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Genetic and phenotypic analyses of claw traits in dairy cattle

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ACADEMIC DISSERTATION

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Abstract

Growing public interest in production animal welfare and the considerable costs (e.g. milk loss and involuntary culling) associated with claw disorders and lameness has resulted in a need to study how claw health can be improved in practice. Good claw health is essential for cows in modern dairy farming since herd sizes are increasing and almost all new herds are loose housed, with the cows walking to the milking parlour or to the automatic milking system and to feed.

Heritabilities for claw disorders are low and the fastest means to improve claw health in the short term is optimizing housing and management practices. However, in the long term direct selection of claw traits or indirect selection of correlated feet and leg conformation traits may be used. Also new approaches to detect lame cows on dairy farms are needed since especially on larger farms lame cows often go unnoticed.

The overall aim of this thesis was to identify the best means to improve claw health through genetic selection and management practices on Finnish dairy farms. The study was divided into three parts. The aim of the first part was to evaluate genetic parameters for claw traits and to determine whether feet and leg conformation traits could be used as indicator traits when selecting for better claw health. In the second part, cow-level and herd-level risk factors affecting infectious and non-infectious claw disorders in tie stalls and loose house herds were evaluated. The aim of the third part was to investigate the effect of lameness on feeding behaviour, feed consumption, and milk yield of dairy cows and to determine whether feeding behaviour of a cow can be used as a reliable indicator for lameness.

The heritabilities for different claw disorders from logistic models vary from 0.01 to 0.20 for the Ayrshire breed and from 0.02 to 0.13 for the Holstein breed. The heritabilities for feet and leg conformation traits were higher than for claw disorders, varying from 0.07 to 0.39 for Ayrshire and from 0.09 to 0.19 for Holstein cows. The genetic correlation between overall claw health and individual feet and leg conformation traits varied from -0.40 to 0.42 for the Ayrshire breed. For Holstein cows, the corresponding figure ranged from -0.51 to 0.45. Cow-level factors (breed, parity, season, year, stage of lactation) had similar effects on the prevalence of infectious and non-infectious claw disorders in tie stall and loose house herds. By contrast, most herd-level factors (housing type, feeding system, bedding material, bed surface, outdoor access, annual number of herd maintenance trimmings) had different effects on infectious and non-infectious claw disorders in tie stall and loose house herds. Lameness seemed to have an effect on feeding behaviour; daily feeding time decreased and feeding rate increased with lameness scores, especially with severely lame primiparous cows.

Estimated genetic parameters were used in selection index calculations to illustrate the approximate gain in accuracy of selection when using direct selection for claw traits and/or indirect selection of feet and leg conformation traits. According to the results, the genetic evaluation method currently used by Nordic cattle genetic evaluation for claw

traits seems to be suitable for Finnish Ayrshire and Holstein breeds; thus, there is no need to include feet and leg conformation traits as indicator traits in genetic evaluations. These findings highlight the importance of claw trimming data collection. However, the inter-claw trimmer variances in the national data were quite high, especially for infectious claw disorders. To enable more reliable national data collection, the training of claw trimmers should be standardized. Because of differences found in herd-level factors between different herd types and disorder groups, the recommendations for housing and management options for individual farms should be based on the previous disease status of the herd and the current housing type. Decreased silage intake and altered feeding time might occur simultaneously or even before changes in the gait of a cow are visible. Changes in cows´ feeding behaviour can be used when developing automated lameness detection systems. In modern dairy operations, advanced technology of feeders and milking stations already exists and could be integrated with such systems as acceleration sensors, visual imaging, and pressure platforms to provide reliable lameness monitoring systems.

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List of original publications

This thesis is based on the following original publications, which are referred in the text by their Roman numerals:

I Häggman, J., Juga, J., Sillanpää, M.J., & Thompson, R. 2013. Genetic parameters for claw health and feet and leg conformation traits in Finnish Ayrshire cows. J. Anim. Breed. Genet. 130, 89-97.

II Häggman, J., & Juga, J. 2013. Genetic parameters for hoof disorders and feet and leg conformation traits in Finnish Holstein cows. J. Dairy Sci. 96, 3319-3325.

III Häggman, J., & Juga, J. 2013. Effects of herd-level and cow-level factors on claw health in tie stall and loose house herds in Finnish dairy cattle. (In manuscript).

IV Norring, M., Häggman, J., Simojoki, H., Tamminen, P., Winckler, C., & Pastell M. 2013. Short communication: Lameness impairs feeding behavior of dairy cows. (Accepted for publication in J. Dairy Sci.).

Publications I, II and IV have been reprinted with the kind permission of their copyright holders. In addition, some unpublished material has been included.

Contributions

Contribution of the author to Studies I-III:
The author participated in planning the study, prepared the data for statistical analyses, carried out the statistical analyses, interpreted the results, and was the main author of the manuscript.

Contribution of the author to Study IV:
The author participated in planning the study, participated in carrying out the experiment, participated in preparing the data for statistical analyses, conducted some of the initial statistical analyses, and was the second author of the manuscript.

Abbreviations

Ay	Ayrshire
CI	confidence interval
EBV	estimated breeding value
ICC	intra-class correlation coefficient
h^2	heritability
h^2adjusted	heritability adjusted to the underlying liability scale
h^2obs	heritability on the observed scale
Ho	Holstein
LH	loose house
NAV	Nordic cattle genetic evaluation
NTM	Nordic total merit
OR	odds ratio
TS	tie stall
SE	standard error
σ^2	variance
σ^2a	additive genetic variance
σ^2random	variance of the random effects

1 Introduction

Several claw disorders are painful and long-lasting often causing lameness and severely compromising the welfare of dairy cows (Alban, 1995; Enting et al., 1997; van der Waaij et al., 2005). Claw disorders are also associated with considerable costs in dairy operations due to milk loss (Green et al., 2002), involuntary culling, and higher replacement costs (Collick et al., 1989; Sprecher et al., 1997).

The dairy industry faces new challenges arising from the growing public interest in animal welfare, increased production costs, and low income from milk sales. To maintain production costs at a reasonable level and keep consumers satisfied, dairy farmers need to take actions towards better claw health.

Heritabilities for claw disorders are low; hence, the fastest way of improving claw health in the short term is by optimizing housing and management practices of dairy herds (van der Waaij et al., 2005). However, in the long term direct or indirect genetic selection may be used to improve claw health. The heritabilities for feet and leg conformation traits are usually considerably higher than the heritabilities for claw disorders. If the correlations between claw disorders and feet and leg conformation traits are sufficiently strong the indirect selection of feet and leg conformation traits can be used for improving claw health (van der Waaij et al., 2005). To improve the efficiency of genetic selection, indicator traits can also be used together with direct selection of claw traits.

Several studies have indicated that it is useful to divide the most important predisposing factors for claw disorders into cow-level and herd-level risk factors (Frankena et al., 1993; Bielfeldt et al., 2005; Sogstad et al., 2005; Capion et al., 2008). Especially on larger farms, because of inadequate monitoring, lame animals often go unrecognized (Potterton et al., 2012); hence, new approaches to detect lame cows on farms as early as possible are needed. In general, behaviour seems to be the best indicator of poor health (Weary et al., 2008). Lying behaviour (Gomez & Cook, 2010) and feeding behaviour (Goldhawk et al., 2009) of dairy cows as lameness indicators have mostly been studied. While lying time seems too variable to be used as a reliable indicator (Ito et al., 2010), feeding behaviour is a more usable indicator of lameness.

1.1 Claw disorders

Claw disorders can be grouped into infectious (hygiene-related) and non-infectious (laminitis- or feed-related) disorders depending on the cause of disorder. For example, heel horn erosion, digital dermatitis, and interdigital dermatitis are infectious claw disorders, whereas sole haemorrhage, sole ulcer, and white line separation are non-infectious claw disorders (Fjeldaas et al., 2007; Buch et al., 2011). Many claw disorders cause lameness, and 90% of lameness is reportedly due to claw problems (Murray et al., 1996). Acute laminitis, sole ulcer, white line separation, digital dermatitis and, interdigital phlegmon are claw disorders known to cause lameness.

1.1.1 Infectious claw disorders

Heel horn erosion

Heel horn erosion, also known as a "slurry heel", can be defined as an "irregular loss of bulbar horn" (Collick et al., 1997). The cause of heel horn erosion is multifactorial with a bacterial component superficial and it has been associated with interdigital dermatitis (Manske, 2002). Urine and manure (Mülling & Budras, 1998), disturbance in the growth of the horn and/or undermining dermatitis (Toussaint-Raven, 1973; Mortellaro, 1994) can lead to a structural breakdown which can cause a loss of the horn tissue. A wet unhygienic environment softens the claw and predisposes it to heel horn erosion (Enevoldsen et al., 1991; Borderas et al., 2004). Heel horn erosion is the most common infectious claw disorder in Finnish dairy cows (Kujala et al., 2004; Liinamo et al., 2009).

Dermatitis

Dermatitis can be caused by physical and chemical agents as well as by micro-organisms. Infectious dermatitis can be divided into interdigital dermatitis and digital dermatitis. Interdigital dermatitis is an infection of the interdigital epidermis that causes an erosion of the skin and is caused by a mixed bacterial infection, *Dichelobacter nodosus* and *Fusobacterium necrophorum* commonly considered the most active component (Laing & Egerton, 1978; Blowey, 1994). Only the most severe cases of interdigital dermatitis cause lameness. By contrast, digital dermatitis comprises painful lesions on the tissue between the claws and the heel, often causing lameness, and is highly contagious (Walker et al., 1995). The cause of digital dermatitis is unclear, although it is widely believed to be the result of a mixed bacterial infection (Walker et al., 1995; Evans et al., 2008).

1.1.2 Non-infectious claw disorders

Laminitis and sole haemorrhages

In general, the term laminitis is used to describe a systemic disease affecting the general condition of the cow (not only the claws). In claws, laminitis is a disorder of the laminar corium of the claw wall and is strongly influenced by housing and management factors such as feeding (Bergsten, 2003). Sole haemorrhages, toe and sole ulcers, white line haemorrhage, double soles, white line separation and deformation of the claw surface are laminitis-related claw disorders (Ossent et al., 1997).

Laminitis can be divided into acute, sub-acute, and chronic laminitis. Chronic laminitis is the result of acute and/or sub-acute laminitis and is seen often a few months after the occurrence of laminitis. Sole haemorrhage (also called sole bruising) is the most common claw disorder associated with subclinical laminitis in Finnish dairy cows (Kujala et al., 2004; Liinamo et al., 2009). Sole haemorrhage is recognised from the red and sometimes yellow (or) blue marks or areas on the sole, and result from localized increased compression of the corium (Smedegaard, 1964).

Sole ulcer

Sole ulcers are a very painful type of non-infectious claw disorder that often causes severe lameness. Sole ulcers are primarily based on mechanical injury by the 3rd phalanx to the corium, basal layers of the sole epidermis, and the basement membrane, arising when the soft tissues inside the sole are damaged and normal horn cannot be produced (Van Amstel & Shearer, 2006).

White line separation

The white line is an extension of the lamellae, a fibrous point of juncture between the wall and the sole of the claw. White line separation (disease) is a disorder that occurs when the sole separates from the side wall of the claw, allowing foreign material to penetrate and infect the white line region often causing lameness (Budras et al., 1996). White line disease is the second common claw disorder in Finnish dairy cows (Kujala et al., 2004).

Corkscrew claw

Corkscrew claw is a malformation in which the claw is twisted throughout its length in a configuration that displaces the abaxial wall. In Finland corkscrew claw is recorded if the twist is over 90° (Kujala et al., 2009).

1.2 Welfare and economics of claw disorders and lameness

1.2.1 Welfare

Growing public interest towards dairy cattle welfare and ethics in milk production has raised new challenges for modern dairy operations. Lameness and claw disorders have been reported as critical welfare and production issues in modern dairy operations, causing considerable pain and suffering for cows (Enting et al., 1997). Rajala-Schultz and Gröhn (1999) found lameness, mastitis, and teat injuries (i.e. foot and leg problems) to have the greatest effect on culling in Finland.

1.2.2 Direct and indirect costs

Claw disorders and lameness are identified as one of the costliest diseases in dairy operations (Kossaibati & Esslemont, 1996; Enting et al., 1997). The economic losses depend on the lactation stage of the cow and the type and severity of the claw disorder. Economic losses are more severe on early lactating cows while reducing both milk yield and fertility (Collick et al., 1989).

Direct costs include decreased milk production, milk losses (Rajala-Schultz et al., 1999; Green et al., 2002), increased labour costs, and veterinary treatments (Kossaibati & Esslemont, 1996; König et al., 2005). Indirect costs comprise increased culling rates, increased replacement costs (Collick et al., 1989; Sprecher et al., 1997), higher fertility costs, and increased risk of other diseases (Barkema et al., 1994).

Milk production

Direct costs through milk losses are mainly due to treatments with antibiotics, whereas milk losses can also be classified as indirect costs when they arise from stress of the cow or lower feed intake (Kossaibati & Esslemont, 1996; König et al., 2005). Several studies have clearly demonstrated that lame cows produce less milk (Rajala-Schultz et al., 1999; Green et al., 2002). Rajala-Schultz et al. (1999) stated that cows produced 1.5 to 2.8 kg less milk per day during the first two weeks after being diagnosed with claw disorders. Amory et al. (2008) studied dairy cows in England and Wales and reported the total milk loss for white line separation and sole ulcer to be 369 kg and 574 kg per lactation, respectively.

Fertility and culling

Poor claw health can have an effect on cow fertility; several studies have reported that lameness extended days open from 11 to 40 (Collick et al., 1989; Barkema et al., 1994). Lameness has also been reported to be an important cause of involuntary culling, and together with higher replacement costs and decreased carcass value of culled animals cause considerable indirect costs for dairy farms (Van Arendonk, 1985; Collick et al., 1989; Sprecher et al., 1997).

1.3 National databases and claw trimming data collection

The national claw health database was established in the ´Healthy Claws` project in 2001 to improve claw health in Finland. No recording system existed prior to 2002. The ´Healthy Claws` project was conducted in co-operation with Suomen Rehu Ltd., the Claw Trimmers Association, and Vetman Ltd. Since 2003, claw trimming data have been routinely collected (Kujala et al., 2009). Data recording is still voluntary for claw trimmers and herd owners. The database has since been transferred from Suomen Rehu Ltd. to Faba, and the data are available to the farm health system and are utilized in genetic evaluations and for research purposes.

Although the claw trimmers are professionals trained to record the most common claw disorders, the training is not equal for all trimmers. Claw trimmers usually record all claw disorders observed in the fore and hind claws of cows. However, national claw trimming data is recorded at a cow level. In general, Finnish claw trimmers usually visit farms from one to four times a year to trim all cows, except individuals very close to calving or about to be culled (Kujala et al., 2009). Data collection was time-consuming in the past; claw trimmers recorded all treatments on a study form during the visit, and herd owners or dairy advisors transferred the data to the database. This created long delays and a new recording system was urgently needed. The new Danish mobile software recording system, where claw trimmers enter data on the database while visiting the farm, has been established. This system allows faster and more reliable data collection than the manual system.

Data collection from routine claw trimmings by claw trimmers has some restrictions. For example, only the most obvious disorders will be recorded and standardized training for claw trimmers is difficult to organize. However, because the records can be obtained nationwide for a large number of cows and herds, the statistical power gained is huge.

1.4 Genetic evaluations of claw health in Nordic countries

Since 2008, selection of dairy bulls and cows in Finland, Sweden, and Denmark has been based on a joint Nordic total merit index (NTM). Claw health has been included in NTM since August 2011. A linear multiple-trait animal model including seven claw disorders (or groups of claw disorders) from the first three lactations is used in the analysis of claw health (NAV, 2012). The harmonization of type traits between the Nordic Cattle Genetic Evaluation (NAV) countries has also been an important issue. In 2011, the NAV began harmonization of claw traits, and the ´Nordic Claw Atlas` was produced in August 2013. The ´Nordic Claw Atlas` contains pictures and written definitions of the traits.

1.5 Lameness detection and locomotion scoring

One important issue on dairy farms is identifying lame cows as quickly as possible since especially in large loose house (LH) herds lame animals often go unnoticed.

Locomotion scoring is used worldwide to count the lame cows on farms and to determine the correlations between lameness and other traits for research purposes. Several locomotion scoring systems focusing on the head, feet, and back movements of a cow or just one or two of these are available. Because locomotion scoring is subjective, intra- and inter-observer reliability is crucial. Some studies have criticized the reliability of locomotion scoring (Flower & Weary, 2006), whereas others have reported relatively good reliabilities (Winckler & Willen, 2001). In LH herds, locomotion scoring can easily be done in the herd alley. In tie stall (TS) herds, where cows are tied from their neck, lameness evaluation can be done by observing how cows stand in their stalls (Sprecher et al., 1997; Winckler & Willen, 2001).

Observing the animals is time-consuming, and thus, several researchers have tried to find better solutions to detect lame animals based on behaviour traits (e.g. Goldhawk et al., 2009; Gomez & Cook, 2010) or using different automatic technological methods (e.g. Flower & Weary, 2006; Pastell et al., 2008).

2 Objectives of the study

General objective of this study was to identify the best means to improve claw health on Finnish dairy farms. The general objective was divided into three research objectives. The first objective was to estimate heritabilities and the genetic correlations for claw disorders in Finnish Ayrshire and Holstein cows and to determine whether feet and leg conformation traits could be used as indicator traits when selecting for better claw health (I, II). Second objective was to evaluate the effect of different cow-level and herd-level factors on infectious and non-infectious claw disorders in TS and LH herds (III). The third objective was to investigate the effect of lameness on feeding behaviour, feed consumption, and milk yield and to determine whether feeding behaviour of a cow can be used as a reliable indicator for lameness (IV).

Studies I-IV contributed to these objectives by determining the following:

I Estimates of heritability for overall claw health and feet and leg conformation traits and correlations between claw health and feet and leg conformation traits in Finnish Ayrshire cows

II Estimates of heritability for different claw disorders and feet and leg conformation traits and correlations between claw disorders and feet and leg conformation traits for Finnish Holstein cows

III Effects of cow-level and herd-level factors on infectious and non-infectious claw disorders in Finnish tie stall and loose house herds

IV Effect of lameness on feeding behaviour, feed consumption, and milk yield of dairy cows and the use of feeding behaviour as an indicator for lameness

3 Materials and methods

3.1 Materials

Six different types of data sets, namely claw trimming data, pedigree data, calving data, feet and leg conformation data, housing and management practice management data, and experimental data from the research farm, were used in Studies I-IV. Table 1 provides the study number, breed, number of cows, number of observations, years when data collected, objective of the study, and data type.

Table 1 *Description of data used in Studies I-IV*

Study	Breed	No. of cows	No. of observations	Year	Objective of the study	Data type
I	Ayrshire	52,598	105,000	2000-2010	Heritability, genetic correlations between claw health and feet and leg conformation traits	Claw trimming data Pedigree data Calving data Feet and leg conformation data
II	Holstein	24,685	65,152	2003-2010	Heritability, genetic correlations between claw disorders and feet and leg conformation traits	Claw trimming data Pedigree data Calving data Feet and leg conformation data
III	Ayrshire and Holstein	TS herds 28,645 LH herds 10,495	TS herds 33,087 LH herds 12,349	2003-2010	Effect of herd-level and cow-level factors on infectious and non-infectious claw disorders	Claw trimming data Calving data Housing and management practice data
IV	Mainly Ayrshire	70	1393[a]	2010-2011	Effect of lameness on feeding behaviour, feed consumption, and milk yield	Experimental data

[a]10-day averages

3.1.1 Claw trimming data

National claw trimming data were used in Studies I-III. The original claw trimming data were collected by claw trimmers, provided by Faba, and included 10 categories; chronic laminitis, over 90º corkscrew claw, digital dermatitis, heel horn erosion, interdigital dermatitis, sole haemorrhage, sole ulcer, white line separation, other claw disorders, and preventive treatment (no claw disorders found in this category). All of the findings were recorded as either 0 (absence of claw disorder) or 1 (presence of claw disorder).

Data were pre-processed for Studies I and II and included only the routine trimmings. Prior to the analyses, duplicate records, clearly false records (cow registered as healthy, but also recorded with a disorder on the same trimming day), repeated records within 7 days from the same cow (first observation was included in the analyses), records for a herd with less than five cows trimmed per trimming day, and records of a cow before the age of 21 months or after 165 months were deleted. Data were pre-processed for Study III by deleting duplicate records and clearly false records, repeated records within 30 days from the same cow, records for a herd with less than eight cows trimmed per trimming day, records of claw trimmers with less than 45 trimming observations, records with missing data for important variables (e.g. claw trimmer, herd), and records of a cow before the age of 21 months or after 165 months.

3.1.2 Pedigree data

National pedigree data provided by Faba were used in Studies I and II. Original pedigree data included pedigree information from all Finnish dairy cows and was traced back five generations for animals with records in studies I and II.

3.1.3 Calving data

National calving data provided by Faba were used in Studies I-III. Original calving data included calving information from all Finnish dairy cows and was added to those animals with claw trimming observations.

3.1.4 Feet and leg conformation data

National feet and leg conformation data were used in Studies I and II. The original conformation data were collected by breeding advisors and were provided by Faba. The data included six different traits, namely bone structure, fetlock angle, foot angle, hock quality, rear leg rear view, and rear leg side view. Feet and leg conformation traits were evaluated on a linear scale from 1 to 9 (Table 2).

The number of observations for different feet and leg conformation traits varied. Some of these traits have been recorded for a longer time and some have been added later, when recorded traits were standardized with other countries.

All feet and leg conformations traits mentioned above are included in NAV genetic evaluations, except fetlock angle, which is a national trait. Fetlock angle was one of the first traits evaluated when recording of feet and leg conformation traits was started in Finland.

Table 2 *Evaluation scale and optimum values for feet and leg conformation traits*

Trait	Scale	Optimum
Bone structure	1 = coarse; 9 = fine/thin	Ay 7.5, Ho 8
Fetlock angle	1 = sickled; 9 = straight	5
Foot angle	1 = low; 9 = steep	Ay 7, Ho 6.5
Hock quality	1 = filled; 9 = dry	9
Rear leg rear view	1 = toes out; 9 = parallel bow-legged	8
Rear leg side view	1 = straight; 9 = sickled	5

Ay= Ayrshire, Ho= Holstein

3.1.5 Housing and management practice data

National housing and management practice data used in Study III were provided by ProAgria Agricultural Data Processing Centre Ltd. The data included information on TS or LH type, feeding system, bed surface, bedding material, outdoor access, and number of annual herd maintenance trimming records.

3.1.6 Experimental data from research farm

Data for Study IV were collected during the winter season 2010–2011 at the University of Helsinki study farm in Viikki, Helsinki. The data were gathered for 220 days, and cows were housed in an insulated LH barn with free stalls and an automatic milking system. The cows were housed in a group of 50 animals and had access to a single milking robot. During the experiment the grass silage consumption, duration of feeding behaviour, and the milking robot information about the number of visits to the milking robot, milk yield, and total body weight were collected. Only feeding bouts longer than one minute were included in the analysis. To measure lameness, cows were locomotion-scored 15 times by two independent observers on average every 15 days. The five-level locomotion scoring system (Table 3) developed by Winckler & Willen (2001) was used. Cows were encouraged to individually walk through the rubber alley of the LH barn.

3.1.7 Merging the data sets

In Studies I and II, all the animals with claw trimming observations were included in the analyses (Table 1). Information on feet and leg conformation traits was added to animals with feet and leg conformation observations (I, II). Calving information was added to animals with claw trimming observations (I-III). In Study III, only the animals that had data on claw trimming, calving, and housing and management were included in the analyses.

Table 3 *Locomotion scoring sheet, modified from Winckler & Willen (2001)*

Lameness score	Description
1 = normal gait	Timing of steps and weight bearing are equal on all four feet
2 = uneven gait	Timing of steps as in 1, but footing may be tender and joint flexion reduced
3 = slight lameness	Irregular foot fall: uneven temporal rhythm between claw-beats, weight not divided equally between four feet (seen as “limp”). A favoured foot will move more quickly than a lame one
4 = moderate lameness	As in 3, but in more than one foot or strong reluctance to bear weight on one foot
5 = severe lameness	Cow does not support weight on one foot or strong reluctance to bear weight in more than one foot

3.2 Methods

3.2.1 Software

The analyses of the Studies I and II were performed with the software package ASReml 3.0 (Gilmour et al., 2009). Analyses of Study III were performed with the SAS statistical software package (version 9.3, SAS Institute Inc., Cary, NC). Analyses of Study IV were performed with the PASW 18.0.2 statistical software package (SPSS Inc., Chicago, IL).

3.2.2 Fixed and random effects

Studies I and II

Year-season, age at time of claw trimming in months, and stage of lactation at time of claw trimming were included in the statistical models for claw traits as fixed effects. Year-season, age at time of conformation trait observation in months, and stage of lactation at time of observation were included in the statistical models for feet and leg conformation traits as fixed effects.

In both studies, the random animal additive genetic effect was included in the models for claw traits and for feet and leg conformation traits. The permanent environmental effect of an animal was included in the models as a random effect on repeated claw trait records. Herd was included in the models as a random effect on claw traits and on feet and leg conformation traits. The claw trimmer and classifier were included in the models as random effects on claw traits and feet and leg conformation traits, respectively.

Study III

In this study, cow-level predictor variables of breed, parity, trimming season, trimming year, and stage of lactation as well as herd-level predictor variables of loose housing type (for LH), tie stall type (for TS), feeding system, bedding material, bed surface, outdoor access, and number of annual herd maintenance trimmings were offered as fixed effects into the model in statistical analyses. Fixed factors with associations significant at $p<0.05$ were included in the final models.

Some cows had multiple observations, thus trimmings were partially clustered within cows and the cows were completely clustered within herds. However, the average number of repeated records was low. Some herds had used multiple claw trimmers, thus herds were partly nested within trimmers. To take into account the importance of clustering cows within herds, models with different specification of random effects, hierarchical and non-hierarchical, were compared, and based on the results, the latter was chosen. To take the differences between claw trimmers into account, the trimmer was included in models as a random effect.

Study IV

Days in milk, parity (primiparous and multiparous), lameness score, and interaction between parity and lameness score were included in the statistical models as fixed effects to analyse the effect of lameness on feeding behaviour. Because of the rare occurrence of observations of lameness scores 1 and 5, these observations were merged with scores 2 and 4, respectively. Time divided into 10-day periods and cows were used as random effects on the repeated statement.

3.2.3 Statistical analyses

Studies I and II

An animal model and the restricted maximum likelihood method were used in analyses of binary claw health data and the linearly scored feet and leg conformation data (I, II). A univariate logistic regression model with mixed effects was fitted to analyse the heritabilities for overall claw health (I) and individual claw disorders (II).

In Study II, a multivariate linear mixed model for four traits at a time was used to estimate the heritabilities and the genetic and phenotypic correlations among claw disorders and among feet and leg conformation traits. In Study I, bivariate mixed model analyses between a binary claw health trait and one feet and leg conformation trait at a time were performed to estimate the genetic and phenotypic correlations between overall claw health and feet and leg conformation traits. In Study II, multivariate mixed model analyses between one binary claw disorder trait and two linear feet and leg conformation traits at a time were performed to estimate the genetic and phenotypic correlations between claw disorders and feet and leg conformation traits. Selection index calculations were performed to illustrate the approximate gain in the accuracy of selection when using direct selection for claw traits and/or indirect selection of feet and leg conformation traits (I, II).

Studies III and IV

In Study III, generalized linear mixed models were used to analyse the cow-level and herd-level risk factors for infectious and non-infectious disorder groups in TS and LH herds. The default optimization method was used (Newton-Raphson algorithm) to take into account the overdispersion. In Study IV, linear mixed models were used to analyse the effect of lameness on feeding behaviour, milk yield, milking frequency and body weight. The heterogeneous first-order autoregressive covariance structure provided the best model fit for the repeated measure and was implemented in the final models.

3.2.4 Binomial model

The phenotypic observations of the claw traits used in all studies were binary; hence, binomial models could give more accurate estimates than linear models. In addition, when heritability and incidence of the binary trait decrease, the advantage of using a threshold model increases (Mrode, 2005). However, with the large number of fixed effects in the model, there might be problems in the estimation of variance components (Misztal et al., 1989; Hoeschele & Tier, 1995); using herd as a random effect might be a practical way to overcome some of these problems (Hoeschele & Tier, 1995). Linear models have been favoured in the data analyses because of easier implementation and lower computing requirements than threshold models, especially when fitting multivariate models (Mrode, 2005).

The residuals of the binary trait are not normally distributed, which is why the logistic regression model was used in Studies I- III in the analyses of claw traits. The probability of observing the claw disorder was defined as in Rodriguez-Zas et al. (1997):

$$p_i = Prob\ (Y_i = 1|\theta) \qquad (1),$$

where θ is a parameter vector including fixed and random effects. The logit of the observation Y_i was defined as

$$log\left[\frac{p_i}{1-p_i}\right] = \eta_i \qquad (2),$$

where p_i is the probability that $Y_i = 1$ and $1 - p_i$ is the probability of $Y_i = 0$ for individual i. When the ratio of these two probabilities is stated in the form of odds, it gives the odds of having $Y_i = 1$ as a result. Also, any factor that increases η_i leads to a concomitant increase in p_i.

3.2.5 Transformation formulas for heritability estimates

To enable comparison of the heritability estimates with previous studies (I, II) and to compare the estimates from different models within Study I, the heritability estimates were transformed with the formulas as in Gilmour et al. (2001).

The estimates from the linear model on the observed scale were transformed to the underlying liability scale by

$$h^2 = \frac{h^2_{obs}}{pq \times \left(\frac{\pi^2}{3}\right)} \qquad (3),$$

where h^2_{obs} is the heritability on the observed scale, p is the incidence of the claw disorder, $\pi^2/3$ is the variance of a standard logistic distribution, and q is the proportion of healthy animals.

The estimates from the logistic model were adjusted to the underlying liability scale by

$$h^2_{adjusted} = \frac{\sigma^2_a}{\sigma^2_{random} + \left(\frac{\pi^2}{3}\right)} \qquad (4),$$

where σ^2_a is the additive genetic variance, σ^2_{random} is the sum of the variances of all random effects, and $\pi^2/3$ is the variance of a standard logistic distribution.

3.2.6 Intra-class correlation coefficients

In Study III, intra-class correlation coefficients (ICCs) were estimated to describe the error variance at the levels of animals, herds, and trimmers. Animals, herds, and claw trimmers were included as random effects in the model, and the random-intercept model was used. The latent-variable approach, which is based on the interpretation of the binary response as arising from an underlying, continuous latent-variable, was used to compute the variance attributable to the animals, herds, and claw trimmers (Vigre et al., 2004). According to this method, the error variance at the observation level is set at a constant value of $\pi^2/3$ (3.29) (Snijders & Bosker, 1999).

The ICCs for animal, herd, and claw trimmer were calculated by the following:

$$ICC(animal) = \frac{\sigma^2_{animal}}{\sigma^2_{animal} + \sigma^2_{herd} + \sigma^2_{claw\ trimmer} + \pi^2/3} \quad (5),$$

$$ICC(herd) = \frac{\sigma^2_{herd}}{\sigma^2_{animal} + \sigma^2_{herd} + \sigma^2_{claw\ trimmer} + \pi^2/3} \quad (6),$$

$$ICC(claw\ trimmer) = \frac{\sigma^2_{claw\ trimmer}}{\sigma^2_{animal} + \sigma^2_{herd} + \sigma^2_{claw\ trimmer} + \pi^2/3} \quad (7).$$

4 Results and discussion

The prevalence of different claw disorders in the final data varied between studies and breeds depending on the data editing criteria used (Table 4). In Studies I and III, one or more claw disorders were found in 24.7% and 37.7% of the Ayrshire cows, respectively. In Studies II and III, one or more claw disorders were found in 49.6% and 43.5% of the Holstein cows, respectively.

The prevalence of non-infectious claw disorders was considerably higher than that of infectious claw disorders in Studies I-III. According to the results of this study and that of Ødegård et al. (2013), infectious claw disorders are not a serious problem in Finland and Norway. However, some previous studies have shown that in countries with a larger average herd size the prevalence of infectious claw disorders is considerably higher (Frankena et al., 1993; Capion et al., 2008). Several studies have reported more infectious claw disorders in LH herds than in TS herds (Manske, 2002; Sogstad et al., 2005). LH herds are becoming more common also in Finland, with virtually all new herds being LH herds, and herd size is increasing, and thus, the disease status for infectious claw disorders should be monitored carefully.

Table 4 *Prevalence (%) of different claw disorders in Studies I, II and III*

Disorder	Study I, Ayrshire	Study II, Holstein	Study III, Ayrshire[2]	Study III, Holstein[2]
Chronic laminitis	0.60	1.37	1.06	0.85
Corkscrew claw	2.38	4.36	*	*
Digital dermatitis	0.08	0.16	0.14	0.14
Heel horn erosion	2.41	4.71	5.53	3.48
Interdigital dermatitis	0.32	0.70	0.74	0.52
Sole haemorrhage	13.91	20.68	17.54	21.52
Sole ulcer	0.76	6.11	1.97	4.38
White line separation	3.95	10.64	6.05	7.73
Other claw disorders	0.27	0.89	4.70	4.92
Preventive treatment[1]	75.33	50.38	62.27	56.46
One or more claw disorders	24.67	49.62	37.73	43.54

* Included in other claw disorders

[1] Cows were trimmed and no claw disorders found

[2] Mean of observations in tie stalls and loose houses

4.1 Estimates of heritability

4.1.1 Claw disorders and overall claw health

The heritability estimates for different claw disorders from univariate logistic models ranged from 0.01 to 0.20 for Ayrshire cows (I) and from 0.02 to 0.13 for Holstein cows (II) (Table 5). In general, the estimated heritabilities were higher for Ayrshire than for Holstein cows. However, the estimated heritabilities for different claw disorders were quite low for both breeds. In Study I, bivariate models gave similar estimates to the univariate models.

The results from this study indicate that claw disorders are heritable, but the estimates are low, which is in line with many previous studies for different dairy cattle breeds (van der Waaij et al., 2005; Liinamo et al., 2009; Buch et al., 2011; Johansson et al., 2011). Possible reasons for low heritabilities might be a strong environmental impact on these traits and the low prevalence of several claw disorders.

Table 5 *Estimates of heritability (h^2) and standard errors (±SE) for different claw disorders from the univariate logistic model*

Disorder	Study I, Ayrshire h^2±SE	Study II, Holstein h^2±SE
Chronic laminitis	0.13±0.03	0.02±0.04
Corkscrew claw	0.20±0.02	0.09±0.03
Digital dermatitis	0.10±0.06	0.13±0.05
Heel horn erosion	0.01±0.00	0.02±0.01
Interdigital dermatitis	0.11±0.03	0.03±0.04
Sole haemorrhage	0.03±0.01	0.02±0.01
Sole ulcer	0.15±0.03	0.08±0.03
White line separation	0.11±0.01	0.04±0.02

In Study I, the estimated heritability for overall claw health was 0.08 on the logistic scale and 0.04 on the observed scale. Also in Study II, the estimated heritabilities from the logistic model were higher than those from the linear model. Heritabilities for overall claw health (I) and the five most common claw disorders (II) from linear and logistic models were transformed to the underlying liability scale to compare the models. When the estimates for overall claw health from the logistic and linear models were transformed to the underlying liability scale heritabilities were of similar magnitude, 0.06 and 0.05, respectively (I). When the estimates for individual claw disorders from the logistic and linear models were transformed to the underlying liability scale heritabilities were also of similar magnitude (II).

According to these results, the linear model would be a good approximation for the data used in Study I and also for the five most common claw disorders in Study II if the transformation formulas are used. However, the number of observations for overall claw health was high in Study I, and in Study II only the five most common claw disorders were compared. A linear model might not yield as good approximation for claw traits with lower incidence. Other studies have shown that the fit of the linear model is poor for low incidence binary traits with low heritabilities (e.g. Mrode, 2005).

4.1.2 Feet and leg conformation traits

The heritability estimates for feet and leg conformation traits from univariate models ranged from 0.07 (foot angle) to 0.39 (bone structure) for Ayrshire cows (I) and from 0.09 (foot angle) to 0.19 (rear leg side view) for Holstein cows (II) (Table 6). Heritabilities of the same magnitude have been reported in several previous studies (e.g. Boelling et al., 2007; Uggla et al., 2008). Estimated heritabilities were in general quite similar in both breeds, except for bone structure and hock quality where heritability estimates were higher for Ayrshire than for Holstein cows.

The results from this thesis indicate that feet and leg conformation traits have higher heritabilities than claw disorders. This implies that those feet and leg conformation traits that have high heritability and are strongly correlated with claw traits could be used together with direct selection of claw traits in genetic evaluations to increase the accuracy of breeding values for claw traits. The lowest heritabilities were found for foot angle and rear leg rear view for both breeds, suggesting that these traits are not useful as indicator traits in genetic analysis for claw traits.

4.2 Genetic and phenotypic correlations

4.2.1 Claw disorders

The genetic and phenotypic correlations among the five most common claw disorders (corkscrew claw, heel horn erosion, sole haemorrhage, sole ulcer, and white line separation) were estimated for Holstein cows (II).

The genetic correlations were mostly low to moderate and ranged from -0.36 (between heel horn erosion and white line separation) to 0.57 (between corkscrew claw and sole ulcer). However, most of the standard errors for genetic correlations were high, which might be due to the low number of observations in individual claw disorders. Low genetic correlations among claw disorders suggest that these disorders have different genetic backgrounds. Large variation in the genetic correlations among claw disorders was also found in previous studies (van der Waaij et al., 2005; Buch et al., 2011; Johansson et al., 2011), indicating that these estimates are breed- and population-specific and should be evaluated separately in each country.

The phenotypic correlations were all low and ranged from -0.24 (between sole haemorrhage and white line separation) to -0.06 (between corkscrew claw and heel horn erosion and between corkscrew claw and sole ulcer).

Table 6 *Estimates of heritability (h^2) and standard errors (±SE) for different feet and leg conformation traits from the univariate (I) and multivariate (II) linear models*

Trait	Study **I**, Ayrshire h^2±SE	Study **II**, Holstein h^2±SE
Bone structure	0.39±0.05	0.17±0.03
Foot angle	0.07±0.02	0.09±0.02
Fetlock angle	0.14±0.02	0.16±0.03
Hock quality	0.30±0.05	0.18±0.04
Rear leg rear view	0.10±0.02	0.10±0.02
Rear leg side view	0.20±0.02	0.19±0.03

4.2.2 Feet and leg conformation traits

Genetic and phenotypic correlations among feet and leg conformation traits (bone structure, foot angle, fetlock angle, hock quality, rear leg rear view, and rear leg side view) were estimated for the Holstein breed (II). The genetic correlations had a large variation and ranged from -0.30 (between fetlock angle and rear leg side view) to 0.83 (between bone structure and hock quality). Some of the standard errors for genetic correlations were high, which might be due to the low number of observations in individual feet and leg conformation traits in the data used in Study II. Most of the genetic correlations were low to moderate and in accordance with previous studies (e.g. Boelling et al., 2001; Uggla et al., 2008). However, as in this study, also Boelling et al. (2001) and Uggla et al. (2008) found a high genetic correlation between bone structure and hock quality, indicating that these traits have similar genetic backgrounds. The genetic correlation between foot angle and rear leg side view was close to zero and weaker than the corresponding genetic correlations reported in earlier studies (Boelling et al., 2001; van der Waaij et al., 2005; Uggla et al., 2008).

Phenotypic correlations had some variation and ranged from low to moderate. The highest phenotypic correlation emerged between bone structure and hock quality and the lowest between fetlock angle and rear leg side view.

4.2.3 Correlations between claw traits and feet and leg conformation traits

Genetic and phenotypic correlations between overall claw health in Study I or the five most common individual claw disorders in Study II and feet and leg conformation traits were estimated for Ayrshire (I) and Holstein cows (II) (Table 7).

Previously reported estimates of genetic correlations between claw disorders and feet and leg conformation traits from different countries have varied greatly from each other, suggesting that these estimates are breed- and country-specific (Boettcher et al., 1998; van der Waaij et al., 2005; Uggla et al., 2008; Laursen et al., 2009). Genetic correlations between overall claw health and feet and leg conformation traits for the Ayrshire breed showed a high variation in Study I, and the highest genetic correlation was found between overall claw health and rear leg side view, suggesting that rear leg side view could be a useful indicator trait for the Finnish Ayrshire breed.

There was also a high variation in the genetic correlations between individual claw disorders and feet and leg conformation traits in Study II for Holstein cows. Most of the genetic correlations ranged from low to moderate, and most were not significantly different from zero. Similar genetic correlations have been reported also in previous studies (van der Waaij et al., 2005; Uggla et al., 2008). Some of the standard errors of the genetic correlations were so high that the estimates were inconclusive. High standard errors might be due to the low prevalence of claw disorders and low number of observations in feet and leg conformation traits. According to the results, indirect selection for better claw health by using feet and leg conformation traits as indicator traits is not efficient for the Finnish Holstein breed (II).

In Study I, the analysis did not converge when the animal model was used for bone structure and hock quality, and these estimates are only indicative. To achieve convergence also for these traits, the sire model was used. The estimates from the sire model were higher and had higher standard errors than those from the animal model (Table 7). The animal model has several good qualities, including that it takes into account all available genetic relationships and has lower standard errors than the sire model (Henderson, 1984; Hudson & Schaeffer, 1984). At the same time, the number of equations in the animal model is much higher than in the sire model, leading to its lower convergence rate (Quaas & Pollak, 1980). Boettcher et al. (1999) reported that the additive genetic variance can sometimes increase without a bound when using the threshold animal model. As in Study I, sometimes when an animal model fails to converge, the convergence criteria can be achieved with a sire model.

Phenotypic correlations between overall claw health (I) and claw disorders (II) and feet and leg conformation traits were close to zero. These results are in accordance with previous studies (van der Waaij et al., 2005; Laursen et al., 2009). Hence, no phenotypic connection appears to exist between claw traits and feet and leg conformation traits.

Table 7 *Genetic correlations between overall claw health (Study I) and claw disorders (Study II) and feet and leg conformation traits*

Trait	Overall claw health[1]	Corkscrew claw[2]	Heel horn erosion[2]	Sole haemorrhage[2]	Sole ulcer[2]	White line separation[2]
Bone structure	-0.40±0.07* -0.29±0.15**	0.07±0.15	-0.10±0.21	-0.21±0.09	-0.04±0.14	-0.26±0.15
Fetlock angle	-0.20±0.07	-0.12±0.12	0.07±0.18	-0.07±0.10	-0.18±0.10	0.04±0.13
Foot angle	-0.29±0.09	-0.50±0.13	0.45±0.19	-0.08±0.06	-0.51±0.12	-0.24±0.11
Hock quality	-0.28±0.08[a] -0.15±0.16[b]	0.06±0.15	0.19±0.22	0.06±0.13	0.29±0.15	-0.23±0.09
Rear leg rear view	-0.07±0.08	0.33±0.12	-0.29±0.18	0.04±0.06	0.31±0.12	0.04±0.14
Rear leg side view	0.42±0.04	-0.09±0.11	-0.22±0.17	0.17±0.04	0.19±0.10	0.04±0.12

[a] Analysis from an animal model, not converged
[b] Analysis from a sire model, converged
[1] Ayrshire breed
[2] Holstein breed

4.3 Selection index calculations

In Studies I and II, the estimated genetic parameters were used in simple selection index calculations to illustrate the approximate gain in accuracy of selection. The example bulls with records from 10 and 100 daughters were used (I, II). In both studies, the accuracy of selection was higher in direct selection of claw traits than in indirect selection of feet and leg conformation traits. For the Ayrshire breed, the use of rear leg side view as an indicator trait together with direct selection of claw health increased the accuracy of selection slightly (I). For the Holstein breed, the use of foot angle or rear leg side view as an indicator trait together with direct selection of sole ulcer did not have an effect on the accuracy of selection (II).

According to the results, rear leg side view could be used in genetic evaluations together with claw trimming records to increase the accuracy of breeding values for claw health in the Finnish Ayrshire breed, especially in bulls with few progeny records (I). By contrast, the use of feet and leg conformation traits in genetic evaluations together with claw trimming records is not efficient for the Finnish Holstein breed (II). These findings support the method that NAV uses in the prediction of breeding values for Nordic dairy cattle breeds. NAV uses genomic information, and the estimated breeding value (EBV) of bulls is based on a large number of daughters. Therefore, the gain in the accuracy of selection due to additional indirect traits is less important. Based on the result of this thesis, there is no need to include feet and leg conformation traits in the Nordic claw health index.

4.4 Risk factors for claw disorders

In Study III, the effects of cow-level and herd-level factors on infectious and non-infectious claw disorders were studied. Most cow-level (breed, parity, season, year, and stage of lactation) factors were similar for TS and LH herds and for infectious and non-infectious claw disorders. However, most herd-level (housing type, feeding system, bedding material, bed surface, outdoor access, and number of annual herd maintenance trimmings) factors were different for TS and LH herds and for infectious and non-infectious claw disorders and should therefore be studied separately. Recommendations regarding housing and management options for an individual herd should be made according to the herd's previous disease status and housing type.

4.4.1 Cow-level risk factors

Categorical cow-level fixed factors ($p<0.05$) used in the final models for infectious and non-infectious claw disorders in TS and LH herds, odds ratios (ORs), and their statistical significance from Study III are presented in Table 8. Some of the important results are reported below together with a discussion of the effects.

Holstein cows had higher odds of contracting non-infectious claw disorders; a finding is in accord with previous studies (Kujala et al., 2009; Liinamo et al., 2009). Ayrshire cows, in turn, had higher odds of contracting infectious claw disorders. However, the overall prevalence of infectious claw disorders was very low, especially for Holstein cows in TS herds.

The prevalence of infectious and non-infectious claw disorders increased together with parity in TS and LH herds in both disorder groups. Similar results have been reported in earlier studies (e.g. Bielfeldt et al., 2005; Somers et al., 2005). The current findings can be explained by the cumulative effect of physiological stress caused by multiple lactations and previous claw disorders and/or other diseases.

Season had a significant effect on the prevalence on claw disorders in TS and LH herds. Risk of infectious claw disorders was highest during winter, in accordance with e.g. Bielfeldt et al. (2005), who found that cows had the highest risk of contracting heel horn erosion and interdigital dermatitis during the winter months. A possible explanation could be that many cows are in peak lactation during winter, which might expose them to claw disorders. In TS herds, the risk of contracting non-infectious claw disorders was highest during autumn, consistent with the study of Bielfeldt et al. (2005), who reported that cows had the highest risk of contracting sole disorder (sole haemorrhage, sole ulcer, and double sole) and white line disorder during autumn. In LH herds, the risk of contracting non-infectious claw disorders was highest during summer and autumn. One explanation for these findings could be the mechanical stress on cows' claws during and after the grazing season.

Table 8 *Cow-level fixed factors (p<0.05) used in the final models for infectious and non-infectious claw disorders in tie stall and loose house herds, odds ratios (ORs) and their statistical significance*

Variable	Category	Infectious, OR		Non-infectious, OR	
		Tie stall	Loose house	Tie stall	Loose house
Parity	1	1	1	1	1
	2	2.19***	2.01***	1.60***	1.41***
	3	2.41***	2.70***	2.93***	2.07***
	4+	2.39***	3.35***	4.27***	2.81***
Breed	Ayrshire	1	1	1	1
	Holstein	0.56***	0.86*	1.43***	1.52***
Season	Winter	1	1	1	1
	Spring	0.76*	0.82*	0.92	0.99
	Summer	0.66**	0.54***	0.91	1.30***
	Autumn	0.75*	0.48***	1.51***	1.27***
Stage of lactation, days	1–60	1	1	1	1
	61–120	0.74	1.11	2.37***	2.24***
	121–180	0.65	0.81**	1.96***	2.04***
	181–240	0.75*	0.91	1.15*	1.62***
	>241	0.70***	0.95	0.67***	1.09*

* P<0.05, ** P<0.01, ***P<0.001

The stage of lactation had a significant effect on the prevalence of claw disorders in both herd types. Cows in lactation for 61-120 days had the highest odds of contracting infectious (LH) and non-infectious (TS and LH) claw disorders, and cows in lactation 1-60 days had the highest risk of contracting infectious claw disorders in TS herds. The findings from our study are in accord with previous studies (Manske, 2002; Liinamo et al., 2009). The observed higher odds for claw disorders in early lactation might be explained by the cows being more vulnerable to contracting subclinical laminitis because of rapid changes in their body weights and diets and lactation stress (Liinamo et al., 2009). Also, laminitis-related lesions, such as sole haemorrhages, can be observed only after approximately two months from the appearance of laminitis.

4.4.2 Herd-level risk factors

Herd-level fixed factors (p<0.05) used in the final models for infectious and non-infectious claw disorders in TS and LH herds, odds ratios, and their statistical significance from Study III are presented in Table 9. Some of the important results are reported below together with a discussion of the effects.

Loose housing type had an effect on the prevalence of claw disorders. Cows in LH herds with solid flooring and free stalls had a lower risk of contracting infectious and non-infectious claw disorders than cows kept on slatted flooring and free stalls. A possible explanation for the higher odds found in slatted flooring could be the hard and uneven slats. Solid flooring enables uniform support for the claws, causing less stress than slatted flooring (Hinterhofen et al., 2006). In the current study, information on the use of manure scrapers was not available. These scrapers might have a considerable impact on herd hygiene, and thus, this information should be added to the data in the future.

Feeding type had a significant effect on the prevalence on infectious and non-infectious claw disorders in LH herds. Cows in LH herds using a total mixed ration feeding system had lower odds of contracting infectious and non-infectious claw disorders than cows fed according to their milk yield (concentrate and roughage fed separately). However, interpreting the results from our study is difficult since mixed ration feeding systems can vary with their ratios of roughage to concentrate between herds.

Rubber mats seemed to be a preventive factor for infectious claw disorders in TS herds, which is in accordance with the study of Liinamo et al. (2009), who reported these cows to have lower odds of contracting heel horn erosion than cows standing on hard surfaces. However, no statistical differences emerged in LH herds and the non-infectious disorder group. Similarly, Sogstad et al. (2005) observed no difference between concrete and rubber mats in the prevalence of claw disorders, but found that bed surface is strongly correlated with the alley flooring type. In this thesis, the alley flooring type was not known and this information should be added in the future to yield more accurate data.

Cows with peat as a bedding material had higher odds of contracting infectious claw disorders in TS and LH herds than cows with other bedding materials. Haltia et al. (2006) reported that peat was associated with a higher prevalence of mastitis and speculated that this could be due to cow hygiene; it is difficult to keep animals clean in peat bedding. This could also be why more infectious claw disorders were found in our study. The lack of bedding used in stalls has been shown to be a risk factor for claw disorders (Faull et al., 1996). However, the amount of bedding used in stalls was unknown in this study and should be taken into account when choosing the best bedding material to avoid infectious claw disorders.

In Finland, most cows in TS and LH herds have access to pasture during summer. However, the data of Study III also contained observations from cows always kept indoors. Cows always kept indoors had higher odds of contracting non-infectious claw disorders in TS herds than cows with access to pasture or an exercise yard at least during the summer. The finding is in accordance with previous reports, and several studies have suggested that it might be more comfortable for a cow to stand or lie down in pasture, which might have a positive effect on claw health (Hernandez-Mendo et al., 2007; Barker et al., 2009). However, cows in TS herds that had access to pasture during summer and an exercise yard during winter were most likely to contract infectious claw disorders, in accordance with the study of Bielfeldt et al. (2005), who found more interdigital disorders in herds with outdoor access. By contrast, some studies have suggested that fully grazing cows are less exposed to the unfavourable barn environment and some mild disorders may heal more effectively in pasture (Somers et al., 2005). Infectious disorders may potentially spread from cow to cow while walking to and from the outdoors. Several studies have reported that pathway construction, and management of cow-traffic leading to the pasture have a considerable impact on dairy cows' claw health (e.g. Chesterton et al., 1989). Therefore, investigating whether e.g. yard design, flooring material, management of cow-traffic indoors and outdoors, and time that the cows are held outdoors daily have an effect on the disorder prevalence is warranted. This information is not currently included in the national data.

The number of yearly herd maintenance trimmings had an effect on the prevalence of infectious (TS) and non-infectious (LH) claw disorders. Cows trimmed once a year had lower odds of contracting infectious claw disorders (TS) or non-infectious claw disorders (LH) than cows trimmed at least twice a year, consistent with previous studies (Holzhauer et al., 2006a; Kujala et al., 2009, 2010). A possible reason for higher odds of infectious claw disorders with more frequent trimmings could be that claw trimmers are a source of infection if they do not properly wash their trimming equipment between cows and farms (Wells et al., 1999). The other explanation could be that claw trimming might be used as a curative measure in infected herds or in herds with a history of claw infections (Holzhauer et al., 2006b).

4.4.3 Claw trimmer, herd, and animal

Claw trimmer and herd variances were higher in the infectious disorder group than in the non-infectious group in TS and LH herds. Whereas, animal variance was higher in the non-infectious disorder group than in the infectious group in both herd types. High inter-claw trimmer variances, possibly due to the difficulty of consistent classification of claw disorders, have been reported in several previous studies (Somers et al., 2003; Bielfeldt et al., 2005; Holzhauer et al., 2006a; Kujala et al., 2009). High claw trimmer variances suggest that standardized training for claw trimmers should be considered for the national recording of claw disorders. For example, some claw disorders might go unnoticed if the cow has a severe claw disorder as well or if the claw disorder is very mild. Some actions have already been taken, and an automated claw mobile system, which will enable faster and more reliable data collection, is currently in test use in Finland.

The high herd variance in the infectious disorder group reflects the importance of herd housing methods in controlling the prevalence of infectious disorders, as also suggested by Liinamo et al. (2009) and Wells et al. (1999). The high animal variance in the non-infectious disorder group can be partly explained by the higher number of repeated records in this disorder group.

Table 9 *Herd-level fixed factors (p<0.05) used in the final models for infectious and non-infectious claw disorders in tie stall and loose house herds, odds ratios (ORs) and their statistical significance*

Variable	Category	Infectious, OR		Non-infectious, OR	
		Tie stall	Loose house	Tie stall	Loose house
Loose housing type	Slatted floor, free stalls		1		1
	Corridors, free stalls		0.52***		0.72***
	Deep litter		2.30**		0.80
Feeding type	Feeding according to yield		1		1
	Mixed ration		0.50***		0.61***
	Partial mixed ration		1.29		1.18
Bed surface	Concrete	1			
	Rubber mats	0.59***			
Bedding material	Shavings	1	1		
	Peat	1.47*	1.97***		
	Straw	0.99	0.81		
	Other	1.10***	1.05		
Outdoor facilities	Summer pasture, winter yard	1		1	
	Summer pasture, winter indoors	0.45*		1.08	
	Summer yard	0.40***		1.05	
	Summer and winter indoors	0.66***		1.46***	
Claw trimmings	At least twice a year	1			1
	Once a year	0.49***			0.81*
	Not known	1.00			

* P<0.05, ** P<0.01, ***P<0.001

4.5 Relationship between feeding behaviour and lameness

The relationship between feeding behaviour and lameness was evaluated in Study IV. Some of the most interesting results are reported below together with a discussion of the effects.

4.5.1 Associations with lameness scores

Total daily silage feeding time decreased and feeding rate increased with higher lameness scores, especially among severely lame primiparous cows. At the same time, severely lame primiparous cows had lower body weights than other cows. The findings from our study are in accord with earlier studies that have reported lame cows to have increased feeding rates and decreased feeding times (e.g. González et al., 2008). The university research herd had fewer silage feeders than cows; thus, cows were probably affected by feeding competition. Previous studies have shown that feeding competition among animals might result in aggressive behaviour (DeVries et al., 2004), reduced feeding time (DeVries & von Keyserlingk, 2009), and reduced feed intake (Collings et al., 2011). Short adaption period to the herd and smaller body size of primiparous cows can make them more vulnerable to the competition, affecting their feeding behaviour (Katainen et al., 2005; Val-Laillet et al., 2008). The faster feeding rate of lame cows might be due to pain in the claws caused by standing on the feeding alley or these cows may eat faster to avoid confrontation with other cows.

4.5.2 Associations with days in milk

Cows in early lactation spent less time feeding, ate at a faster rate, and had shorter feeding bouts. Lame primiparous and early lactating cows, which have the highest demand for energy, seemed to be most affected in their feeding behaviour in this study. Similar findings from early lactating cows have also been reported earlier (Palmer et al., 2012). High milk yield increases standing time of dairy cows (Norring et al., 2012) and possibly due to production stress, high yielding cows can also be predisposed to lameness (Fleischer et al., 2001; Green et al., 2002).

4.5.3 Prediction of lameness based on feeding behaviour

A change in feeding behaviour was noticed when lameness score increased from 3 to 4 or higher; silage intake and feeding time were lower in the two weeks prior to severe lameness being recorded. This indicates that decreased silage intake and feeding time might occur simultaneously or even before the change in the cow's gait is visible. These changes in cows' feeding behaviour can be used when developing automated lameness detection systems. Developing automated lameness detection systems for commercial use is difficult. The system should be able to identify several symptoms that cows might exhibit, and the system should be affordable to farmers. According to Chapinal et al. (2010), a successful lameness detection system should be able to combine more than one sign connected with lameness. Pressure platforms, visual imaging, and acceleration have been studied previously as sources of lameness information (Song et al., 2008; Pastell et al., 2010; Chapinal et al., 2011). For example, Pastell et al. (2010) reported promising findings on the detection of lame cows through changes in their leg weight ratio. One major advantage of the automatic lameness detection systems is that they are observer-independent and the results are repeatable. In modern dairy operations, advanced technology of feeders and milking stations already exists and could be integrated into these systems to provide reliable lameness monitoring systems.

4.5.4 Locomotion scoring sheet and agreement with observers

The agreement between two independent observers in 15 locomotion scorings was 95%, which is high enough to enable reliable results. There are many different locomotion scoring systems available, with the focus on cows' head movement, feet movement, and back movement, or just one or two of these. The locomotion scoring sheet used in Study IV by Winckler & Willen (2001) focused only on movement of feet. This scoring system seemed to be easy to learn and implement in practice. Focusing only on feet movements might improve agreement between observers, and the observer can concentrate on one thing. However, while using this system, it was noted that the criteria for score 1 was impossible to reach for older Ayrshire cows with a big udder between their hind legs. The timing of steps and weight bearing cannot be equal for all four feet if the cow has a big udder pressing against their hind legs. In Study IV, the locomotion classes 1 and 2 were merged together, removing the bias this could have affected the results.

5 Conclusions

This study estimated heritabilities and genetic correlations for claw traits for Finnish Ayrshire and Holstein cows. Based on the results, claw traits are heritable; hence, it is meaningful to predict breeding values for claw traits. However, most of the heritabilities for claw traits were low, and improvement in the traits can be accomplished only in the long term. Heritabilities for feet and leg conformation traits were generally higher than heritabilities for claw traits. Selection index calculations indicated that rear leg side view could be used in genetic evaluations together with claw trimming records to increase the accuracy of breeding values for claw health in Finnish Ayrshire cows. The gain in accuracy was higher for bulls with only a few progeny records. The use of feet and leg conformation traits in genetic evaluations together with claw trimming records was not efficient for Finnish Holstein cows. The EBVs of bulls are based on a large number of daughters in the current genetic analysis in NAV; hence, the gain in the accuracy of selection due to additional indirect traits is less important. According to the results of this study, the current genetic evaluation method for claw traits in NAV seems to be applicable for Finnish Ayrshire and Holstein breeds.

This study showed that most cow-level factors (breed, parity, season, year, stage of lactation) had similar effects on the prevalence of infectious and non-infectious claw disorders in TS and LH herds. Most herd-level factors, by contrast, had different effects on infectious and non-infectious claw disorders in TS and LH herds. Therefore, when deciding on housing and management options for an individual herd, the recommendations should be based on the herd's previous disease status and housing type.

The results from this study highlight the importance of claw trimming data collection. Some steps towards more reliable and faster data collection have already been taken, and a new mobile software recording system has been established. The new system enables more efficient data recording, and records are downloaded to the database without any delay. However, the inter-claw trimmer variances in the national data were quite high, especially for infectious claw disorders, which is mainly due to the non-standardized training of claw trimmers. High inter-claw trimmer variances reveal the difficulty of consistent classification of claw disorders, and the training for claw trimmers should be improved and harmonized to achieve more objective recording of claw disorders. Claw health data are utilized in genetic evaluations and for research purposes, and high inter-claw trimmer variances may reduce the accuracy of these analyses.

This study showed that decreased silage intake and feeding time might occur simultaneously or even before visible changes are seen in a cow's gait. These changes in a cow's feeding behaviour can be used when automated lameness detection systems are developed. The advanced technology of feeders and milking stations is already present in modern dairy herds and could be integrated into previously studied systems, such as acceleration sensors, visual imaging, and pressure platforms, to provide reliable lameness monitoring systems.

6 Future research and developments

According to our results, the use of feet and leg conformation traits did not markedly improve genetic evaluations for claw traits. The correlations between individual claw disorders and feet and leg conformation traits were not analysed for the Finnish Ayrshire breed; these estimates should be analysed in the future to confirm the findings of this thesis.

Some changes should be made to the claw trimming data collection system in Finland to achieve better data quality and provide more uniform data for genetic evaluations and research purposes. The training of Finnish claw trimmers should be standardized and follow-up training should be provided annually to assure objective recording of claw disorders. The new mobile software recording system enables a large amount of claw trimming observations in a short period. It would be interesting to compare the claw trimmer ICCs before and after mobile data collection to determine how the new device affects data quality.

The national housing and management practice data include information on only certain herd-level factors. The underlying reasons for some statistical differences in cow-level and herd-level variables remain unclear. More detailed research is therefore needed to explain these differences. In addition, more precise herd-level indicators should be added to the national housing and management practice data to facilitate future research. Information on the use of manure scrapers, the average amount of bedding used in stalls, herd alley material, herd alley width, exercise yard flooring material and size, time spent outdoors, pathway construction, and more accurate data on cow feeding are needed to reveal the underlying causes for some of the differences found in this thesis. Some aspects in the nationwide data cannot be standardized, and hence, more detailed research should be done in study herds. It is also essential to test whether herd-level factors have an effect on claw health in research herds before adding them to the national data.

Different economic aspects concerning dairy cattle claw health have been studied recently in several countries, but were not investigated here. Since several claw disorders can have a serious impact on the profitability of milk production at herd level and some of these costs may vary between countries, it is important to update the costs for different claw disorders also in Finland. The research should focus on costly infectious disorders, which are a huge problem in many countries. Infectious claw disorders have generally not been a serious problem, but the prevalence of these disorders might increase in the future as the proportion of LH herds grows and herd sizes increase. The economic losses from infectious claw disorders can be dramatic if the majority of cows in a herd are infected.

Developing automated lameness detection systems for commercial use is difficult because the system should be able to identify several symptoms that cows might exhibit and the system should also be affordable to farmers. Not all cases of lameness are due to claw disorders; however, claw disorders and infectious lesions in the surrounding skin are frequent causes of lameness. Decreased silage intake and feeding time can be used as a signs of lameness when developing automated lameness detection systems. However, more research is needed to develop reliable and affordable lameness monitoring systems.

Locomotion scoring is not generally used on Finnish dairy farms. However, LH herds are becoming increasingly common in Finland, and the prevalence of lame cows in these herds is higher than in TS herds. On small farms, lame cows can be detected quite well without locomotion scoring. However, on larger farms lame cows may go unnoticed. Locomotion scoring is a relatively quick and simple method to assess whether cows can walk normally and should be considered in regular use on Finnish farms. If locomotion scoring is done regularly (e.g. monthly), it can be used to identify cows at risk of becoming clinically lame, and these cows can be examined closely to establish the reason for lameness. Locomotion scoring can also be used to predict herd milk loss, which can serve as a criterion to determine whether farm housing and management practices should be changed.

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