetus develop next. In some breeds with wider faces, the time to complete facial slit closure and development takes longer than in other breeds. The "predisoposition" to cleft lip caused by a wide face is due to many genes therefore.

Because multifactorial disorders require a genetic predisposition and an environmental trigger, the recurrence risk is lower than for disorders with single gene inheritance. **The ballpark recurrence risk for a multifactorial condition is 5%.** However disorders with a common trigger may approach 10%. The more close relatives with a particular multifacortial condition that an animal has, the higher its risk of producing an offspring with that condition. Inbreeding also increases the risk since the predisposing genes could then be coming from both sides of the pedigree.

Risk of a Multifactorial Disorder increases:

- More severe the case or the earlier the onset
- Mating is consanguineous
- Trigger is common
- Multiple family members affected

Quantitative Inheritance

Quantitative inheritance is used more commonly by animal scientists and multifactorial inheritance is used more commonly in the medical fields. Quantitative inheritance is a term that denotes polygenic inheritance and environmental interaction. Traits with quantitative inheritance include growth traits such as weaning weight, average daily gain, carcass weight, etc. These traits are obviously affected by the nutrition of the animal, the health of the animal, etc.

Quantitative inheritance is presumed to be "additive" however. In other words, 3 or more genes contribute to the trait in an additive or cumulative manner. Although this may be true for some genes and traits, as discussed in the page on Mendelian and beyond, there are complex interactions of genes and many different patterns of allele interaction which do not fit that well with the mathematical approaches used when assuming quantitative inheritance is additive.

Although coat color may not be a "trait" which leaps to mind as an example of quantitative inheritance, coat color is a good example of many genes interacting to produce the final trait. Since we are beginning to know which genes are involved and the allele interactions and gene interactions for some of them, it becomes clear that additive inheritance is not appropriate for this trait. Sun bleaching is one environmental effect that can cause black coat colors to take on a coppery, almost red, hue. Zinc or copper deficiency in diets may exacerbate pigmentation problems in cattle because these metal ions are required by some of the enzymes in the pigmentation pathway, such as tyrosinase related protein 2 and tyrosinase.

One of the characteristics of meat quality which is used as part of the grading system in North America is the amount of fat, particularly the amount of marbling. One gene which has been shown to affect this is **leptin** and the allele interaction at this locus is additive. Obviously the feeding regime used to finish cattle will also affect the amount of fat laid down and other genes which are yet undetermined likely also play a role. Sometimes such a gene is said to be a gene of "major effect". This implies that it is not the only gene affecting a trait but that its effects are substantial.

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