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TITOLO DELLA TESI:

"BONE STRENGTH OF DIFFERENT PIGS GENETIC TYPES"

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ABSTRACT

The aim of this study was to evaluate the bone strength in different genetic types of pigs. Nowadays, in swine production it is rather common to obtain pigs with weak bones, especially on the hind legs. This weakness causes fractures, which are correlated with losses in carcass weight, hence economical aspects are involved as well, and regard to significant animal welfare issues, too. Because of this, it was interesting to investigate what are the causes of weakness in pig bones of the most important genetic types used in the North European pig breeding, such as *Duroc*, *Hampshire*, *Finnish Landrace* and *Norwegian Landrace*. Bone and joint defects have been linked to high growth rate (different content in collagen), mainly of pigs. The responses of the mechanical properties are also strongly related to feeding. Genetic factors are another probable cause of weakness and the fracture of bones, both linked to *osteochondrosis,* which is rather common in pigs. In this study the bone strength and other geometrical and mechanical parameters, such as the bone mineral content (BMC), the bone mineral density (BMD), the thickness of the ring bone, the cross sectional area and the compression force of the ring bone as well were evaluated. These mechanical parameters were evaluated in bone' rings, which were obtained from the middle shaft of each femur bone of pigs. The bone' ring is a good predictor in mechanical tests for pig bones, as reported from the literature.

The femur rings were weighted and the bone mass parameters were determined using a Lunar Piximus densitometry. There were no significant differences between genetic types. Only the BMC/ring weight was significant different comparing the genetic types by sex. The thickness (min, max and mean values), the sectional area and the Feret of the rings, were determined using the Carl Zeiss program, an image analysis system. There were no significant differences between genetic types and within sex. Finally, the compression force of the pig rings was tested and the bone strength was determined using an Instron Device. There were no significant differences between genetic types and within sex.

The results of this study showed that the bone tests of geometrical and mechanical parameters were not significantly affected by the four different pig genetic types, although these parameters are strongly correlated with the pig bone strength (as reported in literature). The lack of a larger amount of data, hence the availability of animals for testing, and the lack of information about the raising and then the slaughtering of the animals, hasn't allowed a complete comprehension of the probable causes of the bone weakness in pigs. Moreover, the mechanical parameters cannot predict the bone weakness alone, but they have to be evaluated comparing with genetic and feeding patterns together.

RIASSUNTO

L'obiettivo di questo studio è stato quello di valutare la resistenza ossea in differenti incroci suini.

Oggigiorno, nella produzione suina è piuttosto comune ottenere animali che presentano debolezza alle articolazioni ed alle ossa degli arti posteriori. Questa riscontrata debolezza causa fratture, correlate con una riduzione nelle rese in carcassa, coinvolgendo aspetti economici, ma anche il benessere dell'animale, che viene ora molto considerato anche a livello di produzione intensiva. Per questo motivo è stato interessante cercare di capire quali possono essere le probabili cause di debolezza dei più importanti incroci di selezione suina utilizzati nel Nord Europa, come l'incrocio di razza *Duroc, Hampshire, Finnish Landrace* and *Norwegian Landrace*. Difetti ossei e delle articolazioni sono correlati ad un elevato tasso di crescita (diverso contenuto in collagene), soprattutto in suini. Le proprietà meccaniche dell'osso sono fortemente correlate anche con l'alimentazione somministrata agli animali durante la loro crescita. Fattori genetici sono un'altra probabile causa di debolezza e frattura ossea, entrambe correlate all'osteocondrosi, che è piuttosto comune in suini. Nel presente studio è stata valutata la resistenza ossea e altri parametri geometrici e meccanici, come il contenuto minerale osseo, la densità minerale ossea, lo spessore e l'area di anelli d'osso, e infine la resistenza alla compressione. Questi parametri sono stati valutati in campioni di anelli d'osso ottenuti dalla diafisi di ogni femore di suino preso in esame. L'anello di osso, specie nei suini, è un ottimo indicatore di resistenza ossea nei test meccanici, come riportato dalla letteratura.

Ogni singolo anello osseo proveniente da femore di suino è stato pesato ed analizzato con un densitometro Lunar Piximus, per valutare la densità e il contenuto minerale osseo. Non sono emerse differenze statisticamente significative per questi parametri tra gli incroci suini. Soltanto il parametro relativo al contenuto minerale osseo, rapportato al singolo peso di anello d'osso (*BMC/ring weight*), è risultato significativamente diverso fra i due sessi degli incroci suini. Lo spessore, la distanza fra le estremità e l'area degli anelli d'osso sono stati poi valutati utilizzando un programma grafico di analisi d'immagine denominato "Carl Zeiss". Non sono emerse differenze significative né tra gli incroci né tra i due sessi. Come ultima analisi è stata testata la resistenza dei diversi anelli d'osso alla compressione, utilizzando lo strumento Instron, e, ancora una volta, non sono state evidenziate differenze significative imputabili al tipo di incrocio o al sesso.

Dai risultati di questo studio è emerso che i parametri meccanici presi in esame non hanno risentito dell'effetto del tipo di incrocio, sebbene essi siano fortemente correlati con la resistenza ossea in suini (come riportato in letteratura). Il ridotto numero di animali impiegati nel presente studio, e la carenza di informazioni ricevute circa la tecnica di allevamento e la modalità di macellazione degli animali, non hanno permesso una completa valutazione delle probabili cause di debolezza ossea in suini.

VOCABULARY

Several different words in English identify different types of pigs:

- *Boar* - An adult male pig
- *Sow* - An adult female pig
- *Piglet/farrow* - A juvenile pig
- *Shoat* - A young pig between 100 to 180 lb (50 to 90 kg)
- *Gilt* - An immature female pig
- *Barrow* - A castrated male pig
- *Hog* - a domestic or wild adult swine, especially one raised for slaughter because they get fat quick; in its original sense it means a castrated boar aka a male pig without his testicles.
- *Swine* - Synonym for "pigs" (plural) 36

I. *INTRODUCTION*

Fig. 1 Sp. *Sus scrofa* (also called *S. domesticus*)

1.1 The bone weakness in pigs and its correlations with meat quality and animal welfare

Nowadays, most attention has been paid to the economically important performance traits of growing pigs (Ollivier *et al*., 1990). In pig breeding, the main selection traits have been growth rate, feed efficiency (meat content) and carcass composition (lean percentage). For this reason, besides a genetic predisposition, leg weakness problems can be found commonly in pigs (Andersson *et al*., 1995).

Leg weakness is a syndrome characterized by changes in leg position and abnormal locomotion (Jørgensen, 1995). Leg weakness can be explained by osteochondrosis, a generalised change of the cartilage in the articular surfaces of the bones and in the growth zones (Reiland, 1978; Nakano *et al*., 1981). Furthermore, feeding (insufficiency in calcium and phosphate intake, vitamins and available protein) appears to predispose for leg weakness in pigs (Hanssen and Grǿndalen, 1979).

Weak bones fracture easily. These fractures cause losses in carcass weight and are also involved in significant animal welfare issues.

This study is to obtain more knowledge about causes of fracture. Because of this, it is useful to measure the bone strength. Bone strength is a combination of structural, geometric and material properties and it is closely related to fracture risk (van der Meulen *et al*., 2001).

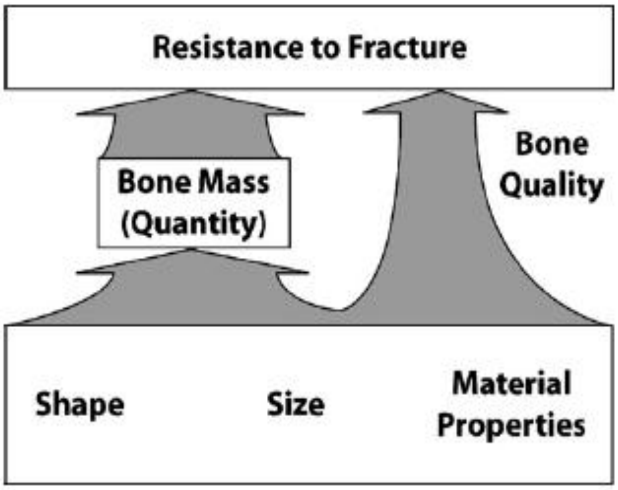


Diagram 2. Schematic presentation of bone strength (Mikic *et al*., 2001. "*Bone quality*")

II. *REVIEW OF THE LITERATURE*

2.1 A brief overview of the living pig species in Europe

Pigs are ungulates native to Eurasia collectively grouped under the genus *Sus* within the Suidae family. They have been domesticated and raised as livestock by many people for meat (called pork) as well as for leather. Their bristly hairs are also traditionally used for brushes. Wild pigs continue to fill these functions in certain parts of the world.
The most important species of pigs are:

- *Sus barbatus* Bearded Pig; Malaysia, Indonesia
- *Sus bucculentus* Vietnamese Warty Pig
- *Sus cebifrons* Visayas Warty Pig
- *Sus celebensis* Celebes Warty Pig
- *Sus heureni* Flores Warty Pig
- *Sus philippensis* Philippine Warty Pig
- *Sus salvanius* Pigmy Hog; NE India, Himalayas

- *Sus scrofa* Domestic pig , wild boar; Europe, Asia
- *Sus timoriensis* Timor Warty Pig
- *Sus verrucosus* Javan pig, Warty Pig; Indonesia, Philippines

(Resource: www.wikipedia.com)

2.2 The swine production

2.2.1 The pig farming

The practice of pig production has changed rapidly over recent decades; new husbandry practices, new understandings of growth, reproduction and health, new appreciations of welfare and environmental impact, new nutritional approaches, and modern reproductive and genetic techniques have all come into being, together with the emergence of new health challenges. The pig industry tends to be concentrated into particular locations.

Intensive piggeries (or hog lots) are a type of factory farm specialized in the raising of domestic pigs up to slaughter weight. In this system of pig production, growing pigs are housed indoors in group-housing or straw-lined sheds, whilst pregnant sows are confined in sow stalls (gestation crates) and give birth in farrowing crates. Pigs are kept in large stalls with large numbers of pigs per square metre. The temperature is raised which allows the pig to spend less energy on keeping its body heat at the right temperature so it gets fat quicker enabling the process to be much more efficient. The use of sow stalls for pregnant sows has resulted in lower birth production costs; however, this practice has led to more significant animal welfare concerns. Many of the world’s largest producers of pigs (U.S., Canada, Denmark, Mexico) use sow stalls, but some nations (e.g., the UK) and some U.S. states (e.g., Florida, Arizona , Nottingham and California) have banned them. Intensive piggeries are generally large warehouse-like buildings. Indoor pig systems allow the pigs' conditions to be monitored, ensuring minimum fatalities and increased productivity. Buildings are ventilated and their temperature regulated. Most domestic pig varieties are susceptible to heat stress, and all pigs lack sweat glands and cannot cool themselves. Pigs have a limited tolerance to high temperatures and heat stress can lead to death. Maintaining a more specific temperature within the pig-tolerance range also maximizes growth and growth to feed ratio. Indoor piggeries have allowed pig farming to be undertaken in countries or areas with unsuitable climate or soil for outdoor pig raising (e.g., Australia). In an intensive operation, pigs will lack access to a wallow (mud), which is their natural cooling mechanism. Intensive piggeries control temperature through ventilation or drip water systems (dropping water to cool the system).

Pigs are naturally omnivorous and are generally fed a combination of grains and protein sources (soybeans, or meat and bone meal). Larger intensive pig farms may be surrounded by farmland where feed-grain crops are grown. Obviously, piggeries are reliant on the grains industry. Pig feed may be bought packaged, in bulk or mixed on-site. The intensive piggery system, where pigs are confined in individual stalls, allows each pig to be allotted a portion of feed. The individual feeding system also facilitates individual medication of pigs through feed. This has more significance to intensive farming methods, as the close proximity to other animals enables diseases to spread more rapidly. To prevent disease spreading and encourage growth, drug programs such as antibiotics, vitamins, hormones and other supplements are administered preemptively.

Indoor systems, especially stalls and pens (i.e., ‘dry,’ not straw-lined systems) allow for the easy collection of waste. In an indoor intensive pig farm, manure can be managed through a lagoon system or other waste-management system. However, waste smell remains a problem which is difficult to manage.

The way animals are housed in intensive systems varies. The use of stalls may be preferred as they facilitate feed-management, growth control and prevent pig aggression (e.g., tail biting, ear biting, vulva biting, food stealing). Sows are moved to farrowing crates, with litter, from before farrowing until weaning, to ease management of farrowing and reduce pig loss from sows laying on them. Dry or open time for sows can be spent in indoor pens or outdoor pens or pastures. Houses should be clean, well ventilated but draught free. Piglets can be subjected to a range of treatments including castration, tail docking to reduce tail biting, teeth clipping (to reduce injuring their mother's nipples) and ear notching for litter identification. Treatments are usually made without pain killers. Piglets are weaned and removed from the sows at between two and five weeks old and placed in sheds, nursery barns or directly to grow-out barns. Grower pigs, which comprise the bulk of the herd, are usually housed in alternative indoor housing, such as batch pens. Group pens generally require higher stockman-ship skills. Such pens will usually not contain straw or other material. Alternatively, a straw-lined shed may house a larger group (i.e., not batched) in age groups. Larger swine operations use slotted floors for waste removal, and deliver bulk feed into feeders in each pen; feed is available ad libitum.

Many countries have introduced laws to regulate treatment of farmed animals. In the USA, the federal *Humane Slaughter Act* requires pigs to be stunned before slaughter, although compliance and enforcement is questioned. Since 2003, EU legislation has:

- required that pigs be given environmental enrichment, specifically they must have "permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, sawdust, mushroom compost, peat or a mixture of such …"
- prohibited routine tail docking. Under the legislation tail docking may only be used as a last resort. The law provides that farmers must first take measures to improve the pigs' conditions and, only where these have failed to prevent tail biting, may they tail dock.

Regardless, intensive piggeries have been increasingly criticized in preference of free range systems. Such systems usually refer not to a group-pen or shedding system, but to outdoor farming system. The outdoor pig industry has grown quickly over the last decade, a factor that has been hastened by the high capital costs of indoor pig housing as well as public demand for a less intensive industry, as mentioned above. Outdoor pig production is largely concerned with the housing of sows and the rearing of the young piglets for the first few weeks of their lives. Pigs are rarely reared to slaughter outside, as they are usually grown in conventional finishing units after weaning. The best sites for outdoor pig production are level free draining soils. Favored soil types include chalk and sand (because they are porous) whereas clays are generally unsuitable. As sows breed all the year round care has to be taken with the choice of field as the ground could become inhospitable for young piglets during winter months and compromise their welfare. Best results are obtained where pigs are kept on grass. Pigs that are housed outdoors have different welfare considerations to those indoors. In winter months when it is wet and cold piglet mortality can be higher and in summer months stock can suffer from sunburn. The farmer must provide a sun screen for these pigs. Outdoor pig units are usually found on arable farms where there is little suitable fencing to contain the animals. For this reason most units rely on temporary electric fencing that can be quickly taken down when the herd is moved onto a new field. Because there is usually plenty of space for the outdoor pig herd, the access routes through the field are generous in size to help prevent heavy rutting in the winter months. Outdoor pig production simplifies some of the waste management issues of pig production. Straw and muck from the sows are returned directly to the soil without machinery. Very often after use the straw from the individual arcs is burnt to prevent cross contamination of disease. Outdoor pig systems are very much part of the arable rotation and this field will be returned to a crop of winter wheat which will benefit from the fertility that the pigs have provided. Pigs remain in the same field for about two years and usually the stocking density will be 6 to 8 sows per acre.

Outdoor systems are usually less economically productive due to increased space requirements and higher morbidity. Outdoor pig farming may also have welfare implications, for example, pigs kept outside may get sun-burnt and are more susceptible to heat stress than in indoor systems, where air conditioning or similar can be used. Outdoor pig farming may also increase the incidence of worms and parasites in pigs. Moreover, some breeds of pig commonly used in intensive farming have been selectively bred to suit intensive conditions. Lean pink-pigmented pigs are unsuited for outdoor agriculture, as they suffer sunburn and heat stress. In certain environmental conditions, for example, a temperate climate, outdoor pig farming of these breeds is possible. There is an alternative to both intensive and outdoor piggeries of pastured pigs where pigs are truly raised on pasture getting most or all of their diet from grazing and foraging; when provided with appropriate field settings, brush and forage, the pigs do not have problems with heat stress or sunburn, manure is naturally spread over larger areas returning the nutrients to the soil and morbidity levels are far lower providing for a higher survival rate as well as better profits for small farms. Parasites and worms are easily controlled through the use of co-grazing species such as poultry as well as natural anthelmintics like garlic. However, management of these problems depends on local conditions, such as geography, climate, and the availability of skilled staff.

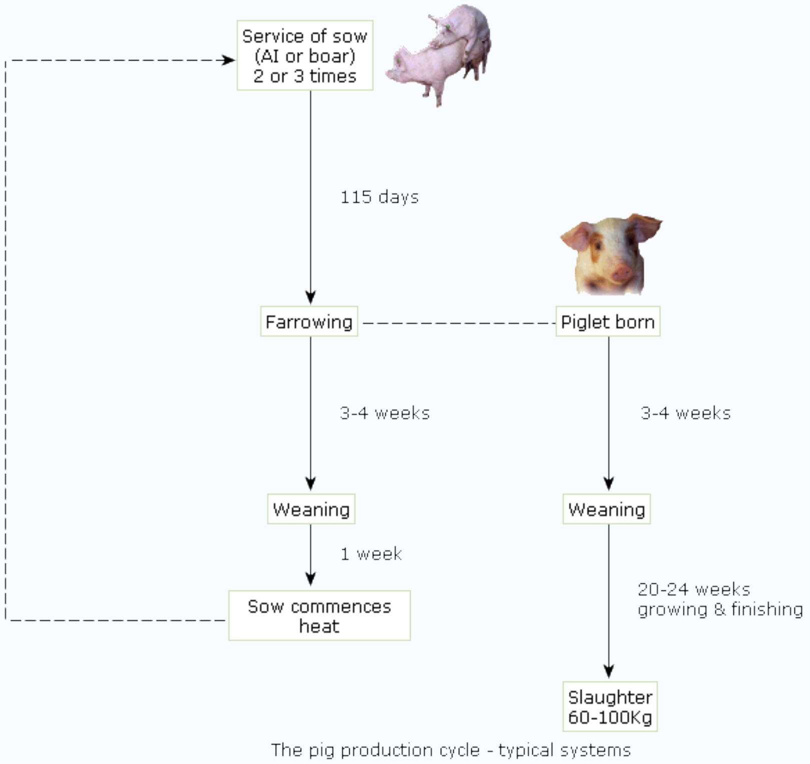


Fig. 2 A typical pig production cycle for European light pigs (www.ukagriculture.com)

2.2.2 The pig slaughtering

Pigs are usually slaughtered after 4-7 months from the receiving moment. Pigs intended for pork are usually slaughtered 1-2 months younger than pigs for bacon. The pigs are transported with trucks that have comparments with an individual capacity of 10-15 pigs.

Before slaughtering, pigs undergo electrical or carbon dioxide stunning. In the first case, they are stunned using high frequency (50 Hz), low voltage electric current applied by means of two electrodes, which are placed on either side of the brine using tongs. The current induces a state of immediate epilepsy in the brain during which time the animal is unconscious. In the later case, the pigs are passed through a well with CO_2 and air atmosphere. Legally a minimum of a 70% concentration of CO_2 by volume is required, but a 90 % is recommended. The pigs are again rendered unconscious due to the acidification of the cerebrospinal fluid upon inhalation of CO_2. With the CO_2 method "blood splashing" is eliminated, and it also removes the human element required in the electrical stunning. During their state of unconsciousness, the pigs are hoisted onto an overhead rail for slaughtering.

Then, the pigs are shackled and hoisted for exsanguination. The stunned animals undergo exsanguination (sticking) with blood collected through a special floor drain or collected in large funneled barrels or vats and sent to a rendering facility for further processing. The carotid artery and jugular vein are cut to drain out blood and to get the muscles relaxed for easy dehairing. Pigs should be allowed to bleed for about 5 minutes. Pig carcasses are not skinned after exsanguination. Instead, the carcasses are dropped into scalding water which loosens the hair for subsequent removal. The carcasses should be kept under water and continually moved and turned for uniform scalding. Hot water (60°C) is sprayed on the carcasses as they pass through the dehairer moving toward the discharge end. The carcasses are removed from this machine, hand scraped, then hoisted again, hind quarters up. Any remaining hairs can be removed by singeing with a propane or similar torch. Then, the carcasses are scraped a final time and washed thoroughly from the hind feet to the head.

After scalding and dehairing, skinning or singeing, the head is severed from the backbone at the atlas joint, and the cut is continued through the windpipe and esophagus. The head is inspected, the tongue is dropped, and the head is removed from the carcass. The head is cleaned, washed, and an inspection stamp is applied. Following heading, the carcass is eviscerated. The hams are separated, the sternum is split, the ventral side is opened down the entire length on the carcass, and the abdominal organs are removed. Intestines are cleaned for sausage casings. The thoracic organs are then freed. After evisceration, the carcass is cut into two halves. The carcass is then well washed to remove any bone dust, blood or bacterial contamination. Commonly, a mild salt solution (KCl 0.1M) is used. Cutting and deboning are easier to carry out at lower temperature. Therefore, the carcasses are transferred to chill tunnels and chill rooms to cool them down to 0-1°C with air velocity typically 5 to 15 mph, for a 24 hour chill period. For through chilling, the inside temperature of the ham should reach at least 3°C. Finally, the carcasses are processed into three cuts of meat(fore-end, middle and hind leg). During further cutting into smaller pieces, the slaughters are assisted in their work by automated transport trays and conveyors. They help in cutting and sorting meat and bone.

2.3 Pig farmed in the Nordic countries

Finland is a viable part of the EU's farming area, but the special northern conditions need to be taken into account in the EU decision-making. The competitiveness of Finnish agriculture suffers from the unfavorable structure. Because the country is large and population is sparse, maintaining the population base in the rural areas is difficult.

The structure of Finnish agriculture has changed in recent years. The number of farms has decreased by more than three per cent a year, in livestock production by as much as seven per cent. In 2007 the number of active farms was 66,800. Efforts have been made to improve efficiency and increase the farm size to respond to the challenges of the time.

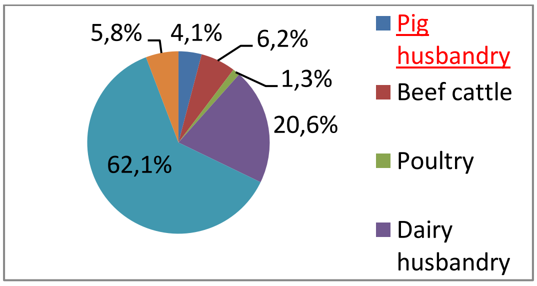


Fig 3. Farming and food in Finland (Ministry of Agriculture and Forestry)

The small size of many farms encouraged the emphasis on milk, eggs, and meat production. In the late 1980s, about 40 percent of farm income came from milk; 30 percent, from meat; 9 percent, from grain; 5 percent, from eggs; and 16 percent, from other products. Regional ecological variations influenced the distribution of agricultural production. In the southern and western parts of the country, where the climate is more favorable and soils are richer, farmers generally produced grain, poultry, and pigs, while in the north and the east they specialized in hardier root crops and in dairying. In the late 1980s, cattle operations remained the mainstay of farming, but Finland's farmers also raised pigs, poultry, and other animals. Most pigs were raised on relatively large, specialized farms. Poultry production increased after the mid1960s to accommodate an increased demand for meat. The most widely planted grain crops, such as barley and oats, were used primarily to feed livestock. Rutabagas and mangels, particularly hardy root crops, also served as animal feed.

2.3.1 The pork production in the Nordic area

When Denmark, Sweden and Finland joined the EU, they also became part of the EU's Common Agricultural Policy (CAP), which has a single market for agricultural products and food. There is a free exchange of goods between member states. Since Sweden entered the EU in 1995, imports of agricultural and food products have risen 70% (Rydhmer, Swedish University). Around 40% of the import consists of products that can hardly be produced in Sweden, but meat imports have also increased a lot. Today, 20% of the pork is imported to Sweden (mainly from Denmark). Denmark, on the other hand, export six times more pork than they consume in the country. Most of that export goes to Germany, UK and Japan. With such an important export, consumers in the buying countries may also influence the breeding goal. A very low acceptance of boar taint in Germany put an end to the development of the entire male production in Denmark in the middle of the 1990's. However in 2001, the ministers of agriculture in Denmark, Sweden and some other EU countries (probably inspired by Norway) declared that castration should be forbidden "in principal". Danbred is now involved in a European genome project on boar taint. The new cooperation between Norsvin and Quality Genetics is an affair over the EU-border. Norway is not a member of the free market in EU and the Norwegian pig producers are paid a much higher price than the Swedish producers. Maybe that explains why Norsvin has the most broad breeding goal of the Nordic breeding organizations, including many different traits. In Sweden, the price to the producer is the second lowest of all EU countries, the production costs are high (8 % higher than in Denmark) and pork imports are increasing. Under this economic pressure, Quality Genetics has hesitated between breeding for bulk production or high quality production, while Norsvin has stated to breed for the entire pig, including as many traits as possible in the breeding goal. It will be interesting to see how these two organizations, placed in so different production environments, will define their common breeding goal and breeding program.

2.4 Pig breeding

2.4.1 The breeding goal: meat quality

There are about 1.2 million pigs in Finland. Half of purebred sows are Finnish Landrace and the other half Yorkshire. The active purebred breeding population is 2000 sows in both breeds. Of this total number of sows, 25% are crossbred between these two main breeds (Rydhmer, Swedish University). In Finland the breeding program proceeds well, a particularity is represented by the small size of farms, the sows reared are nearly all pure bred and almost all the data regarding their performance is collected.

Pork is the most consumed meat in four of the five Nordic countries: Denmark, Sweden, Finland and Norway. A large part of the pork is bought as fresh meat by the consumer and eaten in stews, in meat balls, as baked ham, grilled entrecote, roasted fillet and cutlets. Thus, meat quality should be more important in Nordic countries than in e.g. France, where more pork is bought and consumed as cooked ham (*jambon de Paris*) and other charcuteries. Consequently, Quality Genetics has decided to increase the RN^- allele frequency in Hampshire (Rydhmer, Swedish University). This allele improves taste and juiciness. French breeding organizations, on the contrary, have selected against the RN^- allele, since it gives higher cooking loss and thus is unfavorable for the processing industry. In spite of Nordic food traditions, meat quality is not included in the genetic evaluation in Sweden and Denmark. In Norway and Finland, ultimate pH and meat color (reflectance) are recorded in sibling tests and included in the genetic evaluation. An important genetic fact with regard to meat quality is that all breeds used in the Nordic countries are free from the porcine stress syndrome allele, which causes extreme stress sensitivity and low meat quality (pale, soft and exudative meat). Based on research at the Swedish University of Agriculture, a Swedish eradication programme was already started already in the beginning of the 1980'ies. The selection against carriers of the recessive allele was performed with marker assisted selection, using blood groups as markers. The strategic decision to get rid of the so called halothane gene, in spite of its favorable effect on leanness, also led to an improved animal welfare.

For most consumers, boar taint is indeed considered very low quality of meat. All male pigs raised for slaughter in the Nordic countries are castrated. But castration is painful and this practice is questioned for welfare reasons. In Norway, castration has been prohibited by law recently (2009). Before that time, the castration was performed by veterinarians, using anaesthesia. Androstenone is a sexual pheromone and breeding for reduced sexual function carries risks. An alternative would be to select animals with certain alleles important for androstenone synthesis. Molecular genetic studies of boar taint are performed in several Nordic countries (Rydhmer, Swedish University).

In the Danish and Swedish genetic evaluation different selection traits are included, such as the total number of piglets born per litter, the number of live born piglets, to which follow the number of piglets alive at day five, because of the increased piglets mortality. Of the piglets not reaching weaning, 90 % are stillborn or die before day 5. Danbred takes the main part of piglet mortality into account with this selection trait. FABA continues to select for total born, but also for low number of stillborn and low mortality of live born piglets. Norsvin does not select for piglet survival yet, but litter weight (adjusted for litter size) at 3 weeks is included in the genetic evaluation since 2004. According to results from Holm et al (2005) and Grandinson et al (2005), there are both direct and maternal genetic effects on piglet growth. Furthermore, the correlation between these effects is negative and therefore both components ought to be included in the genetic evaluation in the long run. Some of the breeders in Norway also record birth weight, which could be an alternative selection trait. Grandinson et al (2002) showed that the genetic correlation between birth weight and crushing is negative (high weight - low mortality). The corresponding correlation between birth weight and stillbirth is, however positive (high weight - high mortality).

Another selection trait for vital piglets could be the behavior of sows, which is heritable and related to piglet survival (Grandinson et al, 2003; Vangen et al, 2005), but so far no behavioral traits are included in the genetic programs. According to the Swedish animal welfare law, sows should be kept loose in the farrowing pens, but in Denmark most sows are confined in farrowing crates during the whole lactation. An ongoing EU-project will show whether there are important interactions between genotype and housing environment for maternal behavior.

2.4.2 Selection traits used by Nordic breeding organizations

The hybrid pig can be defined as a cross between two or more selected strains or breeds of pigs of known ancestry and performance. This process of cross-breeding generally results in improved litter performance characteristics in the hybrid progeny when compared with either of the pure-bred parents. Not only are the litter traits important, but growth rate, food conversion and carcass quality are important as well. In the hybrid breeding program the leading aim is to carefully select the two pure-bred lines from which is possible to recognize the desired characteristics that I want to see on the progeny. For instance, if we have a strain of pigs that is known to produce good carcasses, and a further strain that grow quickly and convert their food efficiently, by mating the two together we can produce a hybrid with the trait for carcasses quality and economy of production.

Fig 4. Pig feeding (Report from University of Nebraska 2008)

Finland has unified pig breeding program. The selection objectives for both breeds are identical. The principal objective in pig breeding is total economic value. This includes improving fertility, the daily gain and feed conversion, improving carcass quality by decreasing fat - percent and increasing the lean meat percent and improving the meat quality. The Finnish Animal Breeding Association (called FABA) is responsible for carrying out the pig breeding program with close co-operation with slaughter houses and other interest groups (www.faba.fi).

FABA Breeding is the Finnish national breeding organization, where pig breeders and producers are members. They are responsible for:

- litter recording
- on-farm test
- central station test
- pedigree test (DNA)
- official herd book keeping
- breeding value estimation
- export of breeding pigs and boar semen

The target of their breeding work is to improve economical efficiency of pork production. The traits improved are:

a) **Production traits**

- daily gain
- feed conversation

b) **Carcass quality traits**

- meat- %
- fat- % in back and loin

c) **Meat quality traits**

- pH-value and meat colour from cross-section of eye muscle
- top side of ham

d) **Fertility**

- litter size at birth
- number of stillborn
- number of piglets died before weaning
- farrowing age
- farrowing interval

National, cooperative breeding organizations dominate the genetic improvement in the Nordic countries: Quality Genetics in Sweden, Norsvin in Norway, National Committee for Pig production (Danbred) in Denmark and the Finnish Animal Breeding Association (FABA) in Finland. Pig production has increased on Iceland during the last decades, but the pig breeding is mostly a non-Icelandic activity. Icelandic production is based on regular imports, mainly from Norway and Finland. Although four of the Nordic countries have their own breeding organizations, farmers in Norway, Sweden and Finland partly share the same genetic material. In Sweden, the 35 % of the pig producers that prefer private slaughter plants (instead of the cooperative slaughter organization), have been buying genetic material from Norsvin for many years. Norsvin buys Yorkshire semen from FABA in Finland. In Norway, the terminal sire is a Landrace x Duroc cross. Quality Genetics uses Hampshire and Danbred uses both Hampshire and Duroc as terminal sire breeds. Traditionally, Finnish pigs raised for slaughter are two breed crosses (Finnish Landrace x Yorkshire), but today a large proportion of the Finnish farmers use either Swedish Hampshire or Norwegian Landrace x Duroc as terminal sire (Rydhmer, Swedish University).

The breeding structure in the Nordic breeding organizations is, like in other countries, hierarchical, with nucleus, multiplier and production herds. A large part of the F1 gilts (Landrace x Yorkshire) are, however, produced in the nucleus herds in Sweden, Denmark and Finland, but not in Norway. Sow and piglet traits for the litter recording scheme are recorded in nucleus and multiplier herds. Performance testing of young boars and gilts is done in nucleus herds and in Finland also in multiplier and production herds. In addition to field testing, testing stations are used for young boars in all four countries. The best animals are used for artificial insemination (AI). In Finland, on pig breeding farms the percentage of A.l. is over 70%. All A.I. boars some 300 animal at a time, are reared and tested at two phenotype testing stations. The combined index is based on the boars individual results as well as its sibs' results. The top third of boars tested are accepted for A.I. use. Non AI boars are dissected to record lean content and other traits. In Norway, siblings raised in two large production herds are used for carcass dissection and all AI boars are recruited from the testing station. In Finland, the testing station is also used for sib testing of gilts and castrates. Although the breeding goal seems to be almost the same for all breeding organizations according to their annual reports, the traits selected (Table 1) differ. The models used for genetic evaluation also vary. Some examples: Litter size is analyzed as a repeated trait within Danbred and Quality Genetics, while Norsvin handles litter size from first, second and third parity as different traits in a multivariate analysis. FABA handles litter size in first parity and litter size in the following parities (repeated measurements) in a multivariate analysis. Norsvin includes number of teats in the genetic evaluation, whereas the breeders in the other organizations perform a threshold selection for teat number (at least 14 teats).

Table 1. Selection traits used by Nordic breeding organisations

Type of trait	Organisation	Selection trait
Reproduction	Norsvin	Age at 1st service; Litter size, born alive; Number of teats; Litter weight at 3 wk; Weaning to service interval
	Danbred	Litter size, alive at 5 days
	FABA	Age at 1st farrowing; Litter size, total born; Stillborn; Mortality of liveborn; Farrowing interval
	Quality Genetics	Litter size, born alive; Farrowing interval
Production	Norsvin	Growth rate (age at 100 kg); Carcass leanness; Feed efficiency (25-100 kg); Dressing percentage; Bacon side quality
	Danbred	Growth rate (0-30 kg); Growth rate (30-100 kg) Carcass leanness; Feed efficiency (30-100 kg); Dressing percentage
	FABA	Growth rate (30-100 kg); Carcass leanness; Feed efficiency (30-100 kg)
	Quality Genetics	Growth rate (birth-100 kg); Carcass leanness Feed efficiency (30-100 kg)
Health	Norsvin	Conformation score; Osteochondrosis
	Danbred	Conformation scores; E.coli (MAS)
	Quality Genetics	Conformation scores; Osteochondrosis
Meat quality	Norsvin	Ultimate pH; Reflection; Intramuscular fat (Duroc)
	FABA	Ultimate pH; Reflection
	Quality Genetics	RN^- allele (Hampshire)

(Swedish University of Agricultural Science, Dept of Animal Science. 2009)

Danish pig production is larger than the sum of the production in all the other Nordic countries (23 million pigs versus 3 million pigs produced per year). The breeding facilities, the number of nucleus herds and purebred sows are much larger in Denmark, too. Thus, cooperation between countries is more urgent for Sweden-Norway-Finland than for Denmark. The same high health status in Sweden, Norway and Finland also facilitates cooperation. Indeed, the health status in Danish pig production differs from the other, which are more "strict" regarding PRRS (Porcine Reproductive & Respiratory Syndrome) and Salmonella, than Denmark actually. In March 2005, a three-year agreement concerning the maternal lines was signed by Norsvin and Quality Genetics. According to this agreement, Landrace will be produced in Norway and Yorkshire in Sweden. Thus, the Swedish Landrace nucleus herds are closing down and next year there will be no Swedish Landrace boars at the AI stations. In Norway, they will continue to produce Duroc and use Landrace x Duroc as terminal sires, and Quality Genetics will continue to produce and use Hampshire as a sire breed in Sweden. A group of Finnish farmers has recently decided to buy Yorkshire material from Quality Genetics and Landrace material from Norsvin. At the same time, FABA has started to build a new testing station for the Finnish national breeding program.

Actually, there are various pig testing methods in Finland (Agrifood Research Finland). On farm testing is used as a selection method in all sow herds. A selection index is calculated on the basis of growth rate and the-thickness of back-fat. The on farm test also includes assessment of general conformation, legs and teats. Progeny testing plays the most important role in selection of breeding pigs in Finland. Annually some 1,200 groups each consisting 4 piglets - are tested in seven testing stations. Testing period in progeny test is at the moment from 25kg to 100kg, after that test animals are slaughtered and carcasses dissected. The progeny teat index includes following characteristics: feed conversion, daily gain, fat percent in back and loin, lean meat percent and meat quality. In addition attention is focused on carcass length, back-fat thickness, eye muscle area, lean meat in ham and conformation. Litter recording is carried out on over 1,000 farms to assist farmers in the selection of their animals. The data is also used to calculate fertility index by BLUP (*Best Linear Unbiased Prediction*; It gives the Breeding Values a rating or breeding quality number and is a prediction of the breeding potential of the individual animal and how likely it is that that animal will improve, or not improve, its offspring). This method is used to maintain the high level of fertility of Finnish pig breeds.

2.4.3 Pig breeding influence on the pig market in Nordic countries

The breeding work is of course influenced by the structural changes which are sweeping over European agriculture. The total number of farms in EU decreased 18 % from 1995 to 2003, while the average farm size (area) increased 13 %. The decrease in farm number is largest in animal production. In Finland the number of farms with animals decreased 44 % from 1995 to 2003. The number of Swedish pig farms has decreased 88% since 1980 and the average number of sows and boars per farm has increased from 15 to 92 in these 25 years. In spite of this dramatic change, the average herd is still a rather small family enterprise. The average piglet producer has 80 sows in Sweden, 67 sows in Finland and 44 sows in Norway. The Danish herds are larger, in average 210 sows per herd. Even the nucleus herds follow the same trend like the farms, hence influence the breeding aim, as well. In Norway, where the average nucleus has only 40 sows, it is perhaps easier for the breeders to record traits than in Denmark where the average Yorkshire nucleus has 450 sows. On the other hand, large herds can afford specialized caretakers focusing on e.g. the farrowing unit. This could increase the accuracy of maternal trait records. Furthermore, the trend towards fewer nucleus breeders that are strongly bound to their breeding organization might facilitate the implementation of complicated recording schemes, like behavior data.

The last November 2009, pig market analysts stated the problems are heightened in Finland by cheaper products from Denmark and Germany hitting the market. And they say it will be hard for the Finnish industry to pass on higher prices to consumers (www.mmmtike.fi). The two leading pig meat companies, HK Scan and Atria have both reported drops in profits, despite increasing sales. HK Scan saw sales for the first three months of the year come in at €510.1 million compared to €498.6 million last year. However, EBIT (*Earnings Before Interests and Taxes)* for Finland dropped to €4.1 million compared to €7.3 million last year in Finland. In the Baltic region is was down to €1.4 million from €2.5 million last year. The company said that the performance was eroded by losses in the red meat business. The HK Scan market responsible said: "The difficult situation in the pork market in particular eroded the company's performance in all market areas. The loss-making meat business depressed earnings especially in the Baltic and Finland. Commercial operations furthermore performed with less distinction in March than anticipated, especially in Finland and Sweden." Atria saw Group's net sales rise by 9.9 per cent reaching € 303.4 million compared to € 276.0 million last year. However, EBIT was € 6.8 million compared to € 11.5 million. Atria said: "The increasing cost of raw material across the food chain has hampered the Group's performance. The profitability of Atria Finland has been affected particularly by the imbalance in the price of pork between Finland and the rest of Europe."

2.5 Crossbreds used for this study

Duroc and its origin

Fig 5 Duroc breed (National Swine Registry)

The ancestry of this breed is not entirely known, but the Jersey Reds of New Jersey, the red Duroc of New York, and the red Berkshires of Connecticut have contributed to the formation of the breed. The breed was first called the Duroc-Jersey. Standards were established for the breed in 1885.

The Duroc is red in color, with the shades varying from a golden yellow to a very dark red. A medium cherry red is preferred. Black flecks may appear in the skin, but large black spots, black hair, and white hair are objectionable. Duroc have a medium length and slight dish of the face. The ears should be drooping and should not be held erect. The breed is prolific, and the sows are good mothers. They have good dispositions and produce large quantities of milk. The Duroc is large and has excellent feeding capacity. Most tests related to rate of gain that have been made by agricultural experiment stations have indicated that the Duroc is a very rapid gainer. That's why this breed is very popular in crossbreeding.

Hampshire and its origin

Fig 6 Hampshire breed (National Swine Registry)

This breed was developed in Boone County, Kentucky, from hogs probably imported from England in the early 1800's. The foundation stock, known as the Thin Rinds and Belted hogs, had been raised in the New England states. The breed association was organized in 1893, and although the breed is one of the youngest, it has become very popular. The Hampshire is a black hog with a white belt encircling the body and including the front legs. The back legs are usually black, and no white should appear above the hock. The head and tail are black, and the ears are erect. No white should show on the head. The Hampshire is smaller than some of the other breeds. It has been bred for refinement, quality, and prominent eyes. The sows of the breed are very prolific and are good mothers. It is shorter legged than most breeds and sound on its feet and legs in most cases. The breed has been used extensively in crossbreeding because of its quality, fleshing, and prolific.

Finnish Landrace and its origin

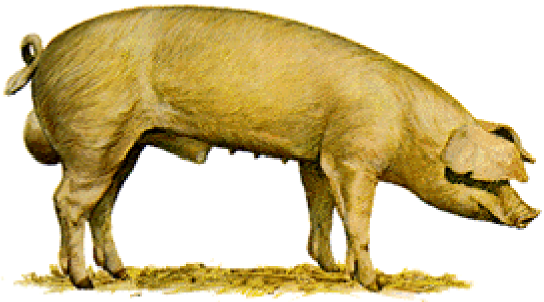


Fig 7 Finnish Landrace breed (National Swine Registry)

The Finnish Landrace has a very similar origin to that of the other Landrace strains of northern Europe. Native stock was crossed with the improved strains of Landrace that were introduced from the other countries, particularly those of the Scandinavian neighbors.

While similar to other Landrace, with their white color and heavy, drooping ears, the breed found in Finland is characterized by an extreme trimness. Because of this, they have been imported as seed stock to other countries that depend heavily on Landrace in their swine producing industry. Swine production of Finland is on a practical basis with much emphasis on farm testing. While the swine improvement program of Finland is relatively new, it has been satisfying to swine producers of the country. Assistance is given the swine farmers in their breeding programs and in their herd bookkeeping.

Norwegian Landrace and its origin

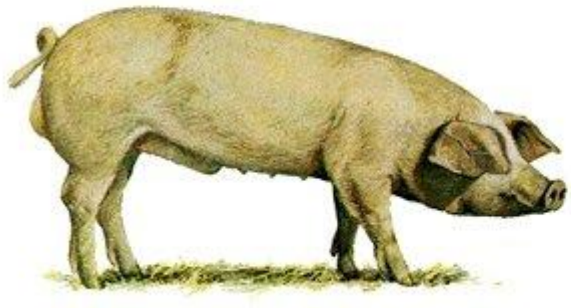


Fig 8 Norwegian Landrace breed (National Swine Registry)

Norwegian Landrace is the leading breed of swine in Norway. Since swine are not as numerous in Norway as in most countries that have a registered strain, the number registered each year is limited. Norwegian Landrace, as well as most of the swine in Norway, are raised in the southern part of the country. Most are found in the area of Hamar. They are white in color and have a heavy drooped ear. The breed originated from importations of Landrace from other countries having the breed. There was then special selection to give the blend of introduced strains a unique adaptation to the environment of Southern Norway. The major aid in this selection has been the breed testing done in a special swine station. In the boar testing station, 2300 boars are tested annually. 2700 siblings are also tested on station. In addition, boars and gilts are tested on farm. The best performing pigs that are sound provide the main source of brood stock for breed improvement. Artificial insemination plays a great part in spreading the influence of superior boars. It is estimated that 90% of the sows are bred by artificial insemination.

Proof that the Norwegian Landrace has found favor in other countries is apparent because breeding stock has been in demand for exportation. Exports have been made, to England, Ireland, Northern Ireland, France, Sweden, Denmark, Canada, Poland, and Czechoslovakia. These countries all have a reputation for producing high class pork products and most have a strain or breed of Landrace of their own. This indicates the importing countries felt there was sufficient merit in the gene pool of the Norwegian Landrace to justify securing some of that stock to broaden the genetic base of their swine.

2.6 Pig bone conformation

2.6.1 Definition of bone and its functions

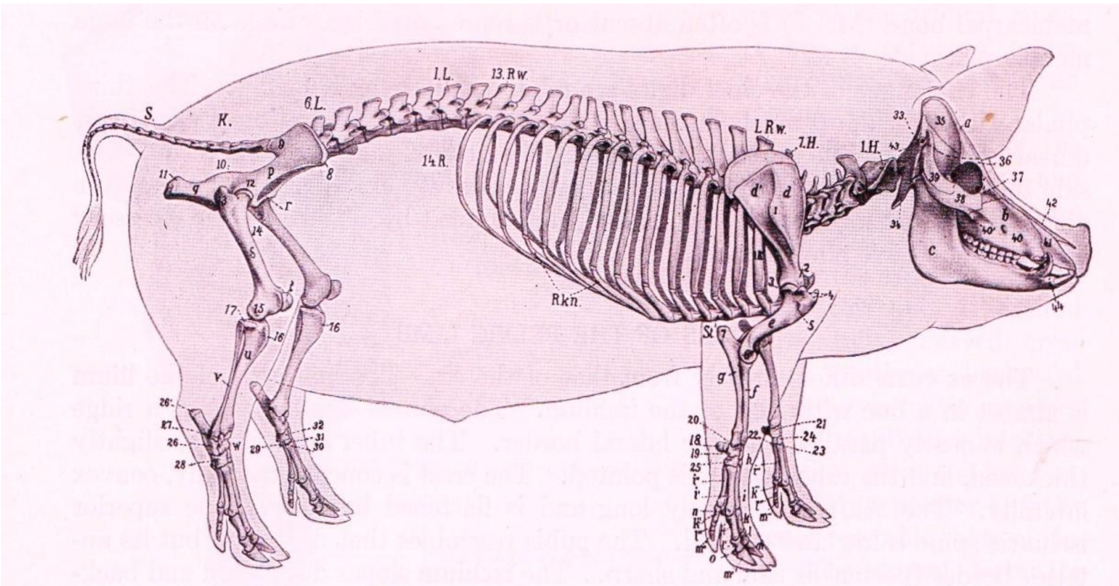


Fig 9 Bones illustration in pigs (“Journal of Animal Science 2004, 82:3118-3127)

Bone is a specialized form of connective tissue. It consists of cells and an mineralized extracellular matrix which allows to distinguish bone from other connective tissue. The mineralization of the matrix produces an extremely hard tissue capable of providing support and protection. The main mineral is calcium phosphate, in the form of hidroxyapatite crystals [$Ca_{10}(PO_4)_6(OH)_2$], found in conjunction with carbonate, citrate, magnesium, sodium, fluoride and strontium ions. Both calcium and phosphate can be mobilized from the bone matrix and taken up by the blood, as needed, to maintain appropriate levels throughout the body. Thus, in addition to support and protection, bone has an important secondary role in the homeostatic regulation of blood calcium levels.

Bone matrix consists of type I collagen and ground substances, such as osteocalcin, osteonectin and osteopontin which are proteoglycans and noncollagenous glycoprotein. The calcium phosphate is deposited along the collagen fibrils and in the proteoglycan ground substance ("Bone", 1975).

We can split the main functions of the bone:

1. Mechanical

- Protection — Bones can serve to protect internal organs
- Shape — Bones provide a frame to keep the body supported
- Movement — Bones generate and transfer forces so that individual body parts or the whole body can be manipulated in three-dimensional space.

2. Synthetic

- Blood production — The marrow, located within the medullary cavity of long bones and interstices of cancellous bone, produces blood cells in a process called haematopoiesis.

3. Metabolic

- Mineral storage — Bones act as reserves of minerals important for the body, most notably calcium and phosphorus.
- Growth factor storage — Mineralized bone matrix stores important growth factors such as insulin-like growth factors, transforming growth factor, bone morphogenetic proteins and others.
- Fat Storage — The yellow bone marrow acts as a storage reserve of fatty acids
- Acid-base balance — Bone buffers the blood against excessive pH changes by absorbing or releasing alkaline salts.
- Detoxification — Bone tissues can also store heavy metals and other foreign elements, removing them from the blood and reducing their effects on other tissues. These can later be gradually released for excretion.

2.6.2 Bone tissue and classification

Bones are the organs of the skeletal system; the bone tissue is the structural component of bone. They also contain other connective tissues of various sorts, including hemopoietic tissue, fat tissue, blood vessels, nerves, joint and hyaline cartilage. The bone tissue and the articular cartilage, where present, allow the good performance in skeletal functions of the bone. The bone tissue is classified as either compact (*dense*) or spongy (*cancellous*) bone (“Bone”, 1975). The compact bone is the dense layer that forms the outside of the bone; the other arrangement has the appearance of a sponge, with trabeculae of bone tissue forming a meshwork in the interior of the bone. The spaces of the meshwork are continuous and, in a living bone, are occupied by blood vessels and medullary cavity, a large cavity filled with bone marrow, that forms the inner portion of the bone. Cortical bone is much denser than spongy bone, with a porosity ranging between 5% and 10%, while the range of porosity in trabecular bone is from 50 % to 90 %.

The location of spongy and compact bone varies with bone shape. Cortical bone is found primary in the shaft of long bones, in which almost the entire thickness is compact while only a small amount of spongy bone faces the medullary cavity. Reverse is true, at the ends of the bone (joints and the vertebrae); Here, the spongy bone is extensive, and the compact bone is little more than a thin outer shell.

2.6.3 Bone structure (focus on the femur)

Bones are classified according to shape. The bone shape is much variable and depends from the mechanical requirements. There are four groups into the bone can be classified:

- Long bones: are longer in one dimension than other bones and consist of a shaft and two ends (e.g. the tibia and the metacarpals)
- Short bones: are nearly in length and diameter (e.g. the carpal bones of the hand)
- Flat bones: are thin and plate (e.g. the bones of the calvaria and the sternum); they consist of two layers of relatively thick compact bone with an intervening layer of spongy bone
- Irregular bones: have a shape that does not fit into any one of the three groups just described; the shape may be complex, e.g. a vertebra

The femur is the largest and most massive bone of the long bones. It has a relatively wide and massive shaft. The shaft is cylindrical but flattened behind, and larger above and below. On the shaft four surfaces might be recognized. The principal nutrient foramen is situated in the proximal third of the anterior surface. The posterior surface is wide, and is limited laterally by a ridge which extends from the trochanter major to the large lateral supra-condyloid crest. In the swine femur there is no supracondyloid fossa. The head is strongly curved, and is marked toward the medial side by a rather large fovea for the attachment of the round ligament. The neck is distinct. The trochanter major, although massive, does not extend above the level of the head. The trochanter ridge and fossa resemble those of the ox. The third trochanter is absent. The ridges of the trochlea are similar and almost sagittal. The extremities unite with the shaft at about three and a half years.

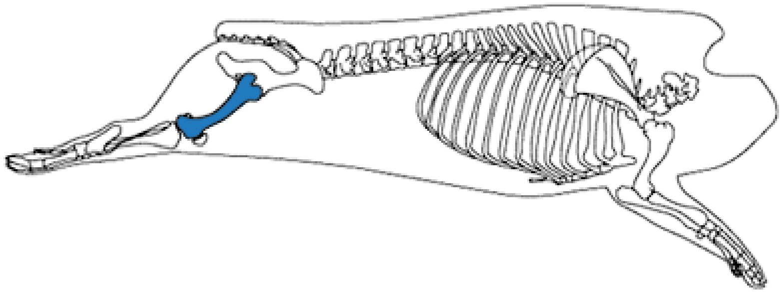
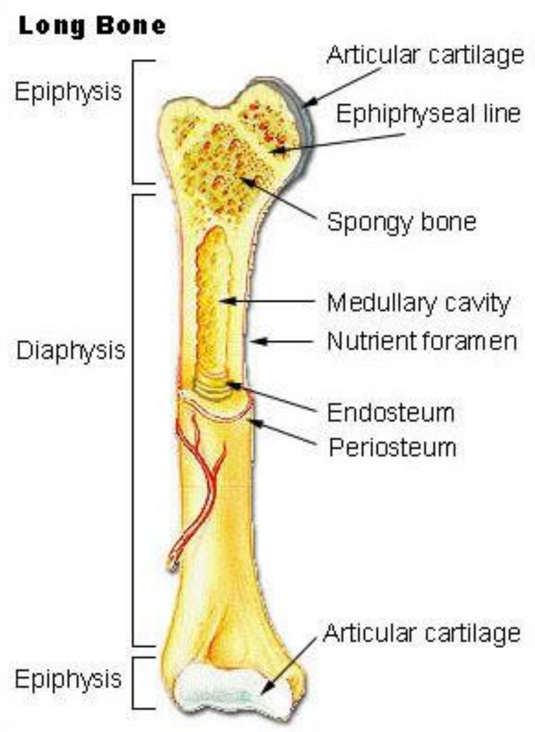


Fig 10 The femur of a hind limb in swine (www.pork.org)



The femur (thigh bone) is the longest and strongest bone in the skeleton, almost perfectly cylindrical in the greater part of its extent. The femur, like other long bones, has a shaft, called the *diaphysis*, and two expanded ends, each called an *epiphysis*. Except the articular surface of the epiphysis which is covered with hyaline cartilage, the outer surface of the bone is covered by a fibrous layer of connective tissue called the *periosteum*. The flared portion of the bone between the diaphysis and the epiphysis is called *metaphysis*. It extends from the diaphysis to the epiphyseal line.

Fig 11 The long bone scheme ("The Anatomy of the domestic animals", Septimus Sisson; 1953)

2.6.4 Bone development and ossification process

Within the bone matrix, in addition to collagen fibrils and glycoproteins, there are spaces called *lacunae*, each of which contains a bone cell, the *osteocyte*. The osteocyte extends numerous processes into little tunnels called *canaliculi*. These run through the mineralized matrix, connecting adjacent lacunae and allowing contact between the cell processes of neighboring osteocytes. In this manner, a continuous network of canaliculi and lacunae containing the cells and their processes is formed throughout the entire mass of mineralized tissue.

Other four designated cell types are associated with bone tissue. They are *Osteoprogenitor cells*, *Osteoblasts*, *Osteoclasts* and *bone lining cells*. All cells except osteoclasts may be regarded as a differentiated form of the same basic cell type, which undergoes transformation from a less mature form to a more mature form in relation to the growth of bone. They originate from the mesenchymal stem cells, which differentiate into osteoprogenitor cells, osteoblasts, and finally osteocytes and bone-lining cells. In contrast, the osteoclast originates from hemopoietic progenitor cells which differentiate into bone-resorbing cells. The bone resorption is an activity associated with the bone remodeling. The osteoprogenitor cells are found on the external and internal surfaces of bones and may also reside in the microvasculature supplying bone. These cells can give rise to the osteoblast which secrete the extracellular matrix of bone. They secrete both type I collagen (which constitutes 90% of the protein in bone) and bone matrix proteins, which constitute the initial unmineralized bone, or *osteoid*. Osteoblasts respond to mechanical stimuli to mediate the changes in bone growth and bone remodeling. Once the osteoid deposition occurs, the osteoblast cell has surrounded itself with incremented matrix, it is referred to as an osteocyte. The osteocyte is the mature bone cell responsible for maintaining the bone matrix. Each osteocyte occupies a space, or *lacuna*, that conforms to the shape of the cell. One of the roles of the osteocytes is mechanotransduction, in which the osteocyte responds to mechanical forces applied to the bone. Different mechanical stimuli, like increased mechanical loading, alter not only gene expression but also the cell’s apoptotic mechanism. Osteocytes can synthesize new matrix, as well as participate in matrix degradation. Such activities help to maintain calcium homeostasis. Death of osteocytes, either through fracture or apoptosis results in resorption of the bone matrix by osteoclast activity, followed by repair or remodeling of the bone tissue by osteoblast activity. The *Osteoclasts* are bone resorbing cells presents in the bone surfaces where bone is being removed.

The primitive embryonal skeleton consists of cartilage and fibrous tissue, in which the bones develop. The process is termed *ossification* or *osteogenesis* (“Bone”, 1975).
There are two different types of bone formation (osteogenesis):

- *Intramembranous ossification*
- *Endochondral ossification*

In both cases the first bone tissue to be formed is primary (woven or immature) bone, which is temporary only, prior to its replacement by secondary (lamellar or mature) bone.
Intramembranous ossification involves the direct formation of bone within primitive connective tissue, whereas with endochondral ossification there is a cartilage model prior to the development of the bone. Intramembranous ossification is typical of the bones that form the vault of the skull, while the endochondral ossification is more common in the developing long bones, in which cartilagenous models become ossified to form the bones of a commercial meat carcass.
The first site of ossification occurs in the primary center of ossification, which is in the middle of diaphysis (shaft).

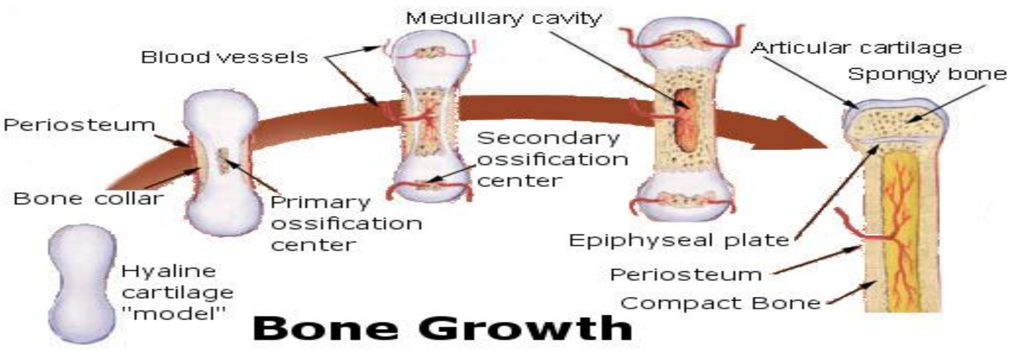


Fig 11 The bone growth (“The Anatomy of the domestic animals”, Septimus Sisson; 1953)

Then, there is the formation of periosteum, the connective tissue membrane which invests the outer surface of bone, except where it is covered with cartilage. It contains a layer of undifferentiated cells (osteoprogenitor cells) which later become osteoblasts. The osteoblasts secrete osteoid against the shaft of the cartilage model (it occurs when the cartilage model would also grow in thickness which is due to the addition of more extracellular matrix on the periphery cartilage surface). This is the formation of the bone collar and it serves as support for the new bone.

Chondrocytes in the primary center of ossification begin to grow (hypertrophy). They stop secreting collagen and other proteoglycans and begin secreting alkaline phosphatase, an enzyme essential for mineral deposition. Then calcification of the matrix occurs and apoptosis of the hypertrophic chondrocytes occurs as well. The hypertrophic chondrocytes (before apoptosis) secrete Vascular Endothelial Cell Growth Factor that induces the sprouting of blood vessels from the perichondrium. Blood vessels forming the periosteal bud invade the cavity left by the chondrocytes and branch in opposite directions along the length of the shaft. The blood vessels carry hemopoietic cells, osteoprogenitor cells and other cells inside the cavity. The hemopoietic cells will later form the bone marrow. Then, the osteoblasts, differentiated from the osteoprogenitor cells that entered the cavity via the periosteal bud, use the calcified matrix as a scaffold and begin to secrete osteoid, which forms the bone trabecula. The osteoclasts, formed from macrophages, break down spongy bone to form the medullary (bone marrow) cavity.

Many bones have secondary (or epiphyseal) centers of ossification. These areas where the cartilage is still retained, are in the epiphyseal plate, located between the diaphysis (the shaft) and the epiphysis (the knob at each end) of the bone. Cartilage cells undergo the same transformation as above. In a young animal, the chondrocytes of the epiphyseal plate are constantly dividing to form new matrix. As growth progresses, the proliferation of cartilage cells in the epiphyseal plate slows and eventually stops. However, the continuous replacement of cartilage by bone, on each face of the plate, results in the obliteration of the epiphyseal plate, termed the *closure of the epiphysis*. This process allows a bone to grow longitudinally without disrupting the articular surface on the epiphysis. The rate of the longitudinal growth of bones is the product of two factors:

- the rate of production of new cells;
- the size that cells reach before they degenerate at the point of ossification.

Mineralisation of articular cartilage and its replacement by bone continues in the adult, though at a much reduced rate than in growing animals. Bone growth in mature animals is restricted to the girth or thickness of the bone, and it occurs by the recruitment of periosteal cells to become osteoblasts.

2.6.5 Bone resorption

Once bone formation has stopped, peak bone mass is maintained by remodelling. A continuous process involving the breakdown and re-formation of bone, the maintanance of maximal bone mineral density and the repair of any damage. Bone resorption is the process by which the organic components of bone are degraded by the lysosomal enzymes of osteoclasts, multi-nucleated cells that contain numerous mitochondria and lysosomes. Attachment of the osteoclast to the osteon begins the process. This allows the release of minerals, such as calcium, magnesium, phosphate and products of collagen, as well as a transfer of calcium from bone fluid to the blood. That's why the bone resorption is coupled with the maintenance of blood calcium levels. The resorption of bone also enables bone remodeling in response to local stresses.

The bone development is regulated by a complex hormonal activity. These hormones exert secondary effects on skeletal development. *Thyroxine*, *insulin*, *growth hormone*, and gonadal hormones tend to be anabolic. The growth hormone (GH) is essential in the bone development both in thickness and in length. The strength and thickness of epiphyseal plates is modified by sex hormones (Oka et al., 1979). Bone resorption is stimulated or inhibited by signals from other parts of the body, depending on the demand for calcium. Calcium-sensing membrane receptors in the parathyroid gland monitor calcium levels in the extracellular fluid. Low levels of calcium stimulates the release of parathyroid hormone (PTH) from chief cells of the parathyroid gland. In addition to its effects on kidney and intestine, PTH also increases the number and activity of osteoclasts to release calcium from bone, and thus stimulates bone resorption. The solubilization of hydroxyapatite in response to parathyroid hormone is probably achieved by a combination of low pH and chelation. Calcitonin (thyrocalcitonin) has an opposite effect and is involved in reducing blood calcium levels. Calcitonin encourages bone tissue formation and can be used in clinical treatment of osteoporosis. Estrogens may inhibit resorption of bone as well, while adrenal corticosteroids stimulate the resorption of bone and inhibit the formation of new bone.

Hormones other than parathyroid hormone and calcitonin have major effects on bone growth. One of these is *somatotropin*. This hormone stimulates growth in general and, especially, growth of epiphyseal cartilage and bone. Oversecretion or absence of somatotropin lead both to severe failure of bone growth.

2.6.6 Bone composition and biologic mineralization

The cells constitute only a very small percentage of the bone tissue, whereas the bulk of the tissue is occupied by the intercellular, calcified, bone matrix. This is best seen in compact bone, in transverse sections of the diaphysis of a long bone. The matrix is initially laid down as unmineralised osteoid (manufactured by osteoblasts). Mineralisation involves osteoblasts secreting vesicles containing alkaline phosphatase. This cleaves the phosphate groups and acts as the foci for calcium and phosphate deposition. The vesicles then rupture and act as a centre for crystals to grow on. Dried bone consists of organic and inorganic matter in the ratio of 1: 2 approximately. The animal matter gives toughness and elasticity, the mineral matter hardness, to the bone tissue.

The organic matrix is composed of type I collagen fibers (about 95%) embedded in an amorphous ground substance consisting of sulfated glycosaminoglycans (chondroitin-4-sulfate, chondroitin-6-sulfate, keratan sulfate) and various bone proteins (bone sialoproteins such as osteopontin, bone-specific vitamin K-dependent proteins as osteocalcin, multiadhesive glycoproteins as osteonectin).

The inorganic matter is composed of water (about 20% total mass) and several crystalline mineral salts. They are 55% of total bone tissue, composed by tri-calcium phosphate (85%), calcium carbonate (10%), tri-magnesium phosphate (4%), calcium fluoride (0.3%), etc. Calcium, phosphate and hydroxyl ions are obtained from the extracellular fluid during bone formation. The first stage in ossification is the deposition of a crystal of calcium phosphate. Calcium phosphate is then converted to hydroxyapatite [$Ca_{10}(PO_4)_6.(OH)_2$].

Removal of the organic matter by heat (500°C) does not change the general form of a bone, but reduces the weight by about one-third, and makes it very fragile. Indeed, the organic matter (ossein) when boiled yields gelatine. Conversely, decalcification, while not affecting the form and size of the bone, renders it soft and pliable.

3 Aim of the study

The aim of the study was to compare the femur bone strength in four pig crossbreds in order to evaluate the effect of the crossbred and sex on this parameter.

Investigations included bone measurements such as densitometry analyse, geometrical measurement and compression test.

The bone strength of the crossbreds was assessed by measuring geometrical parameter such as femur wall thickness, mechanical parameter such as breaking force and measurement of bone mass, mineral content and bone mineral density.

The information obtained could be useful for selecting that crossbred with the best bone quality.

4 Experimental Design

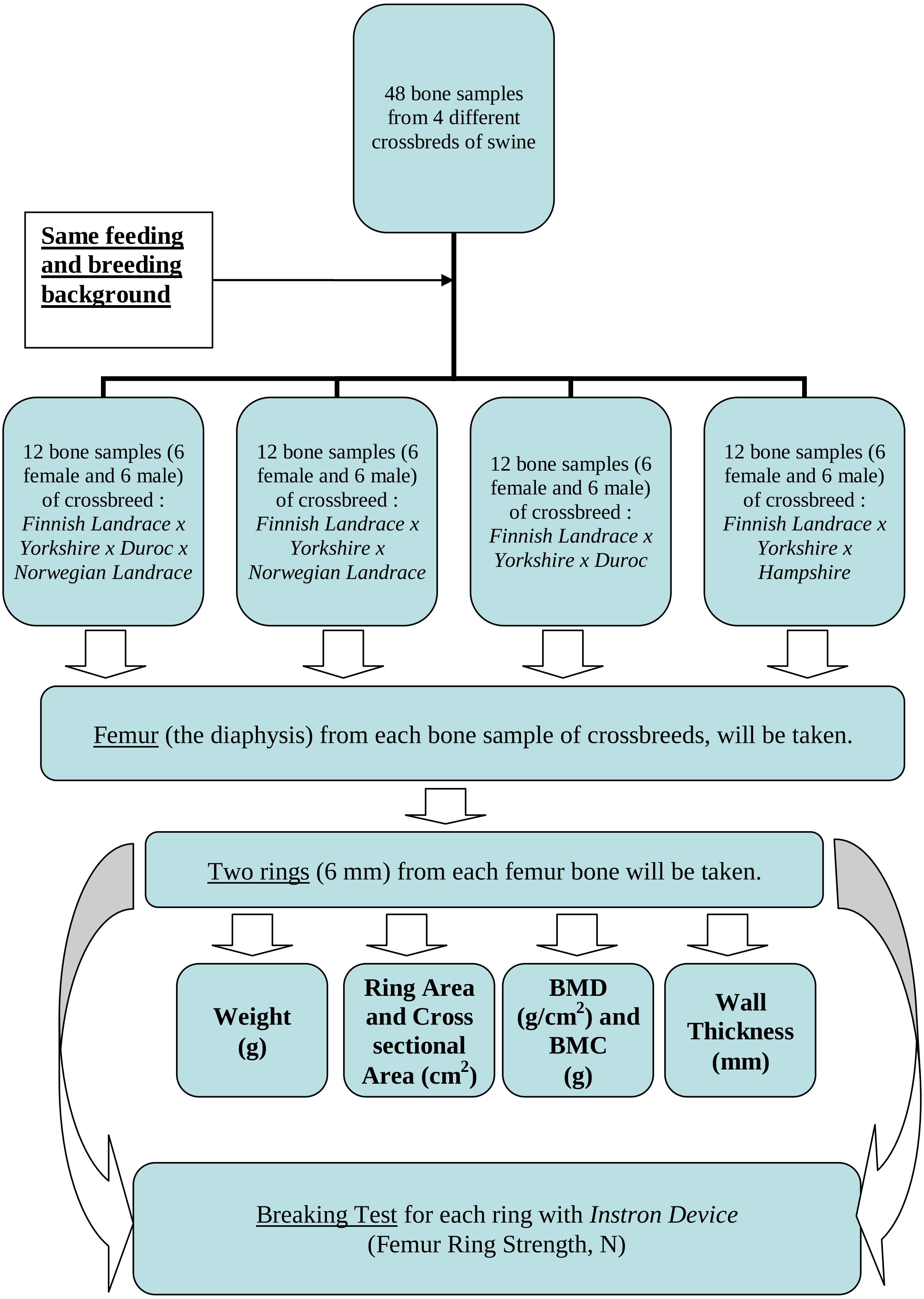


Diagram 2. The design of the study

5 Analytical measurements of bone

5.1 Biomechanical measurements : mechanical and geometrical properties

Although bone densitometry is often used as a surrogate to evaluate bone fragility, direct biomechanical testing of bone undoubtedly provides more information about mechanical integrity (Turner and Burr, 1993). There are a number of different assays that can be used to indicate bone fragility, including bone stiffness, strength, toughness, post yield deformation, fatigue, and creep properties. In addition, these assays can be performed under a number of different loading conditions such as compression, tension, shear, or bending, alone or in combination, and can be applied either cyclically or monotonically, short or long term, and at different loading rates.

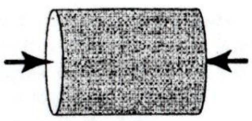
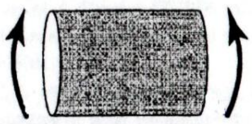
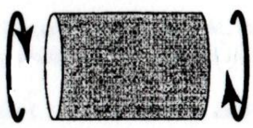
Whole bone structural test	*Structural properties*	*Material properties*	*Geometric properties*
Compression 	failure force displacement compressive stiffness	compressive ultimate stress (strength) compressive strain modulus of elasticity	cross-sectional area
Bending 	failure moment displacement bending stiffness	tensile or compressive ultimate stress tensile or compressive strain modulus of elasticity	moment of inertia about the axis of bending section modulus
Torsion 	failure torque angle torsional stiffness	shear ultimate stress shear strain shear modulus of elasticity	torsional constant about axis of twist* torsional section modulus

Fig 13 Corresponding structural, material and geometric measures for different loading modes of whole bone tests (Van der Meulen et al. , “Bone” Vol. 29, August 2001 101:104)

That most commonly used to evaluate the mechanical properties of bone is a flexure test (Baker and Haugh, 1979), which is more suitable than either tensile or compressive test, to measure mechanical properties of bones from small animals. In the bending test a force is applied perpendicularly to the longitudinal axis of a whole long bone, which is loaded in bending until failure. Bending causes tensile stresses on one side of the bone and compressive stresses on the other. Bone is weaker in tension than compression (Reilly and Burstein, 1975), so in a bending test failure usually occurs on the tensile side of the bone.

Bending can be applied to the bone using either three-point or four-point loading. The span of the specimen that is loaded must be sufficiently long to guarantee an accurate test.

If the length is very short, most of the displacement induced by loading will be due to shear stresses and not bending. The advantage of three point loading is its simplicity, but it has the disadvantage of creating high shear stresses near the midsection of the bone. Four point loading produces pure bending between the two upper loading points, which insures that transverse shear stresses are zero.

Another kind of mechanical test is the tensile test. Tensile testing can be one of the most accurate methods for measuring bone properties, but bone specimens must be relatively large and carefully machined. These specimens are designed so that majority of the strain will occur in the central portion of the specimen. Strain measurement can be accomplished accurately by attaching a clip-on extensometer to the midsection of the specimen. Stress is calculated as the applied force divided by the bone cross-sectional area in the mid-section of the specimen. For a tensile test of bone the intrinsic stiffness is equal to the Young's modulus while the extrinsic stiffness is equal to the Young's modulus per cross-sectional area of the specimen in ratio to the length of the specimen. Therefore, the extrinsic stiffness is dependent not only upon elasticity but also size of the specimen.

The third common test is the compressive test of bone specimens, which is a popular technique, especially for cancellous bone. Compressive tests tend to be less accurate than tensile tests due to end effects imposed on the specimen during the test. Typically cubes or cylinders of cancellous bone, about 7 to 10 mm in width, are cut using an irrigated saw or burr (Mosekilde et al., 1987; Turner and Eich, 1991). The compressive test has several advantages. First, the compressive specimens need not be as large as tensile specimens; second, the fabrication of compressive specimens is not as difficult as with tensile test specimens. Finally, even with measurement error, compression tests are often very precise.

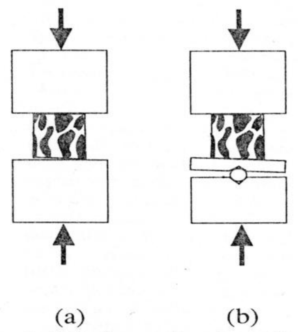


Fig. 11. Compressive test of a cancellous bone cube. In panel a, the loading platens are slightly misaligned with the specimen. This causes a stress concentration at the right edge of the specimen, leading to inaccurate results. In panel b, a pivoting platen is incorporated into the load train to correct for the misalignment.

Fig 14 Compressive test of a bone cube (Turner and Burr, "Basic biomechanical measurements of bone")

Traits that describe the mechanical properties of bone as determined in the tests listed above, are bending moment, stress, moment of inertia, strain, modulus of elasticity and stiffness. These whole bone measurements are influenced by both the material from which the structure is composed (the tissue materials properties) as well as how and where that material is distributed (the geometric form of the tissue). Therefore, neither material nor geometry alone is sufficient to predict the structural failure load. They are independent of the size and shape of the bone. Therefore, when considering whole bone strength, the old saying that “bigger is better” is not always true.

- Bending moment is a measure of the amount of force withstood by the bone. Bending represents the type of force (compressive and tensile) and moment is the product of force and distance. Bending moment is measured in units of force and distance (kilograms-centimeters). Calculation of bending moment allows comparisons between bones of different lengths.
- Stress is a measure of force per unit area of bone. Stress cannot be measured directly, and must be calculated. Stress allows comparisons between bones that differ in size and shape.

The concepts of stress and strain are fundamental to bone biomechanics. Stress may be classified as compressive, tensile, or shear depending upon how loads are applied:

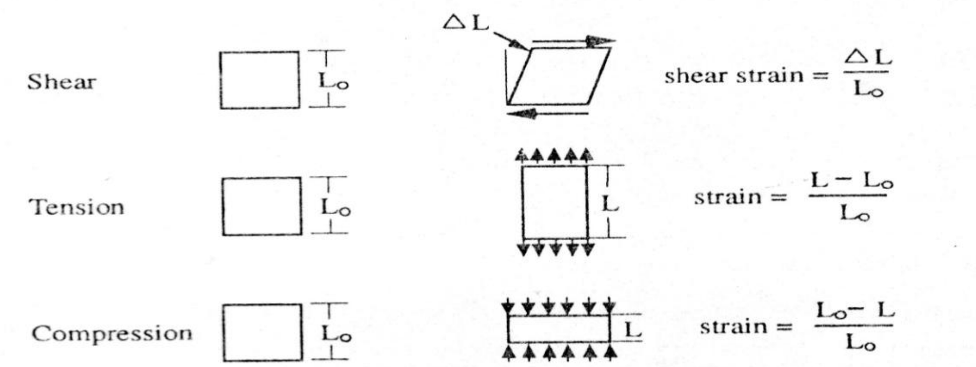


Fig 15 Different types of stress and strain (Turner and Burr, “Basic biomechanical measurements of bone”)

Compressive stresses are developed if loads are applied so that a material becomes shorter; tensile stresses are developed when the material is stretched. Shear stresses are developed when one region of a material slides relative to an adjacent region. Tensile, compressive and shear stresses invariably occur in combination, even under the most simple loading schemes.

- Strain is the measure of the amount of bending per unit of length that occurs as the bone is tested. Strain is unit less, as it is the change in length per unit length.
- The moment of inertia is a measure not only of the area over which the force is applied, but also of the shape in which the area is distributed. Bones are irregular in shape, so that become difficult the determination of this mechanical trait. Crenshaw *et al.* (1981) concluded that the femur of pigs could be closely approximated by definition of an ellipse.
- The modulus of elasticity is a measure of the degree of rigidity of the bone. The modulus of elasticity is determined from the linear portion of a stress: strain curve (Fig 15). The bone returns to its original shape after it has been deformed by a force.
- The structural stiffness is a measure of the resistance to deformation under the applied load.

The relationship between load applied to a structure and deformation in response to the load is called a load-deformation curve. The load deformation curve can be divided into two regions: the elastic deformation region and the plastic deformation region.

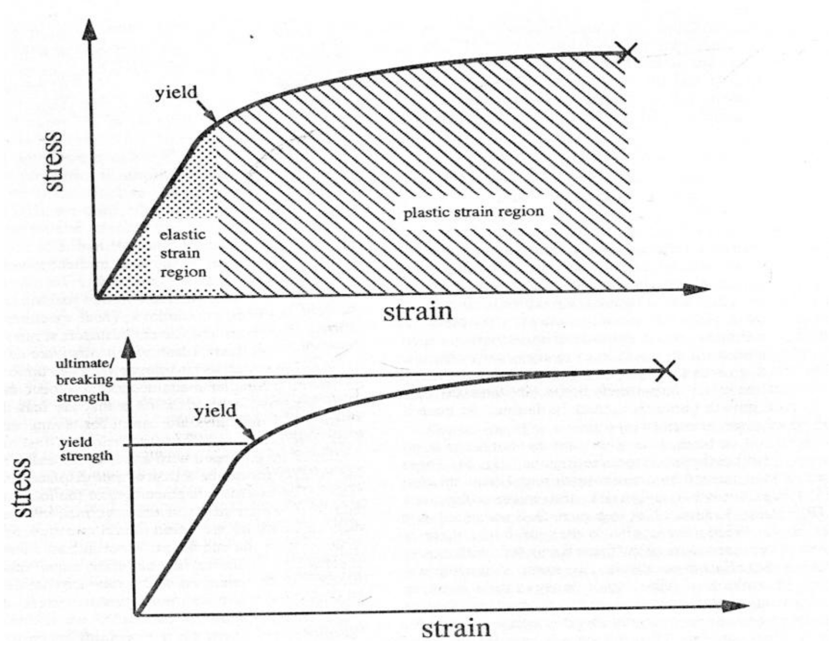


Fig 16 Top: Stress-strain curve divided into the elastic strain region and the plastic strain region. The x at the end of the stress-strain curve marks the stress and strain when fracture occurs. Bottom: Measurement of strength from the stress-strain curve. (Turner and Burr, “Basic biomechanical measurements of bone”)

Within the elastic deformation region the bone imitates a spring; the deformation in the bone increases linearly with increasing load, and after the load is released the bone springs back to its original shape. The slope of the elastic region of the load-deformation curve represents the extrinsic stiffness or rigidity of the structure. Bigger bone will typically have greater rigidity. The slope of the stress-strain curve within the elastic region is called the elastic or Young's modulus. The Young's modulus is a measure of the intrinsic stiffness of the material.

The bone, like other biological structures, has a "grain" or preferred direction. Because of this the Young's modulus varies with direction. The elastic strain region and the plastic strain region of the stress-strain curve are divided by the yield point. The yield point is an imaginary boundary, above which stresses cause permanent damage to the bone structure. This permanent damage is called plastic deformation. In reference the yield point, the elastic strain region is often called the pre yield region and the plastic strain region is the post yield region. A material that sustains very little post yield strain before fracture is brittle. The maximum stress the bone can sustain is called the ultimate strength, and the breaking strength is the stress at which the bone actually breaks. In bone the ultimate strength and the breaking strength usually have the same value, but this is not necessarily true in all materials. Bone in general is not a very ductile material and has little ability to sustain post yield deformation. The area under the stress-strain curve (i.e., the area of the elastic strain region plus the area of the plastic strain region) is a measure of the amount of energy needed to cause a fracture. This property of a material is called energy absorption, or toughness. Toughness is important in bone biomechanics because a tough bone will be more resistant to fracture, even though it may be less resistant to yielding. When a material is repetitively loaded, with loads within the pre yield region of the stress-strain curve, its mechanical properties gradually degrade over a period of time. This degradation of strength with time is called fatigue. In bone, the reduction in mechanical properties is attributed to the formation of small cracks within the bony structure.

The strength is an intrinsic property of bone. The bone strength is the load required to fail the whole bone and it is determined by a combination of bone size, shape, and materials properties (Van der Meulen MC et al., 2001). Bone density is expressed in a number of different ways, including areal bone mineral density from DXA and volumetric bone mineral density from OCT (commonly measured non-invasively) as well as ash density, apparent density, and tissue density or degree of mineralization (commonly measured directly in excised bone specimens). Another commonly used measure related to bone density and mass is bone volume fraction (BV/TV). Bone volume fraction is directly proportional to apparent density and can be used as surrogate measure of apparent density if one assumes variations in tissue are small. Measures of bone mass and density, such as dual-energy X-ray absorptiometry (DXA) measures of bone mineral content (BMC, g) and areal bone mineral density (aBMD, g/cm^2), explain a substantial portion of the effects of bone size, shape, and material properties and are strongly correlated with bone mechanical properties and fracture risk. But these measures do not completely explain fracture incidence. Furthermore DXA measurements have limitations such as repeatability, inability to differentiate cortical and trabecular bone and inaccuracies due to local soft tissue.

Variations exist in “bone breaking strength” data reported from different experiments with pigs of comparable age and nutritional background. This variation may be due to a lack of standardized test conditions or to a failure to use correct equations for calculating mechanical properties. Two factors that contribute to the lack of uniform testing conditions are : the variation in the types of instrument used to measure mechanical properties, and the variation in the procedures used to prepare the bones for testing.

The mechanical properties of bone vary according to the kind of bone being tested (e.g., cortical or cancellous), the age of the bone and anatomical location, and variations in the testing conditions.

For accurate testing results it is best to test bone in its hydrated condition. This can be done by keeping specimens in physiological saline or wrapped with saline soaked gauze during the test.

For accurate measurement of mechanical properties, bone specimens should be tested at 37°C. But, even testing at room temperature (about 23°C) does not change significantly the results of the test.

Freezing before testing does not affect the mechanical properties of bone, but changes in temperature at the time of testing may result in small changes in strength (Sedlin, 1965).

The anatomic part is also important for testing. Femur is a good indicator of bone development, that’s way it has been used instead of metacarpal bones for instance (Crenshaw et al., 1981).

However, much is still to be learned about what makes bone resistant to fracture.

6 Experimental data processing

6.1 Material used

6.1.1 Animals

Four different crossbreds of swine, of both sexes, in total twelve pigs of each crossbred, were used in this study: (*Finnish Landrace x Yorkshire) x (Duroc x Norwegian Landrace)*; (*Finnish Landrace x Yorkshire) x (Norwegian Landrace)*, (*Finnish Landrace x Yorkshire) x (Duroc)* and (*Finnish Landrace x Yorkshire) x (Hampshire).* The pigs have been raised in North European area, in a indoor-outdoor farming system. They had the same feeding (such as shown in table n. 2); feed and water were available *ad libitum*. The diet met the nutritional requirements of growing finishing pigs in Finland (MTT 2006). Then, the pigs were transported in a commercial abattoirs. On arrival, they were unloaded and driven in lairage pens having a capacity equivalent to a truck compartment. The pigs were hold there for 24 hours to recover from fatigue and stress; and they were provided with enough water to flush out intestinal pathogenic bacteria.

The pigs were slaughtered at the same age. The target slaughter weight of the pigs was 115 kg, while the carcass weight of pigs after slaughter was on average 84 ± 4.3 kg.

A femur from each pig of the four crossbreds was cut and sent to the University of Helsinki, at the laboratory of meat technology. So that, forty-eight femurs were obtained and they were used for this study.

6.2 Feeding and breeding background (diets used)

The composition of feed varied during the growth depending on the age of the pigs (Table 2). The feed contained barley, soybean, vegetable oil, L-lysine HCl, L-treonine, DL-methionine, calcium carbonate, monocalcium phosphate, mineral-vitamin-NaCl mixture.

These feeds are expressed such as an average, because they were given in different periods within weaning and growing/finishing breeding. For piglets of all the crossbreds raised, was used a weaning feed which had first a large amount of wheat, oat and soybean fraction; then was given mainly barley and soybean meal. During the growing period from the age of 70 days, was given a large amount of soybean meal; then, in finishing period till to the slaughter age, the soybean meal content was lowered, hence less protein was given to the pigs raised.

Feed costs represent about 75 percent of the total cost of producing pork. The ration fed determines to a large extent the health of the animals, their rate of gain, their productivity in breeding, their feed efficiency, the type of carcasses produced, and the profit from the swine enterprise.

The nutritional needs of pigs vary with age. The needs of breeding animals are affected by their condition at breeding time and by the stage of gestation or suckling period.

Hogs need carbohydrates and fats to provide heat and energy, and to produce lard. Carbohydrates are made up largely of sugars and starches.

Barley meal is the most important carbohydrate food and usually consists of 50% or more of the pig’s diet. Barley has a low oil and fibre content, and is rich in starch. It is considered better than oats as a fattening feed.

Wheat was given to the piglets as well. It may be included at up to 50% of the carbohydrate foods. Wheat is rich in vitamin B and is higher in protein than barley. Oat, like wheat, was given in the weaning feed only. Oats are of limited value in pig feeding due mainly to their low energy value and high fibre content when compared with either barley or wheat.

Table 2 Feed composition used in pig breeding

Diet offered	weaning feed	growing-finishing feed
Ingredients, %		
Barley	51.27	84.81
Wheat	48.44	-
Oat	7	-
Soybean protein fraction	6.49	-
Soybean meal	11.36	12.08
Whey protein WPC 75	4	1
Oil vegetable	1.61	0.24
L-Lysine HCl	0.16	0.05
DL-Methionine	0.025	0.09
Calcium carbonate	1.49	1.31
Monocalcium phosphate	1.17	0.75
Mineral-vitamin-NaCl mixture	0.4	0.4
Calculated nutrient composition		
Feed unit/kg, (FU/kg)	1.01	0.96

Crude protein, g/feed unit	150	127
Apparent ileal digestible amino acids, g/kg:		
- Lysine	9.5	7.5
- Threonine	5.85	4.57
- Methionine and cystine	5.6	4.4
Calcium, g/kg	8.5	7.3
Phosphorus, g/kg	6.4	5.6
Digestible phosphorus, g/kg	3.1	2.4
Vitamin A, IU/kg	4952	5203

Whey is a by-product of cheese making and is essentially a carbohydrate food. It is a highly digestible feed, mildly laxative and is usually fed “sour”. Twelve litres of whey being approximately equal in feeding value to 1 kg of barley meal. Hogs need proteins to develop muscles, body tissues, and offspring. Proteins are made up of a group of acids known as *amino acids*. Twenty-two or more amino acids have been identified; at least ten of these acids are needed by animals. Hogs are simple-stomach animals, hence they must be fed all the essential amino acids.

Feeds are divided into two groups: roughages and concentrates. Roughages are those feeds relatively high in fibre. Concentrates are the low-fibre feeds but with high content in protein. They are classified as vegetable or animal proteins depending upon the material from which they are made. Despite of the better amino acid balance essential that the animal proteins can be guarantee, the crossbreds raised for this project, were fed mainly with vegetable proteins as soybean meal. The soybean meal is the residue after the oil has been removed from imported soya beans. It has a crude protein content of around 38% , but the quality is low. The protein in soybeans is improved by the heating process used in the manufacture of soybean oil meal. Soybean is particularly rich in lysine, an essential amino acid and this makes it the most popular source of vegetable protein for pig rations. Other essential amino acids which have “biological value” were given to the hogs, such as methionine, cystine and threonine, because of their important effect for normal growth. Soybean meal is low in calcium, that’s way was added to the ration a mineral mixture as well. Salt, calcium and phosphorus, are needed in the greatest quantity than trace minerals as manganese, copper, potassium, etc, which are needed in small amounts. Legumes are high in both calcium and phosphorus. Calcium and phosphorus are directly involved in the growth and the formation of bone. In pig, one of the fastest growing animals, is required an adequate minerals support, for building a strong skeleton. Vitamins are included in the feed, too. They are complex substances which have no feeding value in themselves, but greatly help nutrients to function. An essential vitamin for pigs of all ages is vitamin A. A deficiency in young pigs will lead to poor growth, general un thriftiness, and may affect fertility and milking ability in breeding sows. Vitamin A is found in cod-liver oil, and may be manufactured by the pigs if they are fed green food containing carotene, such as dried grass. Water was given ad libitum. Water is important in controlling body temperature. Hogs must have an abundance of fresh, clean water if the best results are to be expected. In selecting feeds to include in swine rations it is always necessary to consider the following factors:

- availability
- cost
- nutritive value
- palatability
- ease of feeding

6.2.1 Pig nutrition and classification of feeds

MTT Agrifood Research Finland is Finland's leading research institute in the field of agricultural and food research and agricultural environment research. MTT has developed a mathematical growth model that takes account of the genetic growth potential of the Finnish pig. The growth model is used in a dynamic programming routine that simultaneously determines the most cost effective feeding strategy at each growth phase of the animals and their most profitable time of slaughter. In addition to porcine genetic growth potential, the model takes account of quality adjusted feed prices, quality adjusted producer prices for pork meat, piglet prices, and the subsidy rates. The growth model was incorporated into an economic optimization model, since the best feeding strategy in terms of biological growth does not necessarily result in the highest net return for the grower. Feeding adapted to the genetic growth potential of pigs is both economically and environmentally sound. An animal with a nutrient supply that matches its growth potential will utilize the ingested nutrients effectively and will not generate an environmental load in the form of excessive nitrogen excretion. On the other hand, not even the best feed will be able to get pigs to produce muscle growth beyond their potential.

MTT: Analysis of body growth links feed costs to carcass value

The various pig breeds each have different growth potential, and even different breeding lines within the same breed may differ from one another in this respect. The MTT study experimentally determined the growth rate and the chemical composition (proteins, water, fat and ash) of the body growth of the Finnish growing-finishing pig stock. The composition was measured at two life stages, i.e. as a piglet and as a slaughter pig. The growth potential was represented by means of the Gompertz function (*[1]). The Gompertz function was fitted to the weekly weighing data specific to each pig. This gave an overall view of the variation between individuals, in addition to the mean of the curve parameters. Knowledge of the variation will assist in predicting the actual growth rate of different individuals, the value of the carcass, and the cost-effectiveness of feeding. In fitting the parameters of the growth curve, the body growth composition of the pigs was also taken into account. With *ad libitum* feeding, the different components for an individual pig followed their own Gompertz functions, which have a common maturity ratio.

*1 : Reported in citation.

Sampling and specimen preparation

In this current study, forty-eight femurs, randomly assigned, were collected from four different crossbreds.

Fig 17 Bone femur of swine, weighting about 500 g

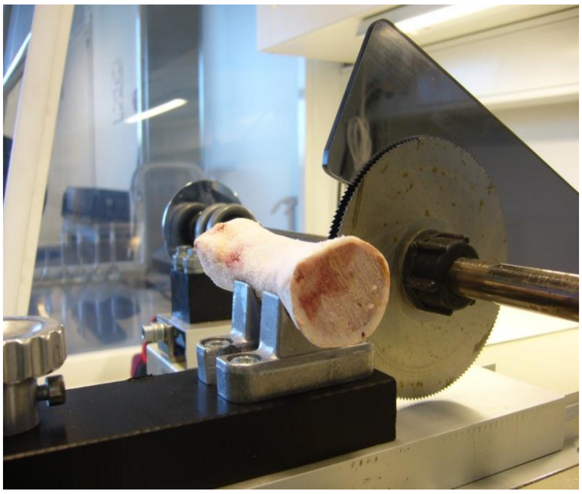
Thanks to a kind help of a meat laboratory technician of University of Helsinki, the heads of the femurs were removed by commercial band saw and kept the thinnest part of them (the *diaphysis*).



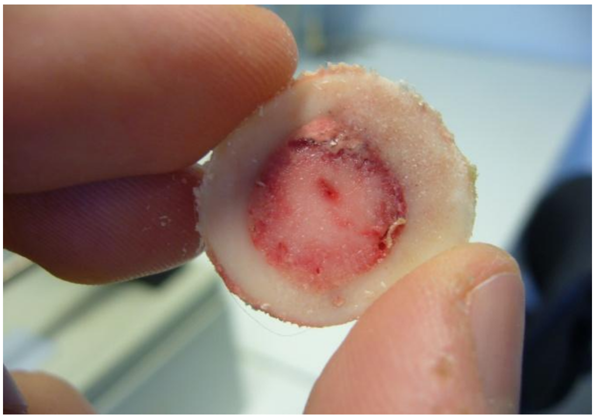
All the femur bones were cleaned from muscle and fat by knife, having a kind assistance of Mr. Jorge de Miguel Lopez, Erasmus student from Spain. The femurs were weighted using technical balance (d ± 0,1 g).

Care was taken to not ruin the bone structure, removing the fat and muscles still attached to the bone.

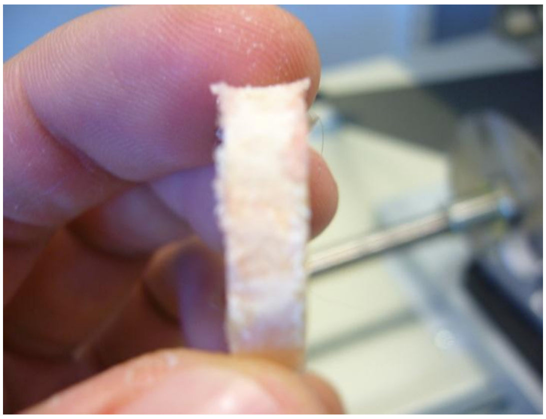
Then, two rings (thickness on average 6 mm) were sawed from each femur bone by double blade laboratory saw (rotaring blades, the instrument has been constructed for this particular purpose at the Department). It was instrumental that the speed of rotating blades was low enough so that the temperature of the bone did not increase markedly during sawing.

The rings were cut from the shaft of the femur, at both sides of the middle of *diaphysis*. It has been used a calliper and took the thinnest part of it. The femur rings were kept in plastic bags with some drops of NaCl 0,9 %, in freezer at minus 18 Deg C. That was necessary to avoid rings getting dry. After thawing, the rings were weighted using technical balance (d ± 0,1 g).



The central part (meat) of the ring was then removed



The thickness of the rings. About 6 mm

7 Methods used

7.1 Lunar Piximus densitometer analysis

The pair of rings obtained from each femur of crossbreds, were analysed first by bone density measurements. The Bone Mineral Content (BMC, g), the areal Bone Mineral Density (aBMD, g/cm^2) and the Femur Ring Area (cm^2) were measured. They were measured from the femur rings by scanning all of them by *Dual-energy X-ray absorptiometry* (DXA), using a *Lunar PIXImus 2 densitometer* (software version 1.42.006.010; Lunar Corporation, Madison,WI). DXA analysis is widely used for studies to measure bone mineral density (BMD in g/cm2) and body composition, because of its excellent precision, low radiation dose, and high speed. The short-term CV (coefficient of variation) for bone mineral density (BMD) measurements is about 1% .

First, the Piximus densitometer, with its attached computer and printer, was turn on and it needed a quick setup and calibration. But, if the machine was moved, then was needed to perform the field calibration which takes about 60 minutes.

The calibration was done using a “phantom mouse” (a tray such as the specimen). It was put in the designated spot and the measurement of quality control phantom was performed. Quality control had to be performed daily. It took about 4-5 minutes. Then, was needed to check up that the values of the phantom were right. They should be 0,0748 g/cm^2 (BMD) and 12.1 % (% fat). If the control test was passed, the densitometer was ready to begin the measurements of samples, otherwise if it said failed was needed to start the control quality all over again (Fig 18). If it still didn’t work, was needed to run a full calibration. Afterwards, the measurements of the samples were done.

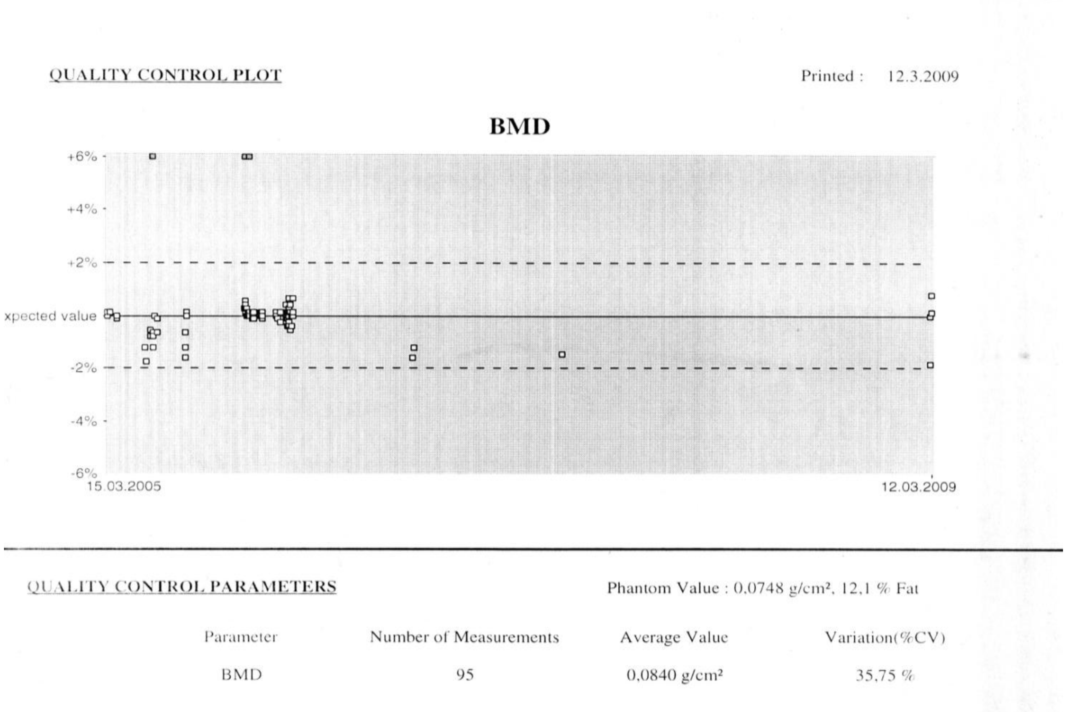
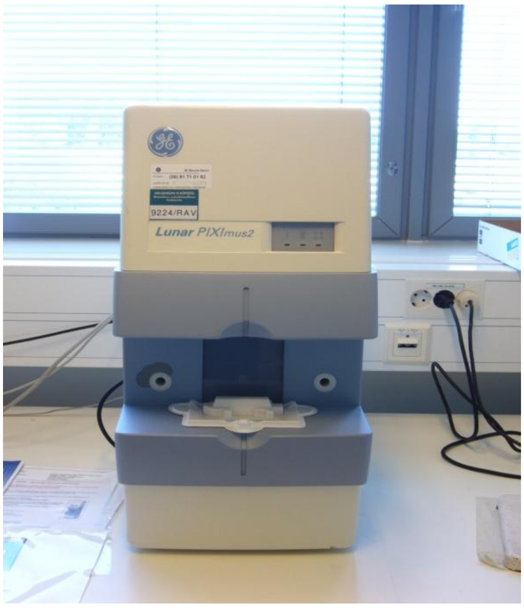
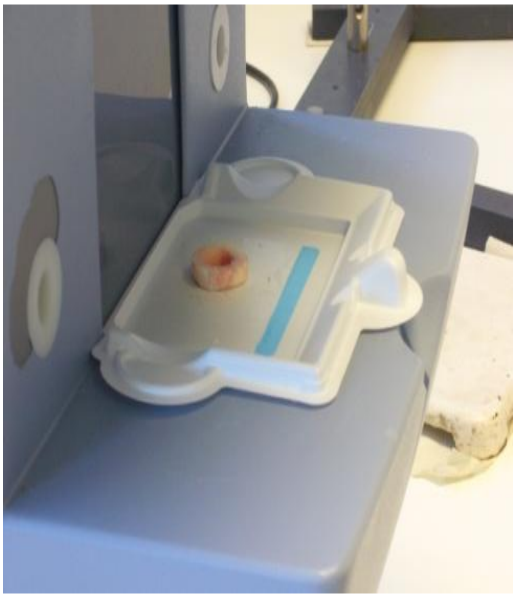


Fig 18 . An example of quality control calibration before the measurement of the sample.

First was added on the main screen of the program some information about each sample (a ring of bone) measured, such as the crossbred, the sex and the weight of it. Then, the sample was put on the sticky tray. Care was taken that it stayed within a blue line, which delimited the area of the analysis. When the measurement was began, x-rays are generated. A collimator directs the x-rays through the subject to the detector, where an x-ray screen and CCD (charge coupled device) camera detect the radiation. The detected radiation is digitally processed, and an image is displayed on the monitor. The measurement took 4-5 minutes.





During the measurements, so when the x-ray unit was active, was safe to maintain a distance of two metres from Lunar Piximus to reduce the radiation exposure. Moreover, was put a radiation exposure badge on the door during procedure.

7.2 Geometrical measurements using by Carl Zeiss program

After the bone mass measurement, the dimensions of the rings were taken. The geometrical parameters like the min, max and mean values of wall thickness, the Bone Sectional Area (cm^2), Feret min (mm) and Feret max (mm) of the rings were measured with an image analysis system using a computer program (KS300, Carl Zeiss Vision GmbH, Hallbergmoos, Germany) attached to an AxioCam MR colour camera using a magnification of 50 mm. Before start with the measurements, was done a geometrical calibration with a blank sheet, taking the area and perimeter of it.

Once the snap of the femur rings were taken, they were analyzed using the grapfic program Carl Zeiss. The mean of the geometrical parameters:

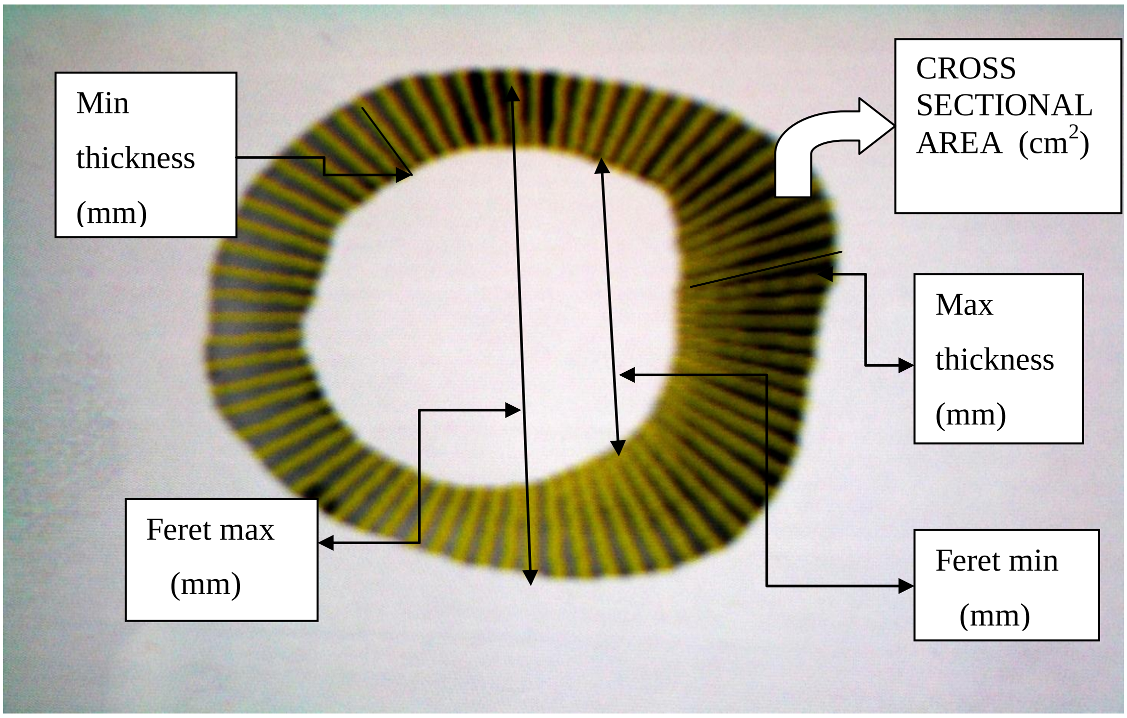
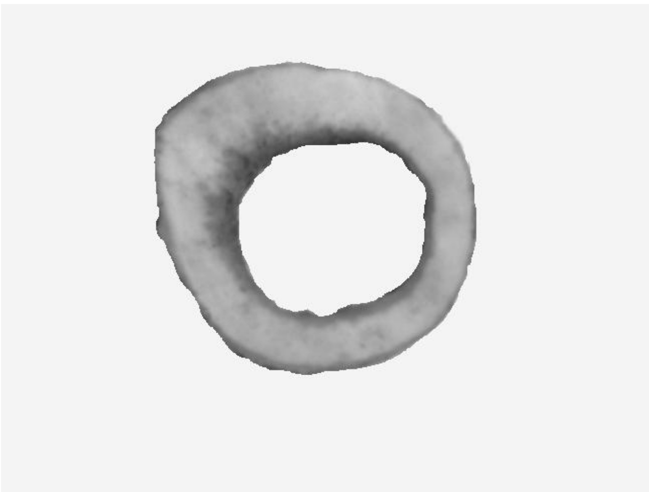


Fig 19. A femur ring bone and its main geometrical parameters

This was a typical ring analysed with Zeiss program (Fig 19). First, each ring was put on a blank sheet in background, and with the camera a picture of it was taken. Then, the Carl Zeiss program calculated the min, max and mean thickness of the rings automatically. Two different kinds of calibrations to determine the geometrical parameters were used, but this pattern doesn't have any influence on the crossbreds and their interaction differences. If needed, was possible to enhance the picture, modifying for instance the contrast, the threshold, automatically. After all measurements of thickness, each ring was saved with an identified number. As we can see, the rings of femur were not circular, they seem somewhat like an ellipsoidal-shaped structure. Therefore, other geometrical parameters were introduced to define them, such as the measures of the Feret minimum and Feret maximum, respectively, the shortest and the longest distance in a femur ring. They are expressed in *mm*. Feret min and max were represented in an histogram with the bone thickness program created by Prof. Eero Puolanne. So, the Feret min and max are different from the min and max values of the rings, that are regarding the thickness of the femur rings. The last geometrical parameter analysed was the cross sectional area. To obtain the cross sectional area value, was used a graphic tool thanks to the Carl Zeiss program, with whom the external and internal part of the ring was merged and removed. The snap of each ring was so modified, having now a blank background (as shown in fig n.?) and the black ring clear. These samples were saved in another way to make a difference from the previously data of the same rings. The cross sectional area is hence different from the area obtained by using densitometer, because the latter means the total area of the femur ring (external plus internal part), instead of the cross sectional which means the area of each ring less the middle part.



(Fig 20). A femur ring of Finnish landrace crossbreed. Sex: male. Was used a tool to merge and remove the external part and internal part around the ring to obtain the cross area.

7.3 Compression test using by Instron

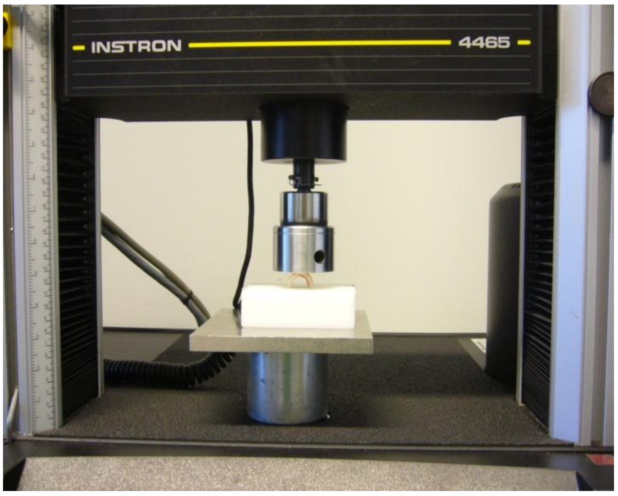
Then, the min and the max value at both sides of the rings were taken using a calliper. This was necessary to have measures of the thickness at both different sides of the ring (that has an ellipse shape).

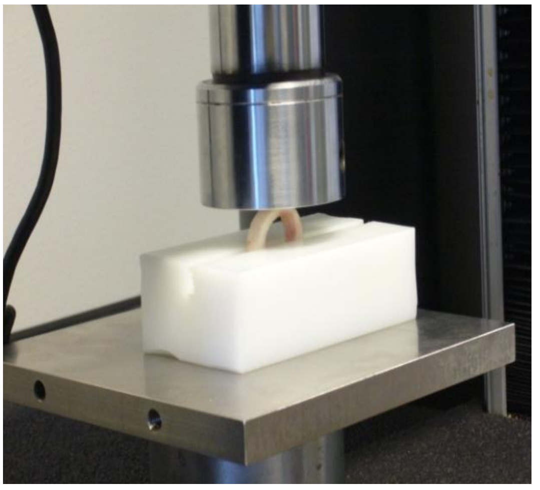
Afterwards the rings were broken with *Instron Device* (Instron 4465 H 2237, capacity 5 N, weight 286 LB - 130 kg ; Instron Ltd, UK) to measure the strength of bone femur ring.

The compression test was done using standard parameters such as: 25 Deg C of temperature, 50 % of humidity, 5 mm/min of crosshead speed and 5 N of machine power. The maximum force required to break the ring of bone was recorded (femur ring strength, N). Setup and calibration of the machine was done before start each analysis.

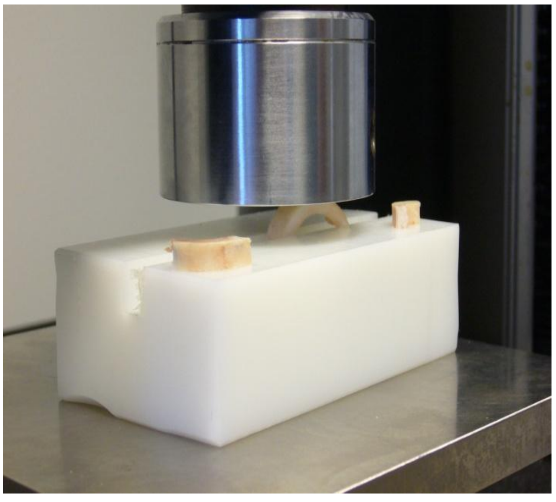
Control panel of Instron Machine. Setup and calibration modality

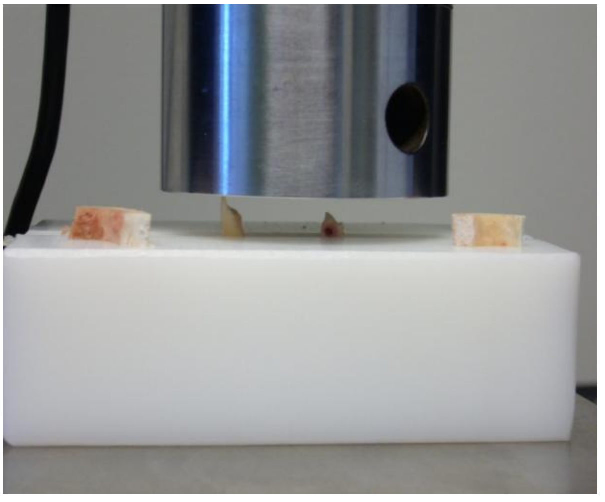
The Instron machine was located in a different laboratory than those in which was performed the bone mass and geometrical analysis. The Instron machine was controlled with PC driven software Instron Series IX and attached with a printer, too. First the calibration of the system was done. The first step was reset the system. Then, switch on the right side and hit the calibration button. The warm up needed about thirty minutes. Then the sample test could begin. Each ring was first well positioned in a tray, ready for the breaking action of the Instron. The sequence of breaking rings was like following :





The tray (called commonly “end-block”) was built right for this experiment. It may keeps the ring in a good way, in neither narrow or wide position. The displacement of the crosshead platen was regulate to be close to the ring.





So, the specimen was compressed and deformation at various loads was recorded. The crosshead adapter used was designed to be centered on the loading axis of the Instron test machine load frame. Plane compression platens were available in a range of diameters.
As shown, the breaking was clear to see even if the peak of maximum load and peak of real breaking was often quite similar and different to differentiate. On average the single test took each one 3 minutes, after that the broken ring was removed.

A graphic from software was elaborated in which the peaks were represented, with different displacement and load strain for each ring of femur sample (Fig 21). The compressive strength is the maximum stress a material can sustain under crush loading. The compressive strength of a material that fails by shattering fracture can be defined within fairly narrow limits as an independent property. Compressive strength is calculated by dividing the maximum load by the original cross-sectional area of a specimen in a compression test.

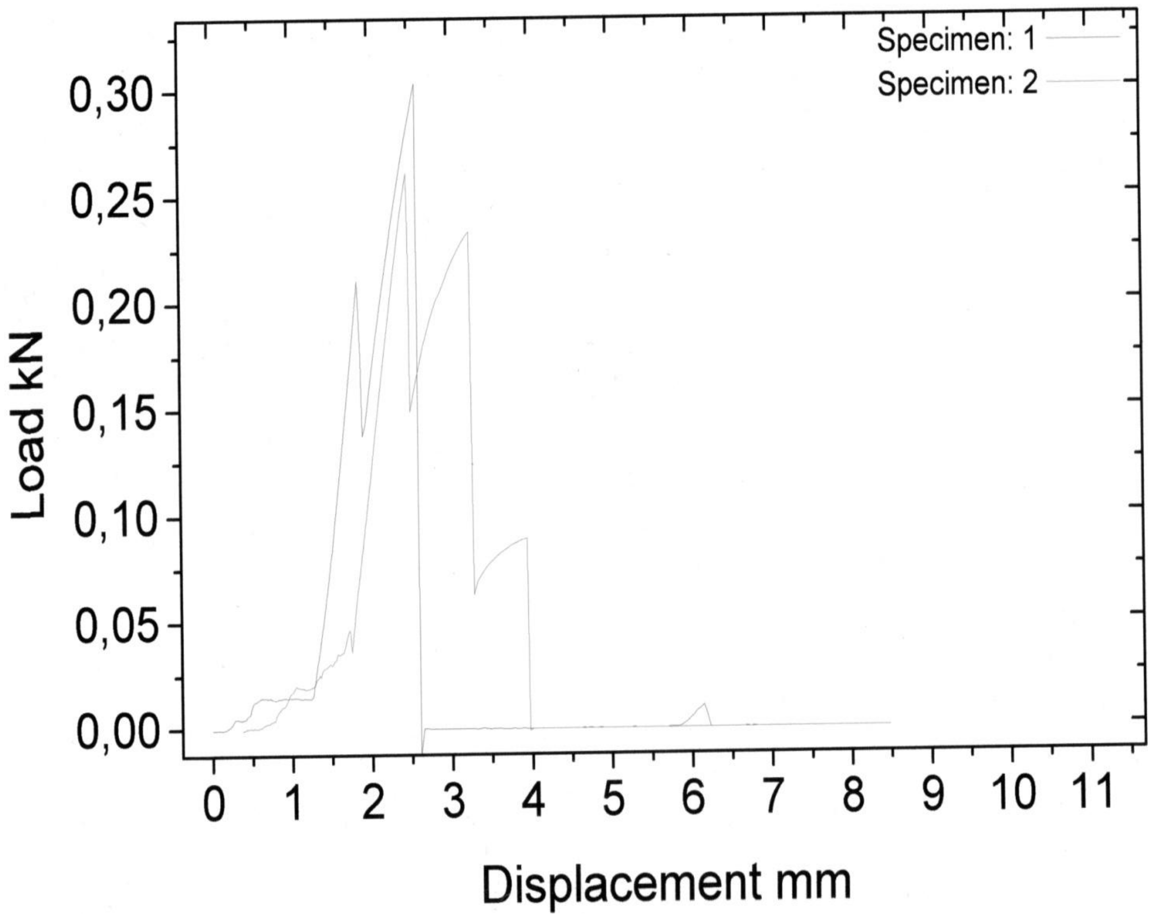


Fig 21. A graphic elaboration from Instron software. The breaking moment of two specimens (bone rings), of the same swine femur, is shown.

8 Results

The effects of breed, sex and their interactions, on each of the mechanical bone parameters from the 96 femur ring bones are reported in Table 3.

Table 3 . Effects of crossbred and sex on bone parameters

	Crossbred (C)				Sex (S)		Significance			RSD
	D	H	FL	NL	M	F	C	S	C*S	
Minimum ring side, cm	0.500	0.498	0.502	0.499	0.499	0.500	0.972	0.810	0.599	0.019
Maximum ring side, cm	0.520	0.513	0.525	0.518	0.513	0.525	0.505	0.060	0.159	0.022
Ring weight, g	2.92	2.90	3.05	3.14	2.93	3.08	0.223	0.109	0.800	0.33
Ring Area, cm^2	3.99	3.97	4.17	4.27	4.02	4.18	0.170	0.186	0.637	0.39
BMC(1), g	1.93	1.92	2.00	2.05	1.94	2.01	0.369	0.261	0.865	0.21
BMC/ring weight	0.663	0.663	0.656	0.653	0.664	0.653	0.144	0.007	0.387	0.013
BMD(2), g/cm^2	0.485	0,485	0,480	0,480	0,483	0.482	0.875	0.904	0.668	0.022
Min thickness, mm	3.65	3.85	3.67	4.01	3.82	3.77	0.300	0.718	0.899	0.53
Max thickness, mm	7.75	8.06	7.81	7.91	7.61	8.16	0.887	0.060	0.317	0.98
Mean thickness, mm	5.45	5.65	5.51	5.73	5.45	5.72	0.548	0.0877	0.957	0.53
Feret Minimum, mm	24.0	24.1	24.7	25.1	24.4	24.6	0.0999	0.508	0.750	1.2
Feret maximum, mm	27.9	27.2	28.2	28.3	27.6	28.2	0.300	0.263	0.164	1.6
Cross-Sectional Area, cm^2	3.22	3.25	3.36	3.48	3.25	3.40	0.309	0.173	0.690	0.37
Break Strength, N	33.9	34.0	33.3	34.0	33.0	34.5	0.992	0.516	0.111	8.4

Breed: D = Duroc ; H = Hampshire ; FL = Finnish Landrace ; NL = Norwegian Landrace
Sex: M = male ; F = female;
Significance: P<0.01
RSD: Residual Standard Deviation
(1) Bone Mineral Content

(2) Bone Mineral Density

In this study were taken into account geometrical and mechanical parameters for the bone strength evaluation of four different pig genetic types (crossbreds). First, were weighted the bone femur rings and were compared between the crossbreds. Femur ring weight was on average 3.0 g. There were no significant differences between pig crossbreds for the femur ring weight parameter ($P \geq 0.05$). Then, were measured the bone mass parameters such as bone mineral content (BMC), bone mineral density (BMD) and the femur ring area. As shown in the table above, there were no significant differences ($P \geq 0.05$) neither between crossbreds or within sex for these parameters analyzed. Anyhow, another parameter was evaluated, the bone mineral content (BMC) expressed to the ring weight; it showed a significant difference ($P \leq 0.01$) between sexes.

The geometrical measurements were performed as well. Min, max and mean thickness were evaluated first; femur wall thickness was on average 5.75 mm ranging from 2.65 to 10.36 mm. Anyhow, there were no significant differences (P ≥ 0.05) neither between crossbreds or within sex for these geometrical parameters individually analyzed. Although, the max thickness parameter of each femur ring was slightly no significant within sex for the pig crossbreds. The maximum and minimum distance (Feret parameter), and the cross sectional area of the femur rings were measured as well. The femur ring area was on average 4.10 cm^2, but the variation was large ranging from 3.27 to 4.97 cm^2, although the pigs were slaughtered at the same age. Instead, the cross sectional area was on average 3.33 cm^2, ranging from 2.63 to 3.95 cm^2. Anyhow, there were no significant differences (P ≥ 0.05) neither between crossbreds or within sex for the geometrical parameters analyzed. At the end, the compression force was tested in each pig femur ring analyzed. The ring measures were taken using a calliper, before to proceed with the compression test. There were no significant differences (P ≥ 0.05) neither between crossbreds or within sex in both maximum and minimum side of each ring measured. Although, the max side of the femur rings was slightly no significant within sex for the pig crossbreds.
There were any significant differences (P ≥ 0.05) neither between crossbreds or within sex for the breaking strength parameter.

The effects of breed, sex and their interactions, on carcass traits and on back leg parameters are reported in Table 4.

Table 4. Effects of crossbred and sex on carcass traits and on back leg parameters

	Crossbreed (C)				Sex (S)		Significance			RSD
	D	H	FL	NL	M	F	C	S	C*S	
Carcass weight, kg	84.6	82.3	85.2	83.5	84.2	84.0	0.584	0.937	0.853	4.5
Femur weight, g	499^{a}	520^{ab}	538^{ab}	523^{b}	522	519	0.043	0.830	0.971	34
Whole Ham, g	12398	12246	12932	12479	12400	12650	0.159	0.241	0.698	788
Ham Meat, g	8539	8392	8943	8604	8488	8770	0.117	0.088	0.583	587
Ham Skin, g	717	735	714	729	709	739	0.954	0.305	0.053	94
Ham Fat, g	1463	1410	1402	1400	1440	1395	0.960	0.623	0.777	329
Ham Bones, g	1670	1687	1780	1731	1705	1732	0.234	0.459	0.510	142
Ham MSF/bone(1), g	6.47	6.25	6.23	6.22	6.26	6.32	0.472	0.673	0.357	0.43
Femur weight/Tot.bones, %	30.9	31.1	30.5	31.0	30.9	30.8	0.915	0.898	0.775	1.9
Ham losses, g	-504	-501	-450	-520	-470	-517	0.503	0.173	0.411	111
Ham MSF/Carcass wt(2), %	12.7	12.7	13.0	12.9	12.7	13.0	0.588	0.109	0.415	0.8
Whole Ham/Carcass wt(3), %	29.3	29.6	30.5	29.9	29.5	30.2	0.359	0.166	0.635	1.7

a,b : P<0.05

Breed: D = Duroc ; H = Hampshire ; FL = Finnish Landrace ; NL = Norwegian Landrace
Sex: M = male ; F = female;
RSD: residual standard deviation
(1) Ham meat-skin-fat/bone

(2) Ham MSF/Carcass weight

(3) Whole Ham/Carcass weight

The carcass evaluation was performed as well to better understanding the bone strength of four different pig genetic types. These values of body conformation and composition of 49 pigs were given directly from the slaughterhouse. All of these carcass traits evaluated were no significant different (P ≥ 0.05) neither between the pig crossbreds or within sex, except the femur weight parameter. It was significant different (P ≤ 0.05) compared between four pig genetic types. This highlight the different bone conformation, especially on the femur hind leg, of the four crossbreds used in this study. Finnish Landrace show the biggest value of femur weight while Duroc show the smallest one. Hampshire and Norwegian Landrace had similar value of femur weight. The femur weight in the bone content was on average 30,9 %.

Pearson correlations was performed on all the bone parameters evaluated (Table 5; Graphic 1).

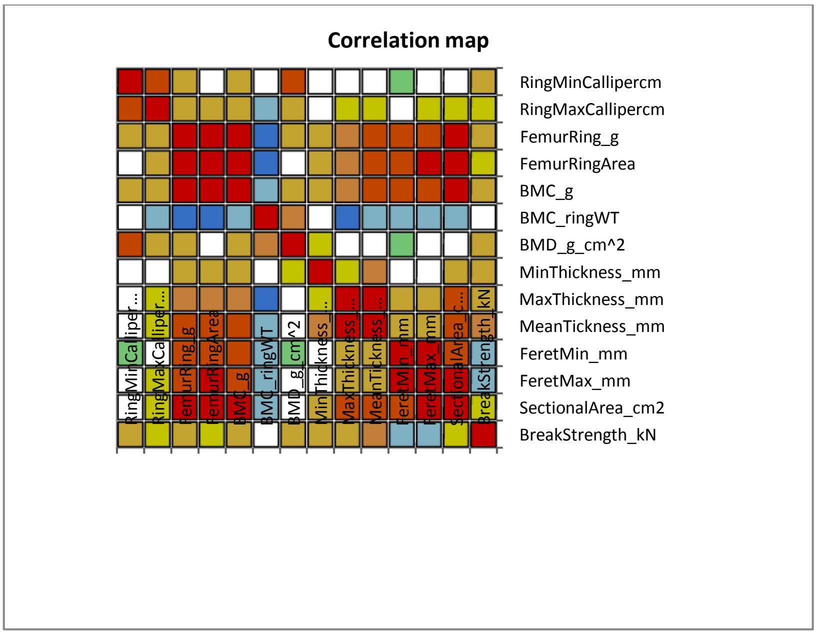
Table 5. Pearson correlations of bone parameters

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.000													
2	**0.656*** **	1.000												
3	0.214	**0.351***	1.000											
4	-0.019	0.201	**0.941*** **	1.000										
5	0.234	**0.318***	**0.981*** **	**0.915*** **	1.000									
6	0.034	-0.262	**-0.406**	**-0.415**	-0.225	1.000								
7	**0.637*** **	**0.332***	0.237	-0.067	**0.339***	**0.404****	1.000							
8	0.042	0.030	**0.301***	**0.287***	**0.322***	-0.004	0.125	1.000						
9	0.083	0.169	**0.573*** **	**0.589*** **	**0.519*** **	**-0.415**	-0.078	0.154	1.000					
10	0.054	0.200	**0.737*** **	**0.740*** **	**0.704*** **	**-0.385**	0.024	**0.499****	**0.822*** **	1.000				
11	-0.141	0.007	**0.654*** **	**0.737*** **	**0.622*** **	**-0.365**	-0.167	0.039	0.227	**0.287***	1.000			
12	-0.004	0.105	**0.781*** **	**0.840*** **	**0.771*** **	**-0.296**	-0.046	0.054	**0.365****	**0.384****	**0.804*** **	1.000		
13	-0.001	0.168	**0.916*** **	**0.957*** **	**0.895*** **	**-0.387**	-0.005	**0.358***	**0.603*** **	**0.790*** **	**0.758*** **	**0.823*** **	1.000	
14	0.246	0.151	0.208	0.116	0.222	-0.004	0.271	0.251	**0.381****	**0.530*** **	-0.241	-0.220	0.143	1.000

*: P<0.05 ; **: P<0.01 ; ***:P<0.001

Variables

1 Min ring side,cm (minimum side of bone ring using a calliper)
2 Max ring side, cm (maximum side of bone ring using a calliper)
3 Ring weight, g (femur ring weight)
4 Ring Area,cm^2 (ring area obtained using densitometer)
5 BMC,g (bone mineral content)
6 BMC/ring weight (bone mineral content per ring weight)
7 BMD, g/cm^2 (bone mineral density)
8 MinThickness,mm (minimum thickness)
9 MaxThickness,mm (maximum thickness)
10 MeanTickness,mm (mean thickness)
11 FeretMin,mm (minimum distance in femur ring)
12 FeretMax,mm (maximum distance in femur ring)
13 Cross-Sectional Area, cm^2 (cross sectional area of femur ring)
14 Break Strength, N (breaking strength capacity of femur ring)



Graphic 1. Correlation map of bone parameters

- Red lightening means high correlation between the parameters
- Orange lightening means lower than high correlation between the parameters
- Blue, light blue, dark green mean intermediate level between high and low correlation
- Green lightening means low correlation between the parameters
- White lightening means no correlation between the parameters

The minimum side of each ring (calculated using a calliper) measured was strongly correlated with the maximum side (r=0.656) and with the bone mineral density (r=0.637) of each ring. This means that the minimum side of ring increases in proportion to the maximum value and to the bone mineral density of the same ring. The femur ring weight was strongly correlated with ring area (r=0.941; Figure 22) and the bone mineral content (r=0.981; Figure 23). This means that the femur ring weight increases in proportion to the ring area and to the bone mineral content.

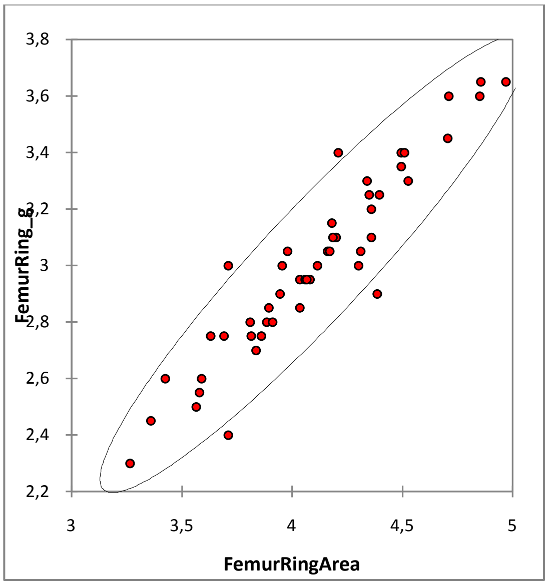


Fig 22. Ring weight correlated with ring area

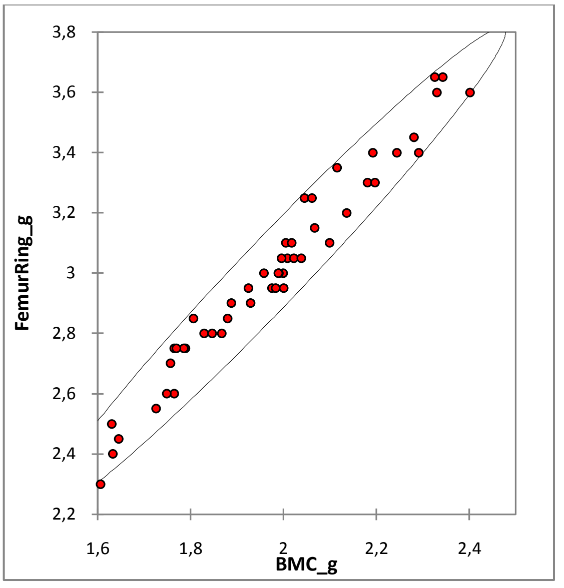


Fig 23. Ring weight correlated with BMC

The femur ring weight was also strongly correlated with max thickness (r=0.573), mean thickness (r=0.737), Feret minimum (r=0.654), Feret maximum (r=0.781) and with the cross sectional area (r= 0.916). But the femur ring weight was negatively correlate with the bone mineral content divided by the ring weight (r= -0.406); this means that the femur ring weight decreases in proportion to bone mineral content/ring weight increase.

The ring area (obtained using a densitometer) was strongly correlated with the bone mineral content (r=0.915). This means that the ring area increases in proportion to the bone mineral content. The ring area was also strongly correlated with max thickness (r=0.589), mean thickness (r=0.740), Feret minimum (r=0.737), Feret maximum (r=0.840) and with the cross sectional area (r= 0.957; Figure 24).

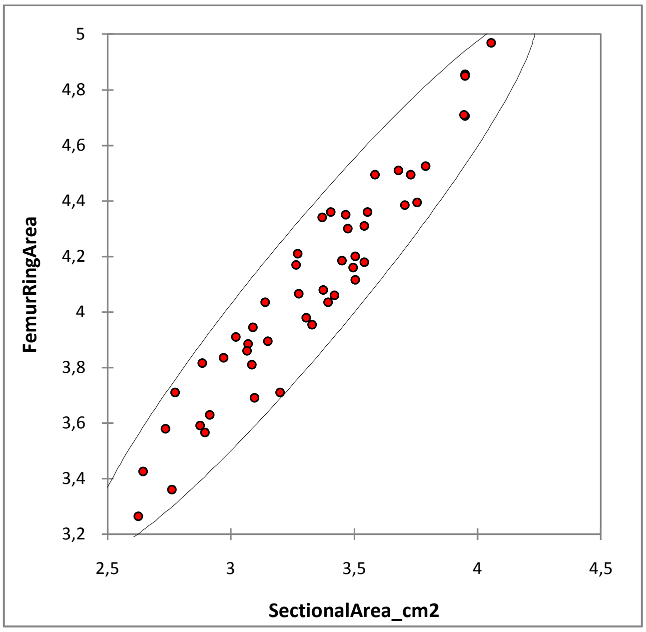


Fig 24. Ring area correlated with cross-sectional area

But the ring area was negatively correlate with the bone mineral content divided by the ring weight (r= - 0.415); this means that the ring area decreases in proportion to bone mineral content/ring weight increase.

The bone mineral content (obtained using a densitometer) was strongly correlated with max thickness (r=0.519), mean thickness (r=0.704), Feret minimum (r=0.622), Feret maximum (r=0.771) and with the cross sectional area (r= 0.895).

The bone mineral content/ring weight was negatively correlated with max thickness (r=-0.415), mean thickness (r= -0.385), Feret minimum (r= -0.365), Feret maximum (r= -0.296) and with the cross sectional area (r= -0.387; Figure 25).

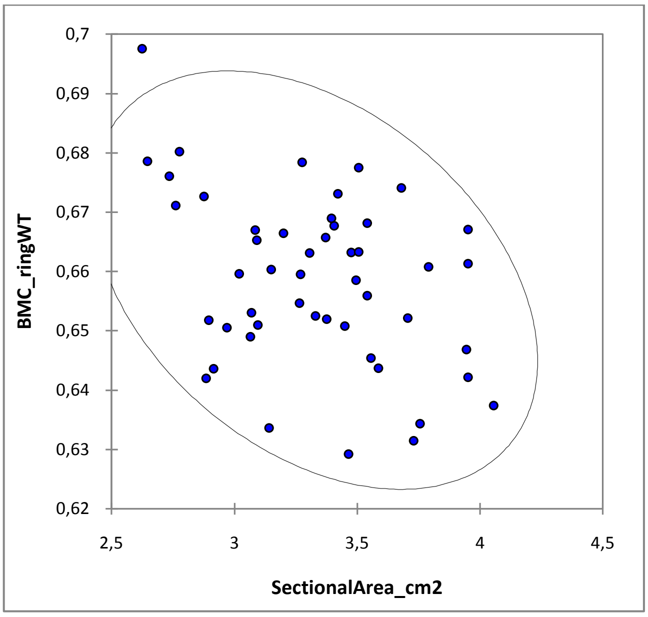
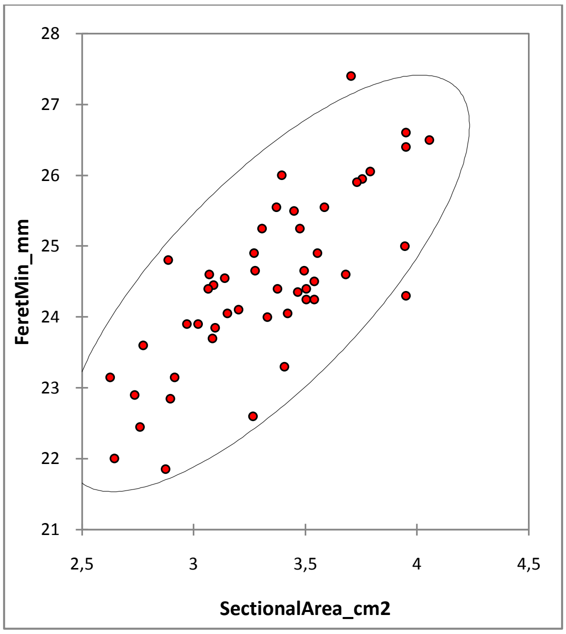


Fig 25. BMC/ring weight correlated with cross sectional area

The maximum thickness (obtained using Zeiss program) was strongly correlated with the mean thickness (r=0.822) and sectional area (r=0.603). The max thickness was also correlated with the the breaking strength (r=0.381). This means that the max thickness increases in proportion to the breaking strength increase.

The Feret minimum (obtained using Zeiss program) was strongly correlated with the Feret maximum (r=0.804; Figure 27) and the sectional area (r=0.758; Figure 26). This means that the Feret minimum increases in proportion to the Feret maximum and to the sectional area increase.



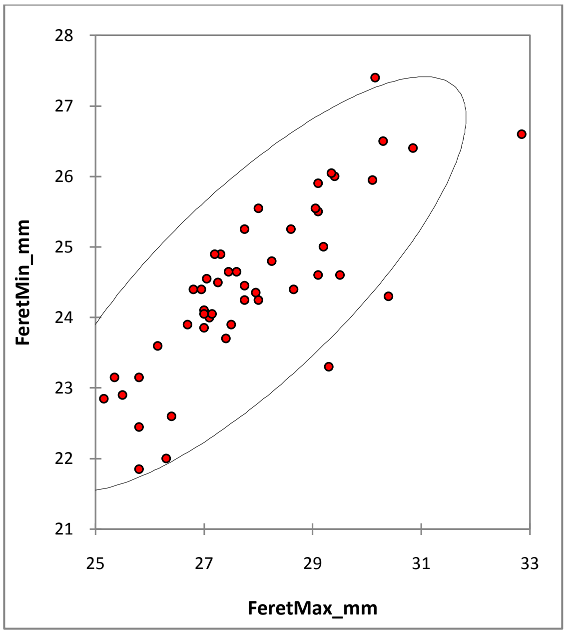


Fig 26. Feret min correlated with sectional area

Fig 27. Feret min correlated with Feret max

Pearson correlations was performed on all the carcass traits evaluated (Table 6; Graphic 2).

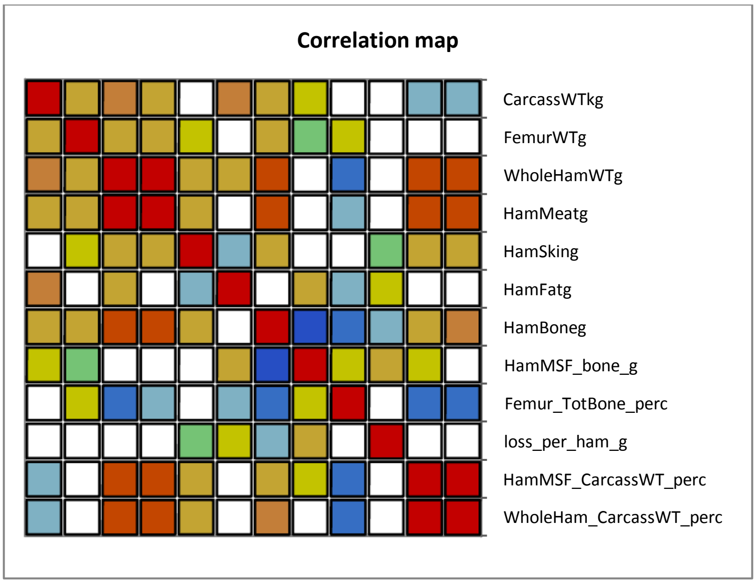
Table 6. Pearson correlations of carcass parameters

Variables	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000											
2	0.281	1.000										
3	**0.535*** **	**0.308***	1.000									
4	**0.387****	0.277	**0.912*****	1.000								
5	0.007	0.127	0.249	**0.306***	1.000							
6	**0.417****	0.008	**0.310***	-0.051	**-0.332**	1.000						
7	**0.293***	**0.334***	**0.686*****	**0.664*****	0.205	-0.063	1.000					
8	0.142	-0.182	0.072	0.031	-0.004	**0.399****	**-0.667**	1.000				
9	0.004	0.120	**-0.427**	**-0.321**	-0.041	-0.258	**-0.474**	0.194	1.000			
10	0.048	-0.039	0.052	-0.093	-0.167	0.177	-0.272	**0.299***	-0.041	1.000		
11	**-0.298**	0.027	**0.623*****	**0.665*****	0.277	0.046	**0.386****	0.121	**-0.467**	-0.063	1.000	
12	**-0.301**	0.074	**0.643*****	**0.675*****	0.265	-0.010	**0.495****	-0.029	**-0.493**	0.015	**0.979*****	1.000

*: p<0.05 ; **: p<0.01 ; ***:p<0.001

Variables

1	Carcass weight, kg	(carcass weight)
2	Femur weight, g	(femur weight)
3	Whole Ham weight, g	(whole ham weight: steak+meat+trimming)
4	Ham Meat, g	(ham-meat)
5	Ham Skin, g	(ham-skin)
6	Ham Fat, g	(ham-fat)
7	Ham Bones, g	(ham-bone)
8	Ham MSF/bone, g	(ham :meat+skin+fat per bone)
9	Femur/Total Bones, %	(femur per total bone)
10	Ham losses, g	(loss per ham during slaughter process)
11	Ham MSF/Carcass WT, %	(ham:meat+skin+fat /carcass weight)
12	Whole Ham/Carcass WT, %	(whole ham/carcass weight)



Graphic 2. Correlation map of carcass traits

The carcass weight was strongly correlated with the whole ham weight (r=0.535). This means that the whole ham weight increases in proportion to the carcass weight increase. The carcass weight is also correlated with the ham meat (r=0.387) and the ham fat (r=0.417; Figure 28).

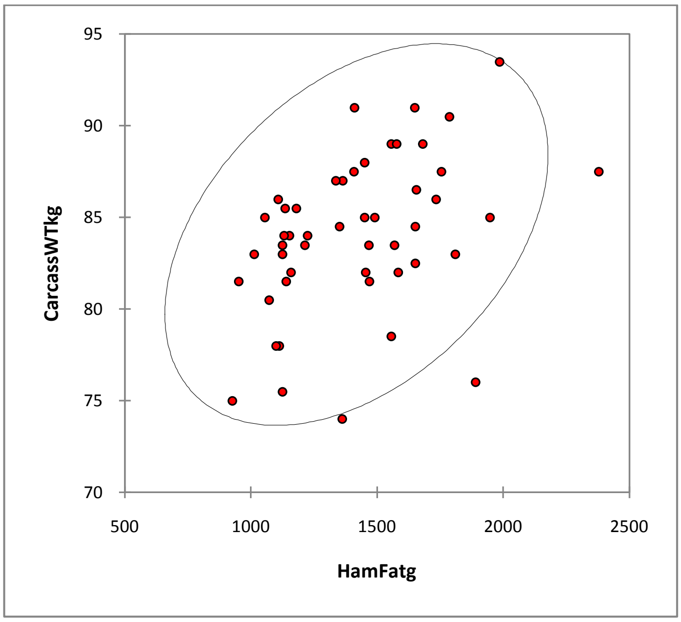


Fig 28. Carcass weight correlated with ham fat

The whole ham weight was strongly correlated with the ham meat (r=0.912), the ham bone (r=0.686; Figure 29), the ham MSF/carcass weight (r=0.623) and the whole ham/ carcass weight (r= 0.643). This means that the whole ham weight increases in proportion to those parameters increase.

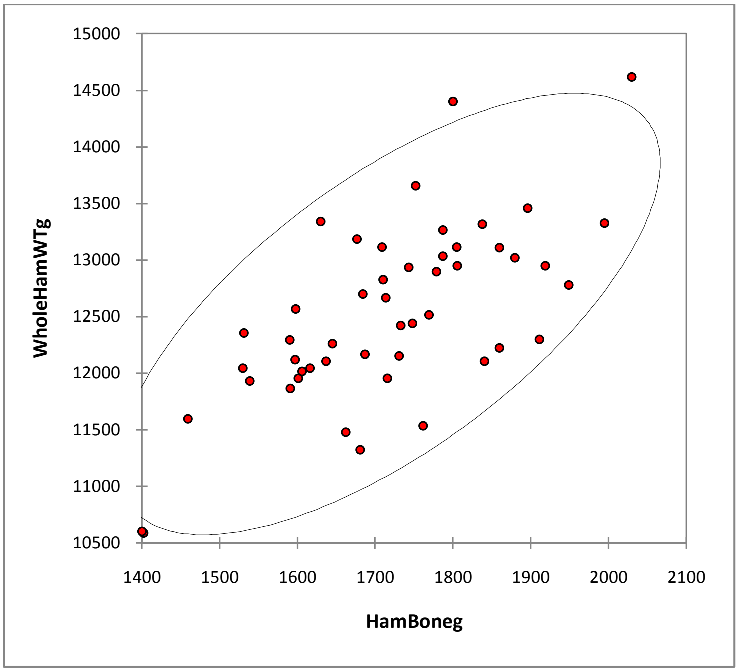


Fig 29. Whole ham weight correlated with ham bone

But the whole ham weight was negatively correlated with the femur/total bone (r= -0.427). The ham meat was strongly correlated with the ham bone (r=0.664; Figure 30), the ham MSF/carcass weight (r=0.665) and the whole ham/ carcass weight (r= 0.675).

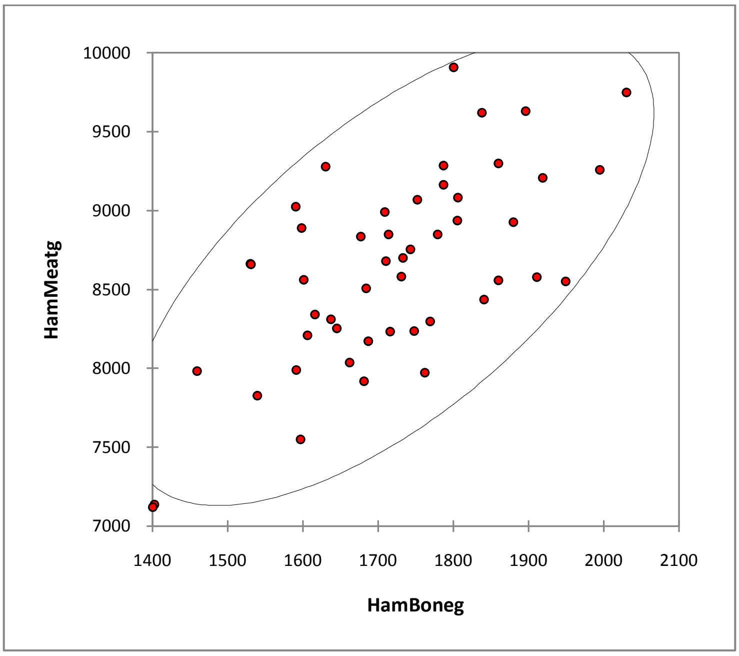


Fig 30. Ham meat correlated with ham bone

The ham skin was negatively correlated with the ham fat (r= -0.332). This means that the ham skin increases in proportion to the ham fat.

The ham bone was negatively correlated with the ham MSF per bone (r= -0.667; Figure 31) and the femur/total bone (r= -0.474). This means that the ham bone decreases in proportion to the ham MSF/bone and femur/total bone increase.

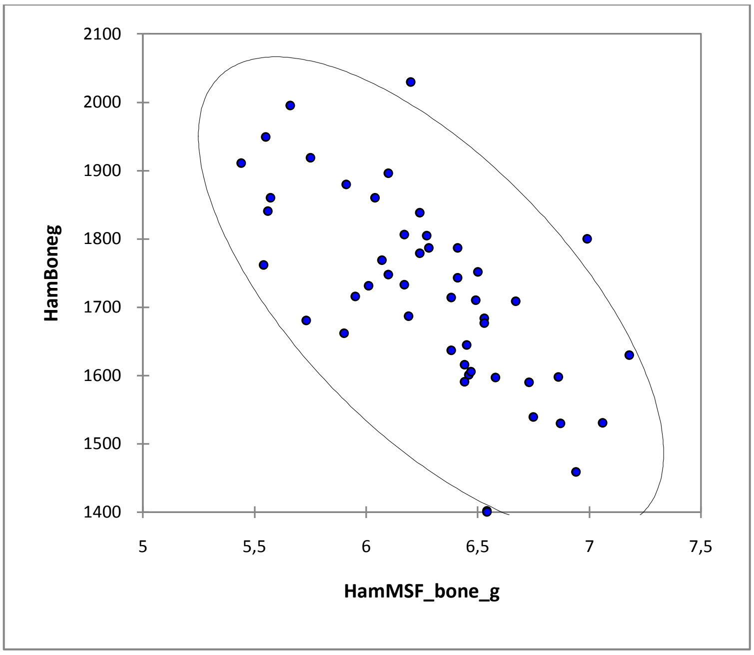


Fig 31. Ham bone correlated with ham MSF per bone

The ham MSF/carcass weight was strongly correlated with the whole ham/carcass weight (r=0.979). This means that the ham MSF/carcass weight increases in proportion to the whole ham/carcass weight increase.

9 Discussion

My primary objective of evaluating the mechanical parameters of bones and their relationship, related to the bone strength, was important for better understanding which is the best combination of bone quality in crossbreds selection. In according with the literature, the bones weakness is highly correlated with the bone mass and the bone strength, and it can be predicted by measuring the mechanical parameters of bones (Keller, 1994). Consequently, based on this aim, 49 carcasses obtained from four different crossbreds of pigs, were randomly taken for inspection.

Bone mineral density and bone mineral content are related to bone size and therefore account predominantly for strength of bone (Crenshaw *et al*., 1981). However, there still exists a 30-50 % of unaccounted variance in mechanical properties from bone density measurements (Teo et al., 2007).

Among the bone mass measurements was interesting that the ring area is strongly correlated with the wall thickness measures of the rings. This correlation means that all the geometrical parameters evaluated may influence the bone strength (Hernandez *et al.,* 2006).

The shape of the bones, related to the geometrical parameters also influence the bone strength. The Feret minimum shows a good correlation with the sectional area. This correlation is important to evaluate the effect of the geometrical measurements on the bone strength. Indeed, larger bones are mainly softer (Tothill *et al*., 2002).

The ring weight has positive correlation with the bone mineral content, as commonly reported in literature (Turner *et al*., 1993).

The bone compressive strength evaluated hasn't had no correlations with the geometrical parameters, except low significance with the maximum value of the ring thickness, but it is not enough to predict a significant difference. Hence, the genetic factor hasn't had no influence on the bone strength capacity.

Some aspects considering materials were considered relevant to be taken into account. When studying animals obtained from the slaughterhouse, it is difficult to determine the exact age of the animals (Voutila, Academic dissertation). They are farmed to grow to a certain weight, which despite the achievements in animal breeding takes different times for different individuals. This is an uncontrolled source of variation in the age-dependent properties of bone strength against fracture risk, in the present work, although a few weeks age difference would not be expected to make a big difference.

The feeding of growing-finishing pigs was based on MTT 2006 nutritional diet (Agrifood Research Finland) and it varied during the growth depending on the age. In this study the diet doesn´t represent a variation factor in bone strength evaluation because it has similar composition for all the pigs grown from the age of 70 days to the slaughter age. The feeding of higher level of Ca and P resulted in an increase in the mechanical properties (ultimate stress, bone strength) and geometrical measurements (cross sectional area and wall thickness), thus bone strength increased (Crenshaw et al., 1981). The feeding is involved in the development of the bone as well. The rate of bone formation is reduced in Ca-deficient bone sample (Pointillart et al., 1999). The effects of genetic pattern, hormonal influence and environmental factors like age and sex, besides the diet, account the bone growth and the fracture risk as well (Kowalik et al., 2005).

Meal-feeding and phosphorus ingestion influence calcium bioavailability evaluated by calcium balance and bone breaking strength in pigs. However, the diet with reduce content of Ca and P doesn´t cause serious fracture, but there is only the risk which it happens. Indeed there is more production of osteocalcin, important in the bone formation. Dietary protein has a positive correlation with bone area and BMD, as well. It plays an important role in bone strength, as it is essential for bone turnover and matrix formation (Oxlund et al., 1995).

10 Conclusions

The main goal of the undertaken study was to investigate the bone strength in four different crossbreds, mainly used in the Nordic area, to obtain information for selecting the crossbred of best bone quality.

Along the increase of growth rate such as important selection trait in pig breeding, the animals react by creating larger but softer bones, comparing with the wild pigs. Therefore, mechanical and geometrical parameters were considered, because of the high correlation with the bone strength and linked to the bone defects as well.

Two rings (about 6 mm of thick) from each femur of swine hind legs were taken and assessed regardless certain mechanical and geometrical parameters, which explain the bone strength, between four crossbreds and within sexes.

The genetic effect of four different pig crossbreds has influenced the femur weight parameter, in which the crossbred *Finnish Landrace x Yorkshire* (mother line) X *Duroc x Norwegian Landrace* (father line) has the heaviest femur weight (538 g), between the four crossbreds. On the other hand, Duroc has the lightest femur weight (499 g), between the four crossbreds. Hampshire (520 g) and Norwegian Landrace (523 g) have instead quite similar femur weight. This significant different in femur weight between the pig crossbreds can be explained by the different carcass conformation of each crossbred. Finnish Landrace crossbred is normally bigger than Duroc crossbred. Despite of this, all the other carcass traits considered didn’t allow to highlight a genetic effect on the pig bone weakness.

The sex effect was evaluated as well between the four pig crossbreds. It has influenced the bone mineral content per ring weight parameter, in which the male animals of the crossbreds have a bigger bone mineral content (0.664) than female animals (0.653) of the same crossbreds, per ring weight. This significant different in bone mineral content/ring weight can be explained by the different ring weight, which is on average bigger in male animals used in this study. Indeed, the only bone mineral content evaluated is not influenced by the genetic aspect of the four pig crossbreds.

All the other bone parameters evaluated didn’t allow to highlight neither a genetic effect or sex effect on the pig bone weakness, despite of some other bone parameters were slightly not significant analyzed by SAS system. Neither the breaking strength, such as the mechanical bone parameter more link to the bone fragility, was different for the genetic effect evaluation between the four crossbreds.

Probably, some parameters evaluated in this study have not been so thorough, linked to the bone weakness pattern, or the number of animals samples could been not enough to allow significant differences in bone evaluation between the crossbreds.

Therefore, in this study was difficult to individuate the crossbred with the best bone quality, because of the too few data available.

The feeding background given for growing and fattening pigs was the same for all the crossbreeds, and the animals were slaughtered at the same age with quite similar live body weight. Hence, the feeding effect on the pig bone weakness has not been considered for this study. The genetic disease and bone and joints fractures, such as the *osteochondrosis*, rather common in pigs, are another probable cause of weakness in swine, but the animals for this study were in a good welfare state, both during farming and after the transportation to the slaughterhouse, so that neither this aspect was considered in this work.

Suggestions for further studies can be made to consider a full evaluation of the influence of different feeding gave to the animals (to evaluate the differences in growth rate on the bone strength) and the influence of genetic pattern within each crossbred. How to avoid problems in animal welfare and meat quality (such as pH, drip loss, colour of the meat), can be involved in the evaluation as well. If considered all together, these factors can be predict much better the pig fragility, than consider each aspect one by one.

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The research team in Finland:

Citation

(*1) : Gompertz curve or Gompertz function, named after Benjamin Gompertz, is a sigmoid function. It is a type of mathematical model for a time series, where growth is slowest at the start and end of a time period. The left-hand or lower valued asymptote of the function can be approached much more gradually by the curve than the upper right-hand or future value asymptote, in contrast to the logistic function in which both asymptotes are approached by the curve symmetrically.

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