Hoof Lesions and Lameness in Swedish Dairy Cattle

Prevalence, risk factors, effects of claw trimming, and consequences for productivity

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Abstract

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This thesis used hoof-health records obtained at claw trimming in 102 Swedish dairy herds during 2 years to study different aspects of hoof health. Most (72%) of the 4,899 trimmed cows had at least one hoof-lesion whereas 5.1% were lame. Hoof lesions and lameness were associated with both individual- and herd-level risk factors. Individual (cow) level risk factors were of greater importance for explaining variation associated with claw-capsule defects than for skin lesions.

Except for claw-horn haemorrhages, hoof lesions were more common in multiparous than in primiparous cows. Moreover, the risk of lameness and hoof lesions (except dermatitis) further increased with parity. Swedish Holsteins were at an increased risk of haemorrhages and sole ulcers compared to other breeds. Cows at 61-150 days in milk were at increased risk of haemorrhages and sole ulcers. Heifers that had calved at a relatively low age were at a decreased risk of hoof lesions. Cows with dirty hooves were at an increased risk of lesions and lameness. The risk of dermatitis or heel horn erosion was three times higher in cows housed in loose-housing systems than in tie-stalls.

There was a negative effect of lameness on longevity (increased risk of culling within the same lactation) and of hoof lesions on reproductive performance. Significant negative associations were found between sole ulcer and first-service conception rate, calving interval, and treatment for anoestrus. Cows with sole ulcers had a higher milk yield than cows without, indicating that high-producing cows are more prone to develop the disease. Claw trimming in autumn reduced both the risk of lameness and hoof lesions in the following spring (~4.5 months later) and the need for acute hoof treatments between trimmings. The results of this thesis demonstrate the importance of hoof health for dairy cow productivity, and of claw trimming in maintaining and restoring hoof health.

Keywords: dairy cows, heifers, animal health, foot and leg disease, laminitis, locomotion, welfare, disease effects, fertility, mastitis, somatic-cell count.

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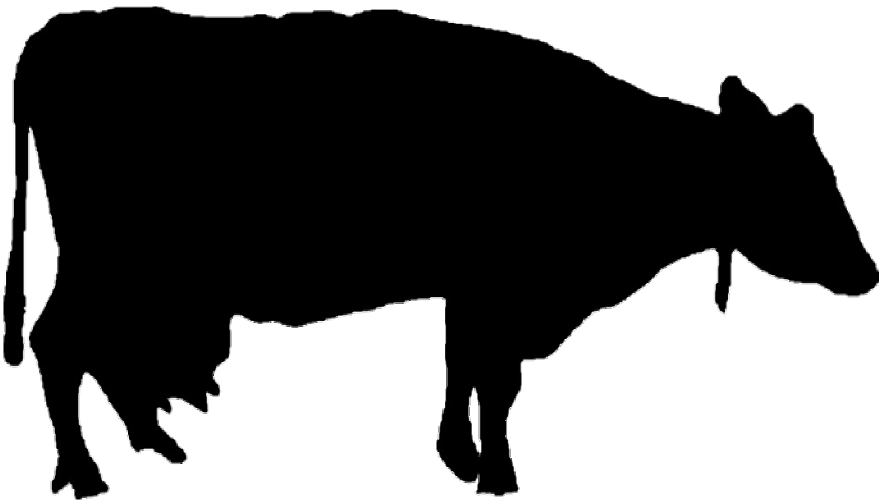
Es ist mir zwar hinlänglich aus der Praxis bekannt, daß der Thierarzt in Bezug auf die Pflege der Hausthiere wenig oder keinen Einfluss auf eine große Zahl ihrer Eigenthümer üben kann. Eine kleine Mühe für die Pflege der Füße ihrer Hausthiere erachten sie für überflüssig; es kostet sie Überwindung, sich derselben zu unterziehen; doppelt größere, selbst mit Kostenaufwand verbundene gegen bereits eingetretene Fußkrankheiten scheuen sie hingegen nicht. Vorurtheil und Nachlässigkeit, fordern auch hierin nicht selten empfindliche Opfer an größern Hausthieren, die durch eine angemessene Wartung und Pflege ihrer Füße leicht hätten erhalten werden können. Darauf aufmerksam zu machen ist der Thierarztes Pflicht.

M. Anker (1854)

Den som förstår sig oppå att skåda en ko,
han behöver icke se någonting annat häri världen.
Han behöver icke känna någon törst däri ögonen mer.

T. Lindgren (1983)

Contents



An early indication of lameness: excessive weight is borne by the front limbs in order to relieve sore hind hooves resulting in an arched back in the standing and moving animal.

Appendix

Papers I-IV

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Manske, T., Hultgren, J. & Bergsten, C. Prevalence and interrelationships of hoof lesions and lameness in Swedish dairy cows. *Preventive veterinary medicine 54*, 247-263.

II. Manske, T., Hultgren, J. & Bergsten, C. A cross-sectional study of risk factors for the hoof health of Swedish dairy cattle. (Submitted manuscript)

III. Manske, T., Hultgren, J. & Bergsten, C. The effect of claw trimming on the hoof health of Swedish dairy cattle. *Preventive veterinary medicine 54*, 113-129.

IV. Hultgren, J., Manske, T. & Bergsten, C. Associations of sole ulcer and lameness at claw trimming with reproductive performance, udder health, and culling in Swedish dairy cattle. (Manuscript)

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Background

There are several recent reports that demonstrate lameness in dairy cows is an economically important production disease (Kaneene & Hurd, 1990; Enting *et al.*, 1997; Fourichon *et al.*, 2001). Most dairy cow lamenesses arise from diseases and lesions of the hooves (Hess, 1904; Murray *et al.*, 1996) – although hoof lesions in many cases do not cause lameness. Many aspects of modern intensive dairy production are likely to influence the hoof health of dairy cows and cause lesions but (mostly due to the lack of reliable records) knowledge about the frequency of hoof lesions and the importance of individual- and herd-level risk factors for the development of lesions and lameness is insufficient.

Claw trimming allegedly has a positive effect on hoof health, and gives a good opportunity to obtain records of hoof health. Although the need for claw trimming has long been recognized (Anker, 1854; Blomqvist, 1895), no large-scale controlled study on the actual effects of claw trimming on the hoof health of dairy cows has yet been conducted.

There is little research published on the effect of subclinical (*i.e.* not associated with lameness) hoof lesions. However, Berry *et al.* (1998) showed that non-lame cows with hoof lesions (dermatitis) might have both an altered lying-down and lying behaviour, possibly indicating a reduced welfare. The effect of subclinical hoof lesions on productivity has not yet been studied.

Introduction

Some historical aspects on the husbandry of dairy cattle

The earliest indication of milking and housing of cattle is a Mesopotamian bas-relief from 3,000 B.C., showing two men milking cows in a reed cattle-shed. The habit of housing cattle (initially in a separate stone-surfaced part of the human dwellings) was introduced to Sweden in the early Bronze Age (1100 to 500 B.C.) (Myrdal, 1999). It has been argued, that housing of the animals in the Nordic countries was more a result of a desire for a rational husbandry, than out of concern for the welfare of the animals (Welinder *et al.*, 1998). Although the housing of cattle appears to have been increasingly frequent in the period 200 B.C. to 200 A.D., keeping animals outdoors all-year-round remained common practise in some parts of Sweden (*e.g.* in the county of Västergötland) well into the 18th century (Welinder *et al.*, 1998).

Through history, owning cattle has been a sign of wealth (Welinder *et al.*, 1998). The Roman words for money (*pecunia*), and private property (*peculium*) from which the English 'pecuniary' and 'peculiar' emanate, both stem from the word for cattle (*pecus*). Indeed, in the early economies of Britain and Ireland, cows were actually used as a unit of currency; the price of a slave-woman, for instance, was three cows (Mariboe, 1994). An indirect measure of how societies value different animals is the severity of punishment sentences admininstered for crimes against that particular species are. In ancient Rome (as reported at ~60 A.D.), killing an ox was a capital crime comparable to homicide (Columella, 1968). Cattle in India are protected by religious statutes probably first developed to safeguard them during droughts or famine when they might have been killed off.

In medieval (c. 1050-1400) Skara, the religious centre of Västergötland, and also Sweden, cattle were the dominating domesticated species (Vretemark, 1997); male animals were primarily kept for work and females for dairy purposes. The widespread use of oxen for transportation made hoof health and lameness an important cattle-health issue – hoof lesions associated with excess wear and overloading were thus emphasized in the early literature on bovine health. First-century Romans appear to have taken good care of their oxen, as illustrated by the following example of prophylactic hoof care:

> *Minus tamen claudicabunt armenta, si opere disiunctis multa frigida laventur pedes; et deinde suffragines coronaeque ac discrimen ipsum, quo divisa est bovis ungula, vetere axungia defricentur* (Columella, 1968). '*Cattle will be less likely to go lame, if their feet are washed in plenty of cold water when they are unyoked after work and if their hocks, the crowns of their hoofs and the division itself between the two halves of the hoofs are rubbed with stale axle-grease*.'

Early knowledge about hoof diseases was surprisingly accurate. Laminitis in oxen was described already two millennia ago as a down-flow of blood into the animals' feet that gives rise to bruises if not treated and takes a long time to heal if the lesions suppurates (Columella, 1968). The suggested treatment method (scarification and bleeding) has been used extensively until relatively recent times.

Some 1,500 years after Columella's work, the Swede Petrus Magni († 1534), later bishop in Västerås, in his *Bondakonst* (a manual on how to run the agricultural business of a large monastery), emphasized the importance of a soft bedding for housed cattle, and also that the flooring should be kept clean in order to protect cattle hooves from rotting (Månsson, 1983). Three centuries later, Nathorst (1876) in his handbook of animal husbandry, stated that the proper care of animals included: correct and purposeful design of housing and stalls, a plenitude of bedding, good care of hooves and claws, and cleanliness of animals and housing. In modern dairy production, dirtiness in stalls and alleys (and thus in animals) remains a major problem (Hultgren & Bergsten, 2001). This is also reflected in the high prevalence of heel horn erosion ('rotten hooves') (*e.g.* Andersson & Lundström, 1981).

According to Anker (1854) and Lundberg (1868), cattle owners often neglect hoof health and eschew prophylactic hoof care. Hess (1904) argued that farmers' ignorance and practical difficulties associated with the examination and treatment of lame cows caused the negligence of bovine hoof-health. Despite these early insights, the general awareness of hoof-health issues to this day is inadequate. In modern scientific reports, it has been stated that farmers exaggerate their respective herds' hoof health status (Wells *et al.*, 1993a; Mill & Ward, 1994; Whay *et al.*, 2002), avoid claw trimming, which is perceived as both perilous and intrusive (Seabrook & Wilkinson, 2000). As a consequence, impaired hoof health remains one of the most important welfare problems in dairy herds.

Intensive dairy production

Production diseases

The increasing practice of dairy production at the end of the 19th century was associated with an increase in the prevalence and severity of hoof lesions (Hess, 1904). Today, decreasing profit margins and general trends in society promote a further intensification of dairy production, which in turn incurs a risk for further decline in dairy cow health and welfare (Logue, 1996; Wierenga & Blokhuis, 1997; Berry, 2001). Studies indicate that increased milk yield might be associated with decreased reproductive performance (Oltenacu *et al.*, 1991; McGowan et al., 1996; Roxström, 2001), impaired hoof health (Fourichon *et al.*, 2001), decreased longevity (Beaudeau *et al.*, 1995; Roxström, 2001), increased risk of mastitis (Gröhn *et al.*, 1995; Faye *et al.*, 1997), and increased mortality (Nørgaard *et al.*, 1999). Due to an unfavourable genetic correlation between milk yield and hoof lesions (Lyons *et al.*, 1991; Groen, *et al.*, 1994, van Dorp *et al.*, 1998), the susceptibility to hoof lesions increases when selection pressure is put on milk yield. It has been speculated that the genetic capacity of high milk yield is associated with a disturbed perfusion of the corium and (or) diffusion of nutrients and oxygen to the horn-producing cells (Lischer *et al.*, 2000).

The above-mentioned associations between milk yield and health are, however, by no means undisputed, other authors (*e.g.* Gröhn *et al.*, 1995) have not demonstrated any relationship between milk yield and different health traits. But when the preponderance of research is considered, it is reasonable to believe that animal welfare will be increasingly compromised by further intensified dairy production – unless improved management, feeding routines, breeding and other prophylactic measures can prevent an increase in the incidence of production diseases.

The driving-force for increased milk yields has largely been economical (Nørgaard *et al.*, 1999). However, in order for increased milk-yields to be cost-effective, profits from increased production pressure and production efficiency have to cover the increased costs associated with a higher incidence of production diseases. Production diseases incur costs in a number of ways: through decreased milk yield, weight-loss, increased mortality and risk of culling and consequently increased recruitment, impaired reproductive performance, increased risk of secondary diseases, costs associated with treatment and prevention, and loss of production potential. Moreover, several production diseases, such as lameness (Enevoldsen *et al.*, 1991a,b; Alban *et al.*, 1996; Hirst *et al.*, 2002), have a high rate of reoccurrence, either due to permanently damaged tissue, persisting challenges or a genetic predisposition.

Housing

Dairy cows in northern Europe are generally kept indoors during winter. Whereas, in summer, most cows are kept at pasture – at least for parts of the day. Numerous reports on a negative association between housing and health, particularly hoof health, have been published (*e.g.* Anker, 1854; Hess, 1904; Andersson & Lundström, 1981; Leonard *et al.*, 1994). On the other hand, there is a large amount of variation in hoof health between herds (Frankena *et al.*, 1992; Clarkson *et al.*, 1996; Whitaker *et al.*, 2000). One cause of such variability might be the use of different housing systems (Thysen, 1987; Faye & Lescourret, 1989). Dairy cow housing is either insulated or not ("warm" or "cold" housing). Cold housing is often characterized by a better air quality and lower humidity than insulated houses – especially in the winter, when heating-costs exclude effective ventilation in insulated houses. At the same time, animals in cold housing are exposed to a sometimes-harsh climate. In a Finnish study (Schnier *et al.*, 2002), no negative health effects of cold housing of dairy cows could be demonstrated. Through history, dairy cows in Sweden have generally been tied while housed and tie-stall systems are still the dominating housing system. In 1997, dairy cows were fixated in >90% of dairy herds (Hultgren *et al.*, 1997). Traditionally, tie-stalls have been of a long-stall type with lockable feeding-barriers, in which cows have had restricted access to the manger. With the intensification of dairy production and an increasing need of prolonged feeding times (and consequent problems with stall hygiene in long-stall systems), ordinary (short) tie-stalls, with unlimited access to the mangers, have become increasingly popular in Sweden.

Tie-stalls, by definition, decrease the freedom of movement and hence, to a varying degree, inflict restrictions upon the welfare of dairy cows. To give tied cows better opportunity to perform behaviours such as rising and lying-down, licking, stretching, *etc.*, ties must allow a certain freedom of movement. With increasing length of the ties, however, the cows will defecate more in the stalls. Daily exercise, shown to be beneficial in preventing health disorders such as calving-related diseases and mastitis, are associated with a higher incidence of veterinary-treated lameness-cases (Gustafson, 1993). Tie-stalls are labour intensive, requiring several daily manual scrapings – a work that many farmers have an aversion to (Seabrook & Wilkinson, 2000). Electric cow trainers have been used to improve stall hygiene and cow cleanliness (Bergsten & Pettersson, 1992), but have been associated with negative effects on reproductive performance and udder health, as well as with an increased risk of ketosis and culling (Oltenacu *et al.*, 1998). Electric cow trainers are currently banned in Sweden. More recently, a rubber-slatted floor has been designed for use with tie-stalls, and was proven effective in reducing exposure to manure and improving hoof health (Hultgren & Bergsten, 2001). Rubber mats in tie stalls reportedly have a positive effect on the hoof health in tied lactating cows (Bergsten & Frank, 1996b; Bergsten, 1994), but a positive effect could not be shown experimentally for pregnant heifers (Bergsten & Frank, 1996a). If claws are not trimmed, the lack of wear in tied cattle causes deformed hooves (Hess, 1904) and predisposes to the cause, or causes, hoof lesions (Anker, 1854; Smedegaard, 1964).

Indoor housing allowing more freedom of movement can be either cubicles (intended for lying only, or for both, lying and eating) or deep-bedded straw packs. The two systems differ in the extent of the bedded surface and the arrangement of lying places. Cows spend more time lying down and ruminating in straw yards than in cubicles (Singh *et al.*, 1994a), they also display a more synchronised lying-behaviour, possibly indicating increased welfare (Fregonesi & Leaver, 2001). In straw yards that are not correctly managed, with sufficient amounts of fresh bedding-material, there is a risk of increased dirtiness and udder-health problems (Fregonesi & Leaver, 2001). In western Sweden, dairy herds on straw packs are rare (~1% of the herds) (Hultgren *et al.*, 1997).

From the 1960's and onwards, cubicle housings have become more and more popular in Sweden. Partly due to a perceived better welfare in non-tied systems (Albright, 1983; Fox, 1983), the political incentives for cubicles (and other loose-housing systems) have been strong, as indicated by the recommendation from the Swedish Board of Agriculture, that dairy cows "should be housed in free-range systems." This demand is accentuated in organic herds; where (according to EEC-rules adopted from International Federation of the Organic Agricultural Movement) free-range housing is to be required from the year 2010. Today, a majority of newly designed housing facilities have cubicles (Hultgren, 2001). Cubicle-surfaces are mostly either concrete or concrete equipped with mats or mattresses. In both cases, varying amounts of bedding (generally chopped straw, wood shavings or saw dust) is used. Deep sand bedding is used only rarely. The advantages of cubicles include cost-efficiency and the possibility to design cubicle-housing systems more efficiently (to be less labour-intensive) and more adapted to the animals' different needs.

The hoof health in cubicle systems is generally compromised relative to tie-stalls (Bergsten & Herlin, 1996; Faye & Lescourret, 1989; Thysen, 1987; Rowlands *et al.*, 1983). Moreover, cows in herds changing from tie-stalls to cubicles have been shown to be at an increased risk of veterinary treatments for lameness for a period extending 12-18 months after the construction was finished (Hultgren, 2002). There is a plethora of suggested causes for the negative effect of cubicle housing on hoof health, *e.g.* increased exposure to contagious agents, increased social stress (Ladewig & Smidt, 1989; Singh *et al.*, 1993; Galindo & Broom, 1993, 2000), uncomfortable stalls either by design or mismanagement (Colam-Ainsworth, 1989; Leonard *et al.*, 1994; Faull *et al.*, 1996), overcrowding (Leonard *et al.*, 1996; Faye *et al.*, 1997), and slippery or excessively rough floors (Kümper, 1994; Faull *et al.*, 1996; Dirksen 1996, 1997). The key issue in designing functional cubicle systems is "cow comfort" (Berry, 2001; Vokey *et al.*, 2001).

To optimise production and reduce hoof exposure to un-yielding contaminated floors, cows are supposed to stand to eat, drink or be milked, or lie-down to rest and ruminate. Idle standing in walkways or half-in and half-out of the cubicles has been associated with social stress (Galindo *et al.*, 2000) or uncomfortable (or otherwise less-than-optimally designed) cubicles interfering with the natural lying-down or getting-up behaviour of cattle (Colam-Ainsworth *et al.*, 1989; Wierenga & Hopster, 1990; Leonard *et al.*, 1994). Prolonged standing times have been associated with an increased prevalence of claw lesions and lameness (Colam-Ainsworth, 1989; Singh *et al.*, 1993; Galindo & Broom, 1993; Leonard *et al.*, 1994, 1996; Galindo *et al.*, 2000). Avoiding social stress and aggression is primarily a matter of spatial supply, the structure of housing conditions, as well as the size and composition of the herd or group (Galindo *et al.*, 2000). The optimum size of a group of dairy cows has yet to be determined. Estimates of maximum group sizes for recognition of individual herd members range from 50 to about 100 animals. Changes in groupings of animals create stress on both the new animals in the group and on those in the existing group (Lamb, 1976).

The flooring in the alleys of Swedish cubicle systems is almost exclusively slatted or scraped solid concrete (Hultgren *et al.*, 1997). More recently, asphalt has earned increasing attention as flooring surface due to its wear-resistant and resilient qualities. Concrete is a non-resilient walking-surface that cows avoid when given the chance (Faull *et al.*, 1996), particularly if suffering from sore hooves (Hess, 1904). Faye & Lescourret (1989) found a higher incidence of lameness in cows on concrete relative to cows on earth floors. Vokey *et al.* (2001) studied different indices of hoof health in animals housed in cubicles with different lying-surfaces and alleys that were either concrete equipped with 1.9 cm thick rubber mats or grooved concrete. In their study, there were no differences in prevalence of lesions between different alley-surfaces, but a positive effect of rubber mats could potentially have been obscured from confounding by parity. Although there were inconsistencies between different measures of hoof health, the authors concluded that alleys with rubber flooring and sand-bedded cubicles appeared most beneficial to hoof health. In a more recent study, Benz (2002) found less severe claw lesions as well as improved behaviour (more caudal licking) in a group of cows on rubber-covered slats compared to those on slippery concrete slats.

Scraped floors generally have good walkability for cows, but fixed manure scrapers impose a potential hazard to cows' hooves, and with physical and chemical wear the flooring may become very slippery. Slatted flooring decreases exposure to manure, but cows on slats show an impaired walking pattern (Herlin & Drevemo, 1997; Telezhenko *et al.*, 2002) with a decreased stride length, more outwards-directed steps and an increased step frequency, compared to cows on solid concrete floors (Telezhenko, *et al.*, 2002). It is possible, that the abduction of the feet can cause a shift of weight bearing, causing compression of sensitive solar tissue and the subsequent development of sole lesions (Bergsten, 2001). Phillips & Morris (2001) showed that cows on a slippery surface walk with more frequent but shortened steps, and Telezhenko *et al.* (2002) reported that there is an inverse relationship between step abduction and step length.

It is likely, that cows with altered locomotion have an unusual mode of wear of the claw capsule, with more wear of the wall, and consequently more weight being carried by the sole. Faull *et al.* (1996) found cows in herds with slippery floors to be at an increased risk of clinical lameness, but having a similar average locomotion score as cows in herds with rougher floor-surfaces. Rough surfaces, on the other hand, induce excess wear by abrasion. New concrete allegedly is more abrasive than old, and wet concrete is more abrasive than dry (Shearer, 1998).

Diets and feeding

In order to accommodate for increased milk yield potentials, feeding has been intensified. Less fibre-rich rations have been associated with an increased incidence of low milk fat syndrome and production diseases, such as left-sided displaced abomasi (Lucey *et al.*, 1986; Stengärde & Pehrson, 2001). With intensified feeding the risk of ruminal acidosis increases (see: Nocek, 1997), the passage-time of the feed decreases, and the consistency and amount of the faeces is altered. Due to difficulties in conducting impeccable studies of the causal chain feeding-disease-production under field conditions, there is a lack of knowledge on how feeding affects health. However, the most relevant factors for the feeding-disease relationship seem to be the proportion of concentrates (or effective fibre) fed, and how it is provided (Østergaard & Sørensen, 1998). The feeding of large concentrate-quantities has long-since been implicated as a cause of bovine laminitis and lameness (Lafore, 1843). Feeding diets without dry hay was associated with a 2.2 times increase in risk of lameness in 45 Michigan dairy herds (Groehn *et al.*, 1992) and the results of Frankena *et al.* (1992) showed that heifers fed hay and concentrates had less severe hoof lesions than those fed silage. The negative effect of feeding heifers silage relative to hay persists through the first lactation (Offer *et al.*, 2001). There is, however, a growing body of evidence that other factors such as parity, breed, stage of lactation and physical and hygienic properties of the under-foot surfaces (Logue *et al.*, 1994; Bergsten & Frank, 1996b; Bergsten & Herlin, 1996; Livesey *et al.*, 1998; Nordlund, 2002) might modify or override the effect of feeding on hoof health.

The amount of manure produced by dairy cows is related to the level of milk production (through the feed intake), but also to the feed's hygienic and nutritional quality, and its composition (Swedish Board Agric., 1995). By comparing the faeces of beef and dairy cattle, one is provided with an indication of the impact of feeding intensity. Whereas a dairy cow on average produces 36-39 kg faeces (per day and 454 kg [1,000 lb] body weight), extensively managed beef animals produce 23-28 kg/d; the dry matter content (as excreted), on the other hand, is similar for dairy cows (10-15%) as for beef (11-13%) (International Labour Office, 2002). More interestingly, a high-yielding cow in peak lactation produces approximately 100 kg slurry per day; thus putting great demands on the design and management of the cow environment.

Excess nutrients either pass down the alimentary tract and are excreted in the faeces or are absorbed and later removed from the body with the urine. The alimentary tract provides an ideal environment for microbial growth, including species and strains that are parasitic or pathogenic. Part of the microbial population is voided along with the faeces, and might, if faeces come in contact with the skin of the animals, be capable of causing diseases. Examples of such bacteria are the Gram-negative anaerobic *Fusobacterium necrophorum subspecies necrophorum* and *Porphyromonas levii* (previously a subspecies of *Bacteroides melaninogenicus*), two organisms found in the rumen and the faeces of bovines (Berg and Scanlan, 1982) and also repeatedly isolated from cases of interdigital phlegmon (Berg & Loan, 1975). The risk of infection increases with the prolonged exposure to faeces that is caused by the relative stickiness of the lactating dairy cow's manure. The association between the physical properties of manure and its effect on hoof health is an interesting area for future research.

Breeding

Different dairy breeds have different levels of susceptibility for hoof lesions (Hess, 1904; Bech Andersen *et al.*, 1991; Alban, 1995). The intensified production has caused a shift towards specialized dairy breeds, such as Holsteins, that are more prone to develop hoof lesions (Andersson & Lundström, 1981; Bergsten, 1994; Huang *et al.*, 1995). Differences between breeds in susceptibility to hoof lesions might partly be due to differences in claw-horn properties and conformation. The degree of pigmentation of the claw horn differs between breeds, and several authors believe that lesions more often affect non-pigmented claw horn (Anker, 1854; Chesterton *et al.*, 1989; Bech Andersen *et al.*, 1991; Tranter *et al.*, 1993; Logue *et al.*, 1994). Moreover, breeds differ in conformation, and leg conformation is heritable (McDaniel, 1997). The importance of structurally correct conformation has long been emphasized. Several conformational traits have been shown to be genetically or phenotypically associated with hoof health traits. In summary, a hock-narrow base-wide stance, sickle-hockedness, shallow toe angles, wide rumps, and a large body weight (relative to body frame size) appears to be associated with more hoof lesions (see Distl *et al.*, 1990) and lameness (*e.g.* Boelling & Pollott, 1998; Boettcher *et al.*, 1998).

Hoof lesions are to varying degrees heritable (Ral *et al.*, 1995; McDaniel, 1997). A large range in the estimated heritability values for hoof disorders has been reported in the literature. Much of that variation is likely due to the recording or measuring system used; Eriksson & Wretler (1990) used records of veterinary treatments and found very low heritability estimates, whereas Baumgartner *et al.* (1990) and Bech Andersen *et al.* (1991) obtained much higher values under experimental conditions. To optimise a breeding program to reduce hoof health problems, direct information on the target traits is of great value (Ral *et al.*, 2001). Both Distl (1995) and McDaniel (1997) emphasised that selection for better hoof health should not be based on a single measure and, furthermore, that it should include information on progeny and other relatives. The procedure used for recording hoof health in **Papers I-IV** was designed to be possible to implement in routine claw trimming in order to gain information on the hoof health status of *e.g.* AI-bulls' progeny. If used in the breeding evaluation of bulls, hoof-health records routinely collected at trimming could contribute substantially to a long-term improvement of dairy cows' hoof health.

Hoof care and management

Management issues relevant to dairy cow hoof health "hoof care" include the meticulous cleaning of stalls, the use of clean and soft bedding, and the correctly performed claw trimming at regular intervals as already stated by Hess (1904). Other issues of importance are: grazing-, feeding- and heifer-rearing routines, treatment-strategies for lame cows, and culling strategies. The increase in herd size and the increasingly more efficient dairy production has led to fewer working hours per animal. The opportunity for frequent positive contacts between animals and handlers has thus been reduced, possibly incurring a risk of more stressful human-animal interactions, negligence of animal welfare and cleanliness, and less efficient heat-detection. Faye & Lescourret (1989) showed that the hoof health was better in herds were a relatively long time was spent watching the animals. The nature of human-animal interactions has been shown to influence general stress-responses in cattle and hence their welfare (Rushen *et al.*, 2001). According to Albright (1983), the most important issue in determining stress in a dairy herd is "the behavior, attitude and consistency of the caretaker". Impatience when handling animals has been shown to increase the risk of lameness (Chesterton *et al.*, 1989; Clackson & Ward, 1991). Rushen *et al.* (1999) showed that the presence of an aversive handler might be associated with reduced milk yields. Moreover, cows in herds where the farmer did not expect to be a dairy producer in five years time had a higher prevalence of lameness (Alban, 1995). Although the cause-and-effect of this latter association was unclear, it is likely that farmers that are not content with their situation take less care of their animals. With the on-going dramatic decrease in the number of Swedish dairy herds, there is a potential for reduced animal welfare in herds that are planning to go out of business.

Mill & Ward (1994) showed that the herd-specific prevalence of lameness was inversely correlated to the level of formal training and hoof-health awareness of the caretaker. Clarkson *et al.* (1996) proposed, that with proper training of herd-personnel, more lame cows would be adequately treated at an appropriate time and thus the duration of lameness cases reduced and the welfare of affected animals improved.

A possible cause for the exceptionally high frequency of lameness and hoof health problems in British dairy herds (Clarkson *et al.*, 1996) was offered by Seabrook & Wilkinson (2000) who reported results based on a questionnaire survey of 238 UK dairy farmers. The farmers were asked to rate their everyday jobs and cleaning of animals and buildings was the chore most intensely disliked, followed by claw trimming. The need for claw trimming in the prevention of hoof lesions has long been emphasized (Anker, 1854; Nathorst, 1876; Blomqvist, 1895; Hess, 1904; Rusterholz, 1920). According to Nathorst (1876) and Hess (1904), cows should preferably be trimmed twice yearly, the frequency depending on how "natural" the dairy cows are kept. In 1997, approximately one-third of Swedish dairy herds were trimmed twice yearly (Hultgren *et al.*, 1998). Hitherto, however, no large-scale controlled study on the effects of claw trimming on the hoof health of dairy cows there has been performed.

Heifer rearing

Acute laminitis has been described in two-months-old dairy calves (Svensson & Bergsten, 1997). Frankena *et al.* (1992) examined the claw-soles of 1141 dairy calves in 123 herds and found that the prevalence of haemorrhages increased with age from 10% in 2.5-month-olds to 70% in 12-months-olds. Bradley *et al.* (1989) found no lesions in calves ≤4 months-of-age, but in 5-10 months old heifers (despite housing on deep-bedded straw packs). Vermunt & Greenough (1996b) found lesions at 6-7 months-of-age and stated that lesions were common at 13 months-of-age. In a university herd studied by Greenough & Vermunt (1991) the severity of sole haemorrhages in heifers increased to a peak at calving. Although sole lesions are common, most are relatively mild; Frankena *et al.* (1992) did not record any sole ulcers in 1141 examined calves. The results of Kempson & Logue (1993) indicate that the susceptibility to sole haemorrhages can be detected by ultrastructural studies of the horn quality in apparently healthy heifers one month before calving.

The high repeatability of hoof lesions (especially in the claw capsule) between lactations (Alban *et al.*, 1996; Offer *et al.*, 2000; Hirst *et al.*, 2002) makes preventing hoof lesions in heifers and primiparous cows of utmost importance in promoting dairy cow welfare. Calves reared on unyielding flooring-surfaces have more sole haemorrhages; 44.6% of calves reared on slatted concrete had sole haemorrhages compared to 4.6% of calves reared in straw yards (Frankena *et al.*, 1992). Heifers reared on soft surfaces might, however, as indicated by the results of Leonard *et al.* (1996) and Bergsten & Frank (1996b), be more susceptible to lesions when entering the dairy herd. A possible reason for this is that the horn growth in heifers is greater than in cows, and if the wear is not adequate there is a risk of overgrowth and since the digital cushion is yet not fully developed at the time of the first calving (Lischer & Ossent, 2002), there is a pronounced need for "external" shock absorption, either through soft flooring, or through well-shaped claws. There are probably good reasons to trim the claws of heifers that have been reared on a soft surface and have overgrown soles before their first calving.

An early calving age for heifers reduces the unproductive period of a dairy cow's life. Current Swedish recommendations suggest a calving age of 24 months.

To attain the recommended body weight for breeding (340 kg) at 15 months-of-age, an average growth rate of ~700 g/d is necessary. Whereas Vermunt & Greenough (1996a) did not find an association between average daily weight gain in replacement heifers and claw horn lesions, Bergsten & Frank (1996b) found more severe sole haemorrhages in tied heifers on concrete with an average growth rate of 746 g/d compared to 652 g/d. The results of Greenough & Vermunt (1991) indicate that heifers with growth rates >800g/d are at an increased risk of haemorrhages. Growth rates exceeding 1.0 kg/d have been implicated as a cause of laminitis and decreased future milk production (Little & Kay, 1979). Hirst *et al.* (2002) did not find an association between lameness and calving age in heifers, when comparing calving at <27 months-of-age with those that calved later.

Welfare

The welfare of an animal has been defined as "its state as regards its attempts to cope with its environment" (Broom, 1996) or as "the satisfaction of wants and desires" (Duncan, 1996). There is no single measure for the welfare of dairy-cows, especially not regarding how animals perceive their situation ("how they feel"). Instead, it has been suggested that welfare can be assessed from changes in stress-physiology, behaviour, mortality, health and productivity (Broom, 1991, 1996; McGlone, 2001; Morrow-Tesch, 2001). Lameness affects several of the above-mentioned parameters. Hence, it is generally agreed that lameness is associated with severly-decreased welfare (*e.g.* Albright, 1983; Logue, 1996; Webster, 1997).

Even if, intuitively, the degree of lameness reflects the associated pain, it is not possible to objectively assess pain in animals (Rutherford, 2002; Whay, 2002). In cattle, the assessment of pain is further complicated by the unwillingness of individual cattle to display pain behaviour, since this (in an evolutionary sense) would make affected animals more exposed to predators (Sanford *et al.*, 1986). Changes in behaviour and physiological parameters have been used as indicators of pain, and it has been suggested that by using a combination of such indirect parameters quantification of pain in animals might be possible (Rutherford, 2002). Cattle in pain have a dull, depressed appearance, and varying degrees of rapid shallow respiration, inappetence, decreased milk yield and weight loss (Sanford *et al.*, 1986). Lame cows are more restless at milking, and lie down more and eat slower while at grazing (Hassall et al, 1993). Margerison et al. (2002) studied 165 dairy cows in a cubicle-herd over a 3-year period and found that lame cows ate a lower number of meals per day, but had longer meal durations and larger meal sizes than non-lame cows, whereas the dry matter intake was unaffected. Excess lying time causes a functionally reduced access to feed; instead resources necessary for milk production are taken from body stores, resulting in a decreased body condition. In housed animals, increased lying-times and lengths of lying-bouts incur increased risks of decubital ulcers.

Whay *et al.* (1997, 1998) showed that cows with hoof-lameness (regardless of severity) had decreased nociceptive thresholds (hyperalgesia). Hyperalgesia can lead to a generalized sensitivity also to non-noxious stimuli at other sites away from the initial lesion (allodynia), making cows sensitive to normally well-tolerated stimuli such as pushing from other cows or farmers and walking or lying on hard or uneven surfaces. Welfare issues related to hoof health in dairy cows concerns pain and altered behaviour in animals with lesions or lameness, the frequency of lesions, the oftentimes-long period between the onset of lesions and treatment and the potentially incorrect or painful treatments. Whay (2002) specified four key issues in preventing chronic pain and hyperalgesia related to lameness: early detection of lame cows, prompt and effective treatment, sympathetic care, and the use of analgesia.

It has repeatedly (*e.g.* Rusterholz, 1920; Whitaker, 1983; Murray *et al.*, 1996; Whay *et al.*, 2002) been stated that most lame cows are not treated by veterinarians, rather by hoof trimmers or farmers, or are left untreated. The relatively little involvement of the veterinary profession in cattle lameness is probably related to the time-consuming and dirty nature of hoof-work, a general lack of knowledge and interest in the area, a lack of proper equipment, and the associated cost for the farmers. In many countries (including Sweden), hoof trimmers treat many lame cows but are legally hindered from performing surgical interventions and administering analgesia – rendering many lame cows remain untreated or treated without analgesia.

An introductory guide to hoof lesions

Hoof lesions can be divided into those that affect the skin surrpunding the claw capsule (digital and interdigital dermatitis, interdigital hyperplasia and interdigital phlegmon) and those that affect the claw capsule (sole and white line haemorrhages, white line fissures, double soles, abscesses, sole ulcers and wall lesions such as sand cracks). The former are generally associated with microorganisms; the latter are generally consequences of laminitis and (or) trauma.

Heel horn erosion

Heel horn erosion is defined as an ”irregular loss of bulbar horn” (Collick, 1997). The loss of horn tissue can be caused by a structural breakdown induced by manure and urine (Mülling and Budras, 1998), or by dermatitis undermining and (or) disturbing the growth of the horn (Toussaint Raven, 1973; Mortellaro, 1994). A manure- and urine- contaminated environment thus predisposes to erosions (Bergsten and Pettersson, 1992; Offer *et al.*, 2001). The effect is enhanced in horn of poor quality (Kempson and Jones, 1998), as sometimes is seen following laminitis (Greenough and Vermunt, 1991).

Dermatitis

Physical and chemical agents as well as microorganisms can cause dermatitis. Infectious dermatitis has been referred to as either interdigital (ID) or digital (DD). ID has been associated with mixed bacterial infections with *Dichelobacter nodosus* as an important component (Kasari & Scanlan, 1987). Although a multifactorial aetiology has been suggested for DD (Leist & Natterman, 1998), *Treponema*-like spirochetes have been isolated from DD lesions (Walker *et al.*, 1995; Döpfer *et al.*, 1997) and are believed important in the pathogenesis. In cows with ID, the skin of the interdigital cleft is moist and reddish (often with an abundant greyish exudate with a foetid odour). In chronic cases, severe hyperplasia and hypertrophy of the interdigital skin, particularly at the dorsal and palmar/plantar commisures, can occur. DD lesions are areas of circumscribed ulcerative or erosive, later possibly granular or proliferative (papillomatous) dermatitis. ID is generally not associated with lameness (Toussaint Raven & Cornelisse, 1972), but DD is. However, due to the oftentimes-difficult distinction between ID and DD (at least in early or mild cases), we have suggested that ID and DD collectively should be considered as "dermatitis" (Manske *et al.*, 2002).

Interdigital hyperplasia

Interdigital hyperplasia (corns, fibroma) is a proliferative reaction of the skin (and subcutaneous tissues) in the interdigital cleft made of fibrous connective tissue. The corns can extend from the dorsal to the palmar/plantar end of the cleft, while filling the entire gap between the claws. Dermatitis, poor claw conformation, incorrect claw trimming, and interdigital phlegmon predispose cows to hyperplasias.

Interdigital phlegmon

Interdigital phlegmon is an inflammation of the interdigital skin and underlying tissues caused by a mixed infection with *Fusobacterium necrophorum* and *Porphyromonas levii* (Berg & Franklin, 2000). Affected animals are acutely lame (generally only one limb is affected) and have an extensive swelling of the distal extremity. Most affected animals are depressed, febrile and have a reduced feed intake, resulting in a decreased milk production (Bergsten, 1997). In the Nordic countries, interdigital phlegmon mainly occurs at grazing (Bendixen *et al.*, 1986; Alban *et al.*, 1996) or in loose housing systems with close and frequent contacts between animals.

Laminitis

According to Ossent & Lischer (1998), laminitis lesions develop in three phases: In Phase I, vasoactive substances such as histamine and endotoxins cause blood vessels in the corium to either constrict, resulting in hypertension, or paralyse and dilate, resulting in haemostasis. The vessel walls are consequently subject to damage and become permeable to blood and serous fluids. The increased intraungular pressure causes both a further reduction in blood-flow and pain; hence, cows with acute laminitis may be severely lame. The resulting proliferation of the intima of the vessel walls and arteriosclerosis often found in claws with gross pathological changes attributable to laminitis (Andersson & Bergman, 1980; Boosman *et al.*, 1989) can cause a chronic hypoperfusion.

Blood that has passed through the damaged vessel walls becomes incorporated in the sole and white line horn and appears at the bearing surface after the claw has been worn or trimmed. Such haemorrhages usually occur in many hooves simultaneously, at least bilaterally (Le Fevre *et al.*, 2001) and can be used as indicators of previous laminitis episodes (Bergsten, 1994). Due to the reduced circulation (supply with nutrients and oxygen), the horn-tissue produced during a bout of laminitis is of inferior quality, weakening the dermal-epidermal junction at the *stratum germinativum*. The attachment of the pedal bone to the claw capsule may become weakened enough to allow for a sinking or rotation of the bone, thus compressing the sensitive tissues of the solar corium (Phase II). More recently it has been shown that events associated with calving weaken the strength of the connective tissue (Tarlton *et al.*, 2002). It is, however, unclear if these are events are physiological (due to hormonal changes that are associated with calving and the onset of lactation such as the increase in relaxin and oestrogen) or related to management issues, such as the introduction of a lactation diet.

The weakened integrity of the horn in the white line allows for ascending infections and makes the area more susceptible to shearing forces that may cause white line fissures or abscesses (Mülling *et al.*, 1994; Budras *et al.*, 1996). Later (Phase III), macroscopic lesions develop in the claw capsule: horizontal "hardship grooves" may become visible at the proximal claw wall and with repeated grooves the toe wall eventually may become concave, and sole haemorrhages and sole ulcers results from continuous compression of the solar corium under the flexor tubercle (Smedegaard, 1964). The pain associated with such sole lesions is more related to the severity than the extent of the lesions (Whay *et al.*, 1997).

For further elaborations over the different lesions, their pathogeneses, and interrelationships see **Papers I** and **II**.

Claw conformation and overgrowth

Bovine hooves are designed to protect the distal extremity from wear and from contact with harmful substances and microbes, to facilitate walking by ensuring a good grip, and to act as shock absorbers. The distribution of load between limbs, and between and within claws is primarily influenced by body-, hoof- and claw conformation. The weight of the animal is not evenly distributed over the four hooves; even during pregnancy the front hooves carry more weight (Scott, 1988). In the correctly shaped hoof (most-often seen in heifers at pasture before first calving), weight is approximately equally distributed over the two claws.

The corium is protected from pinching under the pedal bone by the attachment of the bone to the claw capsule and by the digital cushions. The pedal bone is firmly attached to the walls of the capsule by bundles of collagenous fibres (Westerfeld *et al.*, 2000). The loading on the hoof is thus transferred into a pulling force of the pedal bones attachment to the claw-capsule. The fibrous attachment of the pedal bone is strong (Dietz & Heyden, 1990), particularly in the abaxial wall (Maierl *et al.*, 2000). The corium is further protected from contusions by an adipose tissue, a "fat pad" underneath the pedal bone (Dietz & Heyden, 1990), much similar to the gel- or air canals in modern running shoes. The function of the digital cushions is not fully developed in heifers (Lischer & Ossent, 2002), making primiparous cows more susceptible to contusions of the solar corium. Moreover, once damaged the digital cushions do not regenerate (Lischer, 2000). With an accumulation of lesions over time, older cows will thus be more predisposed to contusions of the solar corium, with subsequent development of sole haemorrhages and ulcers.

The somewhat weaker attachment between the pedal bone and the claw capsule in the axial part of the capsule allows a slight mobility of the bone forming a part of the shock-absorbing mechanism of the distal extremity. In a functionally shaped claw, the corium underneath the most-movable part of the pedal bone is protected from contusions through an external concavity of the sole. The weight-bearing surface of the claw consists of the wall, the outer part of the sole, and the bulb. On level ground, a concave sole will transfer the weight load to the wall, and also cause the claws to spread slightly. Grazing heifers have a more concave sole than lactating cattle exposed to concrete flooring, and heifers calving at pasture retain their sole-concavity longer than heifers adapted to concrete surfaces before calving (Tranter & Morris, 1992). Housing, especially in cubicle-systems, is often associated with an increase in exposure to manure and urine. Such a more-or-less constant exposure to wetness causes a softening of the claw horn (Mülling & Budras, 1998), thus preventing the normal shedding of sole horn. Concurrent abrasion from rough concrete flooring wears down the walls, causing the soles to become flattened. With a flat sole, the external shock-absorption is lost, increasing the risk of solar corium contusion. Overgrown soles are associated with more-prevalent sole lesions (Tranter *et al.*, 1993; Livesey *et al.*, 1998), a decreased efficiency of the claw-mechanism (causing decreased circulation in the horn-forming tissues), and an increased propensity to slip (Dietz & Heyden, 1990). By providing a plenitude of soft bedding in stalls or cubicles (Colam-Ainsworth *et al.*, 1989) or resilient flooring in alleys (Benz *et al.*, 2002), the negative effect of sole overgrowth can be reduced, by replacing the internal shock-absorption with an external ditto.

Horn is produced through keratinisation and subsequent cornification (Mülling & Budras, 1998). The latter process, in which the horn tissue hardens, is time-consuming. Horn produced at the toe, where the wall is relatively long has hardened during a longer time period and is consequently more resistant to wear than the horn more posterior in the claw. The harder horn at the toe combined with more pressure being exerted on the posterior parts of the claw, causes the toe length to increase and the toe angle to decrease (Figure 1) (Wells *et al.*, 1993a).

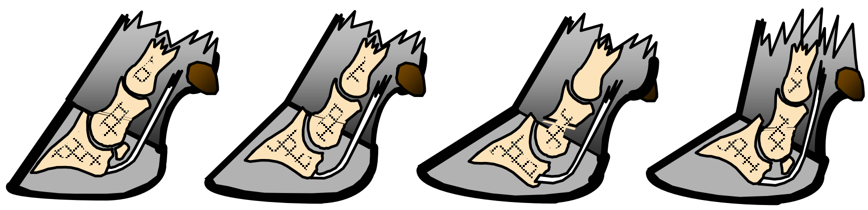


Figure 1. In a situation with little wear the claw angle becomes shallower as the claw overgrows increasing the risk for compression of the solar corium under *Tuberculum flexorium* and the subsequent development of a sole ulcer

A long toe and a shallow angle will both transfer additional weight to the posterior parts of the claw, thus further increasing the risk for compression of the corium and sole lesions (Hess, 1904; Rusterholz, 1920; Smedegaard, 1964). Cows with overgrown claws have an impaired gait compared to cows with well-shaped claws (Boelling & Pollott, 1998; Wells *et al.*, 1993a). The long shallow toe acts as a lever when the animal is walking, straining the insertion of the deep flexor tendon at the flexor tuberosity. A strained tendon-insertion might result in an irreversible exostosis; thus increasing the risk of future solar corium pinching – a contributing cause for the high risk of recurrence of sole lesions (Enevoldsen *et al.*, 1991; Alban *et al.*, 1996).

Under natural conditions, wear balances horn growth, whereas under intensive-production conditions wear may be reduced in tie-stall housing or increased in cubicle. "Proper" claw overgrowth (*i.e.* increased claw measurements) primarily occurs in housing systems with little or no abrasion from the flooring (*e.g.* deep-bedded straw packs and tie-stalls equipped with rubber mats) or on soft pastures. A genetic predisposition has also been suggested (Glicken & Kendrick, 1977). The growth rate is greater in young than in mature cows (Tranter & Morris, 1992; Hahn *et al.*, 1984). Therefore, heifers kept on deep bedding or soft pastures are at an increased risk of developing overgrown hooves (Vermunt & Greenough, 1995). Hence, heifers should be trimmed before first calving (Scharko & Davidson, 1998).

With a base-wide stance (caused either by the increasing udder-size – due to milk production and oedema, pregnancy, change in housing at first calving, or a genetic predisposition), the soles of the lateral hind hooves (rather than the walls) will carry excess weight (Figure 2). Moreover, increased pressure on the sole will result in a compensatory increased horn growth, inducing a further increase in weight bearing (Toussaint Raven, 1973). Thus, with increasing age, there is a shift of weight bearing towards the lateral claws (Ossent *et al.*, 1987). The assymetry is more pronounced in housing with concrete alleys and concrete or rubber mattress stalls, compared to sand stalls or rubber matted alleys (Vokey *et al.*, 2001). It has long been recognized (Anker, 1854; Stockfleth, 1863; Rusterholz, 1920), and more recently shown using advanced technology (Ossent *et al.*, 1987), that the increased weight bearing associated with such asymmetries predispose to claw lesions, such as sole ulcers. The sole concavity is restored when animals are turned-out at grazing on dry, non-abrasive grounds (Tranter & Morris, 1992); an alternative method of improving the claw shape is through trimming (Toussaint Raven, 1989).

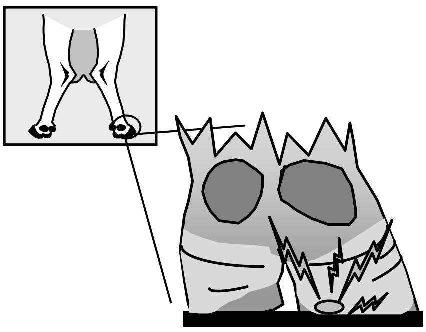


Figure 2. A hock-narrow, base-wide posture results in weight bearing on the sole of the lateral claw

Aims

The present thesis was intended to elucidate some aspects of the hoof health of dairy cows using hoof-health records obtained at claw trimming. More specific aims were:

1) To study the prevalence of hoof lesions, and to describe the associations between different lesions within hooves, cows, and herds, and between lesions of the same type in different hooves within a cow.

2) To investigate associations between animal- and herd-specific risk factors and different hoof lesions and lameness.

3) To study the effect of claw trimming on hoof health as described by the prevalence of hoof lesions, lameness, and claw measurements at the subsequent claw trimming and by the need for acute hoof treatments between scheduled trimmings.

4) To study the effect of hoof lesions and lameness on different aspects of productivity.

Methodological considerations

Acquisition of study herds

Data analysed in **Paper I-IV** emanate from commercial dairy herds in southwestern Sweden, an important dairying area with 32% of the national dairy-cow head-count (Jordbruksstatistisk årsbok, 2001). A questionnaire-survey was carried out among all 4,204 dairy farmers in the area in 1996, to obtain information on dairy cow housing systems, general management and claw-trimming routines (Hultgren *et al.*, 1997). After specific reminders to non-repliers, a total of 1,989 farmers responded to the questionnaire, representing 47% of all dairy farmers or fully 50% of all dairy cows in the area. Herdsmen were also asked for their interest in participating in a hoof-health study, and herds for inclusion in the presented studies were selected from the positive replies to this question.

In August-September 1996, 86 herds complying with a set of inclusion criteria (see **Paper I**) were selected for the first study year (housing season 1996-1997). For the purpose of the claw trimming study (**Paper III**), 50% of the animals in 64 herds were trimmed and examined at autumn trimming (October-January) whereas all animals were trimmed and examined at spring trimming (February-May); in the remaining herds, all animals were trimmed and examined at both autumn and spring trimming. For various reasons not related to hoof health issues, three herds were lost to follow-up; hence, the hoof health was examined twice in 83 herds during year 1. For year 2 (housing season 1997-1998), an additional 16 herds complying with the original inclusion criteria were added. One of these herds was lost to follow-up. Hence, although hoof-health records were obtained from a total of 102 herds, the makeup of study herds varied between **Paper I, II, III** and **IV**. Details on the selection of herds for inclusion in the different studies are presented in respective papers.

There is a risk of selection bias in the acquisition of herds: farmers answering the questionnaire and agreeing to enter the study might have been more interested in hoof-health matters, and their herds might thus have had a better hoof health status than other herds in the population (Mill & Ward, 1994). On the other hand, herds that had experienced hoof-health problems might also have been more likely to enrol in order to get qualified help. In order to examine how the selection-procedure might have influenced the external validity of the study, characteristics of 101 study-herds (one herd burned down before the cow environment had been studied) were compared to the results of the initial survey (Table 1, page 27). Herds with short tie-stalls or cubicles were intentionally over-represented among study herds. The slightly more frequent use of rubber mats in the study-herds than in the survey may reflect the different distribution of housing systems (a higher proportion of short stalls). Moreover, since smaller herds (according to the survey) are less likely to have stalls with rubber mats, the lower restriction on herd size might have contributed to this difference.

In all study herds, cattle were trimmed routinely. The slightly higher frequency of claw trimming and the more frequent use of a professional hoof trimmer might indicate a greater awareness about hoof health issues, and thus a better hoof health than in the source population or more prevalent lesions requiring trimming, but it might also be related to differences in herd size. In summary, study herds were representative of dairy herds of the relevant size in south-western Sweden, although with a slight possibility of better-than average hoof-health status.

Table 1. A comparison between distribution of dairy herds in the source population (all dairy herds in five counties of south-western Sweden, 1997), on certain housing and management factors as indicated by a questionnaire survey, and 101 study herds from **Paper I-IV**

	Survey	Study
Housing system		
Long tie-stalls	47%	32%
Short tie-stalls	39%	53%
Cubicles	6%	15%
Flooring in cubicle herds		
Solid concrete alleys	38%	33%
Slatted concrete alleys	62%	67%
Lying surface		
Rubber mats	44%	50%
Bedded concrete	43%	40%
Combinations	13%	10%
Bedding		
Long straw	6%	9%
Chopped straw	47%	48%
Wood shavings/saw dust	30%	28%
Combo	18%	13%
Other	1%	1%
Claw trimming		
"When necessary"	22%	13%
Approx once yearly	44%	49%
Twice yearly or more	34%	39%
Hoof trimmer		
Farmer	23%	13%
Hired professional	76%	87%
Herd size		
25-29	18%	1%
30-34	19%	6%
35-39	13%	21%
40-49	21%	25%
50-59	11%	22%
60-74	10%	12%
75-99	5%	10%
100-	3%	4%

Description of study herds

Information on study-herds' housing systems, feeding routines and management was collected at special visits to the herds between November and May during the two study years. Actual measurements were preferred (building measurements, temperature and humidity); other factors (*e.g.* dampness of lying surfaces, abrasiveness of floors, level of air-ammonium) were subjectively scored according to scales that had been agreed upon beforehand. Information about factors that could not be directly observed at the visits (*e.g.* previous hoof trimming history, heifer rearing, feeding routines, amount of bedding used, *etc.*) was obtained by interviews with the farmers.

Due to the longitudinal design of the study, there is a risk of qualitative interaction between the observer and the observed (Ducrot *et al.*, 1998). In the presented studies, the risk emanates from several aspects: it is possible that farmers answered questions about their routines in a manner they thought appropriate, or that they changed their behaviour after having been interviewed. It is also possible that farmers changed their routines during the study (contamination bias). Biases resulting from contamination are conservative; they decrease the nominal effect of exposure. The risk of such bias was reduced by not offering direct comments on the hoof health during the run of the experiment.

Housing of lactating animals

In 87 herds, lactating cows were housed in tie-stall systems and in 15 herds in cubicles. The average size of cubicle herds was 85 cows, compared to an average of 48 cows in tie-stall herds. Five herds had changed housing system in the year preceding the study, one from long-stalls to feeding cubicles, two from long to short tie-stalls, one from long stalls to cubicles and one from short stalls to cubicles. Tie-stalls were either long (31 herds) or short (55 herds). Cows in all but two tie-stall herds (with milking in a separate parlour) were milked in their stalls.

Almost all buildings for lactating cows were insulated and mechanically ventilated. The quality of the ventilation was subjectively assessed according to the smell of ammonia. In all but two herds, the animals were at pasture for 3-5 months in the summer; cows in the two zero-grazing (cubicle) herds had daily access to open-air exercise pens during summer.

Differences in the design and management of different housing-systems, as well as details about participating herds are presented in **Paper II**. In summary, long-stalls were equipped with lockable feeding barriers to restrict access to the manger between feedings. Short stalls were equipped with fixed or adjustable bow-supports or other means (*e.g.* neck bars) to keep cows off the feeding table. In 50% of tie-stall herds, chopped straw was used as bedding; the rest used saw dust, a combination of straw and saw dust, wood shavings, or long straw. The amount of bedding used per animal and day varied greatly between herds. Gutter grates were more common in combination with short than with long tie-stalls. In the 25 stables with gutter grates, long straw was not used as bedding. Where no grates were used, the depth of the gutter varied between 12 and 35 cm (mean 22 cm). Stalls were cleaned (scraped) between two and sixteen times per day. Cubicle herds had solid scraped or slatted concrete-alleys. The abrasiveness of the flooring was subjectively scored as slippery or moderate to rough. The animals were grouped according to lactation status or udder health or not grouped at all. In none of the herds, primiparous animals were grouped separately. The number of animals per feeding place varied between 0.9 and 2.0 (median 1.4) and the number of animals per cubicle varied between 0.8 and 1.6 (median 1.2). In about 50% of cubicle herds, cubicles were equipped with rubber mats; in the remaining, the lying surface was bedded concrete.

Housing of replacement heifers and dry cows

Pregnant heifers in tie-stall herds were either tied on littered concrete (43 herds), kept on a slatted concrete floor (19 herds), on a straw pack (12 herds), or in combinations of these systems (9 herds), whereas pregnant heifers in cubicle herds were kept in boxes with slatted concrete flooring (7 herds), on a straw pack (6 herds), or tied on littered concrete (2 herds). The housing of replacement heifers could be categorised according to Table 2.

Dry cows in tie-stall herds were generally tied, but in eight herds, some or all dry-cows were kept on a straw pack. In cubicle herds, dry cows were kept on slatted concrete floors with cubicles (8 herds), on a deep-bedded straw pack (4 herds) or in tie-stalls (3 herds).

Diets and feeding

Concentrates and roughages (mainly grass-clover silage and hay) were fed separately in all herds but one, in which a total mixed ration (TMR) was fed. In cubicle herds, concentrates were fed by means of a transponder (n=11), or 2-7 times per day (n=4). In tie-stall herds, concentrates were fed 2-10 times daily, separate from the roughages. In 50% of tie-stall herds, mainly in short-stall systems, roughages were fed ad lib.

Concentrate rations were either based on individual animal performance (n=43), standardised milk-yield-based recommendations (n=43), or the farmers' personal calculations (n=12). In 16 herds concentrates were fed before roughages at some time during the day. Information on amounts of concentrates fed at calving and at 14 days in milk was obtained from 93 herds by interviewing the farmers.

Table 2. Distribution of study herds on different housing-systems for replacement animals

3-months-old	Heifers before service	Heifers after service	N
Slatted concrete	Slatted concrete	Slatted concrete	19
Slatted concrete	Slatted concrete	Tie-stalls	10
Slatted concrete	Tie-stalls	Tie-stalls	15
Deep packed straw	Deep packed straw	Deep packed straw	14
Deep packed straw	Deep packed straw	Tie-stalls	10
Tie-stalls	Tie-stalls	Tie-stalls	15

The quality of the information on feeding thus gained was somewhat dubious – one farmer, for instance, reported the feeding of 18 kg concentrates to primiparous and 21 kg to multiparous cows two weeks after calving, thus exceeding a credible total dry-matter intake.

The average daily increase in concentrate ration in the two weeks following calving varied for primiparous cows between 0 and 1.1 kg (mean 0.49, SD 0.19) and for multiparous cows between 0 and 1.2 kg (mean 0.54, SD 0.22). To avoid collinearity between different factors related to concentrate feeding, several factors were reduced to a categorical variable reflecting the initial amount of concentrates and the daily increases in ration, using Ward's hierarchical cluster analysis (SAS Institute Inc., 2000). Four classes were created: two with relatively small (~3 kg) concentrate ration fed at calving, of which one later had a rapid increase in ration (0.8-0.9 kg/d) and one had a more moderate increase (0.5-0.6 kg/d); a third group started at a medium ration (5-6 kg) and had a slow increase (0.4 kg/d), the final group started at a higher ration (7-9 kg/d) and increased at a moderate rate (0.5kg/d).

Hoof care

All included herds were on maintenance claw-trimming schemes before entering the study; in 39 herds, the cows were trimmed twice yearly; in 47 herds, once yearly, and in the remaining 12 herds, "when necessary". In the herds that used to trim once yearly, this was most commonly (n=34) done in the spring, in the remaining herds it was done on a running schedule through the housing period. The trimming was commonly performed using a hammer (mallet) and blade, an electric grinder, or a combination of these. In 13 herds, the farmer performed the claw trimming, in the remaining herds a professional hoof trimmer was hired. Eighteen tie-stall herds sometimes used a footbath during grazing. In cubicle herds, the use of footbaths was more frequent (10 of 15 herds) and baths were also used while the cattle were housed.

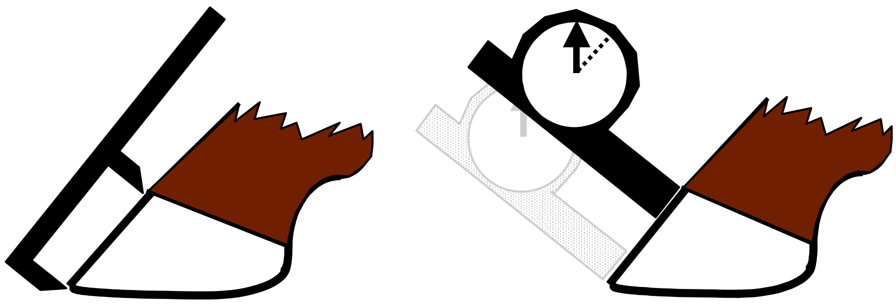
Selection and examination of animals

All cows and all heifers in ≥7 months of gestation in each herd were considered eligible for examination. Animals were lost to examination for humane reasons (periparturient animals and animals suffering from other severe diseases not immediately related to the hoof health, *e.g.* acute mastitis, milk fever), or practical reasons (*e.g.* dry cows housed off the premises, or for other reasons not available, or impending slaughter). Miscoding or other human errors and other unspecified reasons accounted for further losses. Exclusions of some cattle close to slaughter were made due to the farmers' unwillingness to trim these animals. Because hoof lesions (lameness) are an important cause of culling, we made an initial attempt to collect and examine the hooves of all slaughtered animals in order to avoid selection bias. Unfortunately, this attempt had to be abandoned due to lack of resources. Since the risk of culling in our study was increased by lameness (**Paper IV**), an underestimation of the prevalence of hoof lesions and lameness in living cows is likely.

The locomotion was assessed when cattle were led to the trimming box. The conditions for examining the gait of the animals were often suboptimal. There is a risk that lameness prevalence might have been underestimated because of this.

Measurements of the lateral left hind claw were obtained before trimming. The length of the toe was measured along the dorsal border using a vernier calliper, from the tip of the toe to the proximal end of the claw capsule (the periople) (Figure 3). The toe angle was measured at both the proximal and distal 2 cm of the toe wall by a commercial angle meter (Mitsutomo® Level and Angle Finder).

Fig. 3. Measurements of the claw capsule obtained at trimming: toe length, and distal and proximal toe angle



Due to the nature of the claw capsule, horn lesions can be regarded as retrospective records of insults to the horn-forming tissues that have occurred during the time period when the capsule was formed (Bergsten, 1994). Some lesions *e.g.* sole and white line haemorrhages can be caused by transient challenges, and thus are of a limited extent. Such lesions might disappear during trimming. Hence, hoof lesions were recorded both during and after claw trimming. The lesion status of all eight claws of all animals was recorded. Several lesions were scored on 4-level ordinal scales. In the analyses of **Paper II**, **III** and **IV**, only hind hooves were considered; moreover, multi-level scores were dichotomised and lesion aggregates were constructed to incorporate several lesions measured at cow level. Thus, there was a marked loss of information. The aggregation was based either on hypothesized common pathogenesis, or empirical knowledge that specific lesions tend to occur simultaneously, and done in order to facilitate the analyses and results of respective paper. Discrepancies between the different lesions in actual causative mechanisms and the effect of trimming would have reduced the chances of finding statistically significant associations between exposures and the prevalence of lesions. Moreover, different development of lesions with time since housing, as *e.g.* the results of Bergsten and Pettersson, (1992) indicate for dermatitis and heel horn erosion, would have interfered with the results in the longitudinal **Paper III**-study.

Hoof health measurements

Information on dairy cow hoof health can be obtained from examination of culled or live cattle. Live cattle can be examined directly; alternatively, one can utilize already existing records, or one can design a record-keeping system purposefully. Whereas the hoof health of culled cattle easily and reliably can be investigated regarding the prevalence and severity of hoof lesions, the lesions' effect on the welfare of the animals (*e.g.* as reflected in locomotion scores) can not be estimated. Moreover, since lameness is an important cause of culling (Collick *et al.*, 1989; Sprecher *et al.*, 1997; Swedish Dairy Assoc., 2002), there is a risk for selection bias, probably resulting in an overestimation of the prevalence of (severe) lesions.

Whereas farmers continuously interact with their animals, and thus have a good chance of observing lesions and lameness, they differ markedly in their astuteness and their perception of what is normal (''normal' is what one sees every day'). Hence, it is not surprising, that farmer-records commonly underestimate the prevalence of lameness and of (severe) hoof lesions (Wells *et al.*, 1993a; Mill and Ward, 1994). Veterinary treatment records depend on a chain-of-actions where a farmer has considered an animal to be lame, decided to call for a veterinarian, and the veterinarian has diagnosed and recorded the case. Since other persons than veterinarians treat most lame cows (Murray *et al.*, 1996), veterinary-treatment records of lameness will also underestimate the actual lameness prevalence. Moreover, the decision of the farmer to call for a veterinarian to treat a lame cow depends on several factors, *e.g.* his (or her) familiarity with the symptoms, the acuteness of the illness, positive experiences from previous veterinary-treated similar cases and a fair prognosis after treatment. Veterinary-treatment records thus likely have a selection bias in the type of lameness cases, favouring *e.g.* interdigital phlegmon. Vokey *et al.* (2001) concluded that several measures (*e.g.* lesion scores, locomotion, and clinical lameness) should be considered concurrently in studying hoof health, and that different hoof health measures might give contradictory results.

In **Paper I-IV**, hoof-health records from claw trimming were used. Such records should yield more-sensitive estimations of the prevalence of hoof lesions and hence more valid estimations of the strength of association between hoof lesions and lameness, than either farmer- or veterinary-treatment records.

Statistical analyses

In **Paper I**, a variance-components analysis was performed using generalized linear mixed models (GLIMMIX macro run in SAS 8.01 SAS Institute Inc., 2000). Because of the similar hoof-health status of the two hind hooves (resulting in severely underdispersed residuals), hooves within cows could not be used as unit of observation. Instead, hoof-health status was collapsed over cow. In the cow-level analyses, evidence of underdispersion was adjusted for by constraining the residuals to 1 (corresponding to no extra-binomial variation). Associations between lesions were studied using Spearman's rank correlations. At the hoof and cow levels, correlations were calculated on binary scores, whereas correlations at the herd level were calculated on the herd-specific animal-level prevalence of the different lesions. In order to compensate for some of the increased risk of Type-1 errors with multiple comparisons, the α-level was set to 0.01.

In **Paper II**, the degree of clustering of the hoof traits on the herd-level was estimated as the intracluster (or intraclass) correlation coefficient (ICC) (Kerry & Bland, 1998) using the formula: ICC = (MSA – MSW)/(MSA + [η-1]MSW) where MSA and MSW are the ANOVA between- and within-herd mean squares respectively, and η is the adjusted average herd size. Associations between risk factors and outcomes were modelled using logistic regression. In the individual-level analyses, outcomes were presence or absence of specific hoof lesions or lameness at the cow-level; in the herd-level analyses, outcomes were the herd-specific animal-level prevalence of the same hoof-health traits. Non-independence of risk factors (multicollinearity) was assessed using logistic regressions, in which each independent factor was regressed on all other factors collectively, reconstructing or omitting independent factors that to a large extent were explainable by variation in other factors. Non-independence of observations (clustering) was accounted for using the generalized estimating equations (GEE) approach (Liang & Zeger, 1986) in the GENMOD procedure of SAS, assuming exchangeable correlation-structures. The risk of Type-I errors was decreased by assigning significance only to associations with P_{LR}-value ≤0.01. Model fit was either assessed by analysis of predictive ability within deciles of predicted risk (Hosmer & Lemeshow, 1989) or indicated by the deviance chi-square statistic combined with a comparison of predicted and observed numbers or prevalence of lesions and lameness within covariate patterns.
Herd-level analyses were adjusted for unequal distribution of significant individual-level non-intervening risk factors. For example, stage of lactation was found to be a significant risk factor in the individual-level analysis of haemorrhages of the sole or white line in primiparous cows, thus this factor (expressed as the proportion of cows within the stage of lactation at increased risk) was offered for inclusion in the corresponding herd-level analysis. Factors that were considered to be intervening factors were not offered for inclusion (hoof dirtiness, for instance, was considered an intervening factor between housing and management factors and hoof lesions). For outcomes where GEE-analyses gave evidence of underdispersion, estimates and standard errors were validated by comparison with the results from generalized mixed-effects logistic regression (GLIMMIX). Data set limitations made multivariable analyses of risk factors that were unique to subsets of herds (*e.g.* for tie-stall or cubicle herds) unfeasible. Instead, univariate associations between such factors and hoof-health traits were presented.

In the analysis of **Paper III**, GLIMMIX was used to study the effect of autumn claw trimming on hoof health at spring trimming, applying a binomial distribution of residuals and a logistic link function. Herd-within-year was entered as a random effect and autumn claw trimming and a variable set of covariates were entered as fixed effects. Covariates offered for inclusion in the regression models were those a priori considered to be possible confounders. Full models were reduced using a backwards step-wise elimination-procedure of non-significant (P_{LR} >0.05) fixed covariates. First-level interaction terms between treatment and the covariates in the reduced model were tested for inclusion in an analogous manner. The residual variances indicated slight underdispersion. In the final analyses, the residuals were constrained to 1 (equivalent to no extra-binomial variation).

In **Paper IV**, the associations of sole ulcer (ULCER) and lameness (LAME) to reproductive performance, udder health, milk production, and culling in the studied lactations to were analysed separately using the MIXED procedure (for continuous outcomes) or GLIMMIX macro (for binary and count outcomes). For binary outcomes, a logit link was applied and a binomial distribution assumed, constraining the residual covariance to equal 1. For count outcomes, a log link was used, assuming a Poisson distribution. In each multivariable model, either ULCER or LAME was forced in. Other independent variables with unconditional associations (the model containing only the tested predictor and random herd) with the different outcomes at P_{LR} ≤0.30 were offered for inclusion. For each outcome, the full model was reduced by a backward-stepwise procedure. Following the reduction of the models, first-level interaction terms between ULCER (or LAME) and the main effects were tested by a new backward-stepwise elimination procedure. Graphical examination of residuals (distribution and association with predicted values) and identification of outliers indicated the goodness-of-fit for linear regressions. The overall goodness-of-fit of logistic models was assessed by analysis of predictive ability. Moreover, the residual covariance (before constraining) was compared to the expected value of 1 for binomial distributions. If the residual was <0.8, or if there was some other indication of lack of fit, the result was confirmed by re-fitting the same model using the generalized estimating-equations (GEE) technique (Liang & Zeger, 1986) - assuming an exchangeable correlation structure between herds - in the GENMOD procedure of SAS. For the Poisson models, the goodness-of-fit was assessed by comparing mean observed and predicted numbers within each covariate pattern (stratum) formed by categorical covariates, and the results were confirmed by GEE models.

Recorder agreement

The reliability of observations is limited by the precision of the recording system, the agreement between different observers (raters) (interrater agreement) and the agreement between ratings by the same rater obtained at different times (repeatability, or intrarater reliability). In a study with more than one rater, low intrarater reliability will limit the interrater reliability. The extent of agreement between two ratings depends on how well the raters agree on what is to be assessed and how to perform the assessment. If assessment scores reflect an underlying continuous scale, disagreements may also arise from different perceptual ability, or from different choice of threshold values in the categorisation process. Agreement is generally increased by the use of direct measurements instead of subjective scores. In the study of bovine hoof health, such direct measurement techniques have been evaluated for claw lesions using image analysis (Leach *et al.*, 1997; 1998) and for locomotion using high-speed cinematography (Herlin & Drevemo, 1997), hoof-track measurements (Telezhenko *et al.*, 2002), and weight distribution (Rajkondawar *et al.*, 2002).

Still, however, most observational research in bovine lameness is based on subjective scores, particularly for evaluating locomotion and lesion severity.

Different approaches to agreement testing have been used in published hoof-health studies. Whereas interrater agreement can be assessed using live cattle, the assessment of intrarater agreement (repeatability) causes a problem: some time need to elapse between the repeated assessments for the observations to be independent and hence the claws may need to be re-trimmed and their appearance may change. The use of photographic records of hoof lesions has been proposed to overcome this problem (Bergsten, 1993; Leach *et al.*, 1998; Vokey *et al.*, 2001). However, the quality of photographic records limits the performance of such a test, and it is not unlikely that the actual agreement is underestimated (Leach *et al.*, 1998).

In the statistical analyses of hoof-health scoring-agreement Spearman's rank correlation coefficient (Bergsten, 1993; Wells *et al.*, 1993a; Leach *et al.*, 1998), observed proportion of agreement (Wells *et al.*, 1993a; Murray *et al.*, 1994), or the kappa coefficient (Wells *et al.*, 1993a,b) have been used as measures of agreement. Spearman's correlation (or Pearson's correlation for normally distributed data) measures the degree of association between ranks (values); a systematic difference in recording between raters would thus not be detected. Moreover, it can only be used for pair-wise comparisons of raters. The observed proportion of agreement is likely to be inflated by chance-agreements and the estimated proportion of agreement may thus overestimate the actual underlying agreement. The most widely adopted method to adjust for such chance agreement is kappa (Cohen, 1960). The kappa coefficient (κ) is calculated as the ratio of the observed excess over chance agreement to the maximum possible excess over chance, where the chance-agreement is based on the estimated prevalence of the outcomes (Fleiss, 1981). In a simple sense, $\kappa = 1.0$ when there is perfect agreement, $\kappa = 0.0$ when there is no more agreement than what would be expected by chance, and $\kappa < 0.0$ when there is less agreement than would be expected by chance alone. Landis & Koch (1977) presented benchmark values for the interpretation of kappa coefficients and although stated to be "clearly arbitrary", these values have been widely adopted. The interpretation of the kappa coefficient is not straightforward (Byrt, 1996). In particular, the extreme values kappa can attain are governed by the (perceived) prevalence of the outcome (Kraemer, 1979; Kraemer & Bloch, 1988; Lantz & Nebenzahl, 1996). What could be considered a poor agreement might thus be due to population characteristics rather than the observation procedure (Kraemer, 1979).

In order to make a *post hoc* assessment of the agreement within and between raters in **Paper I-IV**, photographic slides of the left hind hooves of all cows were obtained during the field study using the method of Bergsten (1993). Two hundred slides were selected for a study of the reliability of the scoring method. Slides were selected to represent a wide range of the lesions and three time periods (the first week of the study, day 100 and day 146) in the first year of the study. The selection of slides was made blind to the raters. The raters later evaluated the slides using the original scoring system for lesions, except for sole ulcers, which were scored 0-2 on the slides, since level 3 used in the original recording scheme was determined by criteria that were not assessable from a slide. The slides were assessed twice with a 30-minutes pause between sets. In the pause, the slides were reordered to make the repeated observations independent of each other. All lesions were assessed on every slide, but due to poor quality of some slides, assessment of all lesions was not possible for all slides. The omission of lesions was based on the discretion of the raters; hence, the number of assessed slides varied between raters. For the interrater reliability study, only slides that all raters accepted were included in the analysis. The number of slides included in the final analysis was 187 for heel horn erosion, 170 for sole haemorrhage, 192 for sole ulcer and 161 for white line haemorrhage.

Kappa coefficients for intrarater agreement were calculated using the FREQ procedure in SAS (SAS Institute Inc., 1997). For the study of interrater agreement for binary traits, a two-way random effect model (Shoukri & Pause, 1999) was run under the GLM procedure in SAS to generate an analysis-of-variance table (assuming an additive model, random raters and no between rater-and-slide interaction). The interrater agreement for the four ordinal categorical lesions was assessed according to Fleiss (1981). In order to assess a possible fatigue effect on the scoring accuracy, the interrater agreement was assessed on ratings from both repetitions of the intrarater test. The consistency in the use of the rating scale over the first year was assessed for the least experienced rater, by comparing the scores from assessments of slides to the scores for the corresponding hooves made by the same rater during the field study. Heterogeneity in the magnitude of the difference between the assessments in the field and from the corresponding slide for different time periods was considered to represent a sway in the use of the recording scale. No formal test of homogeneity was applied.

Kappa coefficients for intrarater agreement for the different lesions were generally high (0.50-0.92), but varied between raters; rater A had high repeatability scores (κ = 0.68-0.92 for the different lesions) whereas rater B scored somewhat lower (0.50-0.83). Averaged kappa coefficients over all three raters were above 60% for all lesions. The high reliability found for sole ulcer was probably due to the clearly defined severity scores. Differences between raters were explainable by different amounts of experience in the use of the scoring procedure. No obvious difference between interrater reliability assessed from the two repeats was found, indicating that the precision of the ratings was not overtly affected by tiredness.

The interrater reliability of lesions scored on ordinal severity scales was assessed at different outcome levels as well as for overall agreement. The overall kappa (measuring the extent of agreement in assigning an object to a specific category) was calculated by regarding the raters as exchangeable (Fleiss, 1981). The total interrater agreement for lesions assessed using ordinal scores was between 0.40 and 0.78. Within lesions, the agreement coefficients were generally highest for the differentiation between score 0 and 1; *i.e.*, there was relatively more agreement on the existence of lesions, than on their respective severity. By dichotomising the ordinal scores, as was done for the papers in this thesis, an even higher degree of reliability was probably attained.

Since the scoring in the field was performed during the entire claw-trimming procedure, and lesions (particularly claw-horn haemorrhages) might disappear during trimming, no direct comparisons between lab and field assessments were possible. However, except for sole haemorrhages that were scored slightly higher in the field the observed differences were small. Mean differences and errors of the means were used despite the scores from both assessments being ordinal or binary. An attempt to illustrate a possible sway in scoring for a novice rater during the first five months of using the scoring system was made. Since it was believed, that the risk of swaying was greater in the beginning of the study, slides from several days in the first study week were re-assessed, together with slides of hooves originally assessed on days 100 and 146. A possible sway was depicted as the average difference in scoring between assessments on slides (after completion of the field study) and the actual scores obtained under field conditions. After the first week, in which the scores for sole haemorrhages swayed slightly with decreasing amplitude, scores were consistent over time.

Results and general discussion

Claw lesions were very common among cows in Swedish dairy herds; most (72%) of 4,899 dairy heifers and cows had at least one hoof-lesion (**Paper I**). The most-common lesions were heel horn erosion (41% of examined animals), sole haemorrhages (30%), interdigital or digital dermatitis (27%) and abnormal claw shape (21%). Less prevalent lesions were: white-line haemorrhages (14%), white-line fissures (8.8%), sole ulcers (8.6%), double soles (3.3%), verrucose dermatitis (2.3%), and interdigital hyperplasia (1.8%). The herd-specific animal-level prevalence of animals affected with any hoof lesion varied between 44 and 100% (Figure 4). The prevalence of lesions is comparable to international studies (Vaarst *et al.*, 1998; Philipot *et al.*, 1994a; Smits *et al.*, 1992). It is interesting to compare our prevalence estimates with those presented by Andersson & Lundström (1981), who examined the hooves of 594 randomly selected cows from a slaughterhouse in western Sweden. Although contaminated by a selection-bias in the latter study, differences between the results in **Paper I** and in the study by Andersson & Lundström reflect changes in the hoof-health status of Swedish dairy cattle over the last two decades. Below, such differences in lesion prevalence will form a platform for expansions on some issues related to the findings in **Paper I**-**IV**.

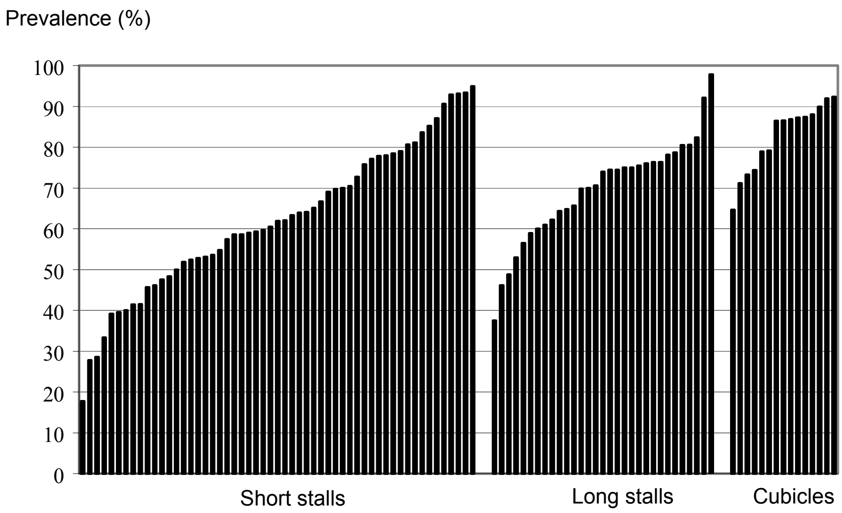


Fig. 4. Distribution of herd-specific animal-level prevalence of animals with any hoof lesion, within housing system

Dermatitis and heel horn erosion

The prevalence of dermatitis and heel horn erosion, lesions that have been associated with a manure-contaminated environment (Bergsten & Pettersson, 1992; Philipot et al, 1994b; Rodriguez-Lainz *et al.*, 1999; Hultgren & Bergsten, 2001), was 2.4-2.8 times higher in **Paper I** than reported from 1981, despite a more narrow definition of lesions. Such an increase most likely reflects an increased intensity in dairy production with a more frequent use of cubicle housing and an increased milk yield (and thus manure production). The between-herd proportion of variation for heel horn erosion was 62%, which was high relative to other hoof lesions (**Paper I**). The large between-herd variation might be explainable by different levels of hygiene in the hoof-environment, due to housing design and management. Herds with a high prevalence of heel horn erosion also had a high prevalence of erosive and proliferative dermatitis, interdigital hyperplasia and double sole (**Paper I**). Such correlations between lesions would be expected if the lesions were caused by common or separate but coexisting causative mechanisms, if one lesion caused the other, or if the lesions reflect different developmental stages of the same disease.

Our findings support earlier ideas (*e.g.* Andersson & Lundström, 1981; Offer *et al.*, 1997) that housing increases the risk of dermatitis and heel horn erosion, and that the severity of these lesions increase with time since grazing. The risk of dermatitis or heel horn erosion was approximately three times higher in cubicle-housed animals, than in animals housed in short tie-stalls (**Paper II**), probably due to the more-or-less constant exposure to manure, and an increased spread of contagious agents between animals. Severe dirtiness of the hooves was also shown to be an important predictor of both sole ulcers (OR = 2.00) and double sole or white line separation (OR = 2.18) relative to cows with less dirty hooves (**Paper II**).

In contrast to the controlled experiment of Bergsten & Pettersson (1992) we could not show an effect of electric cow trainers on the prevalence of heel horn erosion or dermatitis (**Paper II**). However, electric trainers had been banned before the onset of our studies; it is thus possible that many of the trainers were not in use, although fitted. Due to the cross-sectional design of our study, it is also possible that herds with hoof health problems were more likely to fit electric trainers than herds with a relatively good hoof health.

There was no difference in the prevalence of dermatitis or heel horn erosion between slatted and scraped solid concrete flooring (**Paper II**), possibly due to low statistical power. In contrast, Thysen (1987) studied records of hoof health obtained at trimming in two cubicle herds that had been split into one part with a scraped solid concrete floor and one part with a slatted concrete floor, and found significantly more dermatitis and severe heel horn erosion in cows on the solid floor (although the overall percentage of cows with heel horn erosion did not differ between the two flooring types). Smit *et al.* (1986), studied the hoof health in 81 Dutch dairy herds and found a significantly lower severity of dermatitis in herds with slatted floors than in herds with a solid floor, or with combinations of the two types of floors. However, in these earlier studies, floors were generally scraped twice daily, today a more frequent use of the scrapers is common. Elevated separate feeding places in cubicle housings have been suggested as a means of reducing exposure of the hoofs to manure (Bergsten, 2001).

Neither dermatitis nor heel horn erosion was significantly associated with lameness when hoof lesions were analysed collectively (**Paper I**), which is in agreement with the results of Logue *et al.* (1994). Philipot *et al.* (1994a) studied the hoof health of 4,896 cows in 160 French dairy herds and found a weak association (OR = 1.4) between heel horn erosion and lameness. An association between dermatitis and lying behaviour has been reported in not-lame cows (Berry *et al.*, 1998), possibly indicating that animals with such lesions alter their behaviour to relieve pain from other challenges than walking.

Although no therapeutic effect of trimming on dermatitis or heel horn erosion was apparent in **Paper III**, a positive effect is still possible, since the relatively long period between trimming and re-examination of the hooves (~4.5 months) might have caused new lesions to develop in once cured hooves. Manson & Leaver (1989) could not show a beneficial effect of claw trimming on the curing of dermatitis-lesions six months after trimming, whereas Manske *et al.* (2002) showed that claw trimming was associated with curing one month after trimming. Other therapeutic and prophylactic measures in the control of dermatitis and heel horn erosion have included footbaths, used extensively for cleaning of the hooves and (or) application of therapeutic substances (*e.g.* Blowey, 1990; Rodriguez-Lainz *et al.*, 1999; Manske *et al.*, 2002). The beneficial effect of footbathing has long been recognized (Anker, 1854). It appears, however, that the hygiene of the environment must be improved to achieve a lasting improvement in heel horn erosion status (Bergsten & Pettersson, 1992; Lischer *et al.*, 2000).

Haemorrhages of the sole and white line

The prevalence of sole haemorrhages in **Paper I** was half that presented by Andersson & Lundström (1981). However, the two estimates are hard to compare due to different definitions of lesions. The proportion of variance due to between individual relative to between herd variability was high (>80%) for haemorrhages of the sole and white line (**Paper I**), indicating the importance of individual-level causative factors. In primiparous cows, the only significant predictor was stage of lactation, with cows in mid lactation being at a greater risk of lesions than cows in other lactation stages, whereas in multiparous cows, breed and parity also contributed significantly to the risk of lesions (**Paper II**). In the presented papers, no attempt to study the importance of a genetic predisposition in the development of these lesions was made. Under practical circumstances, stage of lactation is confounded with time of exposure to the dairy herd environment. It is thus difficult to distinguish between the effects of housing and calving. Chaplin *et al.* (2000) studied sole lesions in early pregnant heifers and recently calved primiparous cows of the same age. They found more severe lesions in heifers in late than in early pregnancy, indicating an effect of gestation on the prevalence of sole haemorrhages (either through increased weight-bearing or hormonal changes), and more severe lesions in lactating primiparous cows than in early-pregnancy heifers, indicating a direct effect of calving not related to housing. Bergsten and Frank (1996b) studied 21 heifers calving in April-May that had been housed since November and found a significant increase in sole haemorrhages after calving. Late pregnancy and calving is associated with marked growth of the foetus, mammary gland development, hormonal fluctuations and onset of lactation conveying a concurrent transient hypocalcaemia and hypophosphataemia (El-Ghoul *et al.*, 2000); concurrently, changes in feeding, housing (especially for autumn-calving heifers), and social environment when entering the milking herd occur, challenging the hoof health integrity. Through ultrastructural assessment of the quality of the white line of heifers one month before calving, Kempson & Logue (1993) could predict if an animal would develop sole haemorrhages by 20 weeks after calving; indicating that predisposing factors were present already during pregnancy. The higher prevalence of haemorrhages of the sole or white line in primiparous than in multiparous cows (**Paper I**) is in agreement with earlier reports (Bergsten, 1994; Bergsten & Herlin, 1996) and is probably due to the plethora of changes occurring at the time of first calving (Bazeley & Pinsent, 1984; Blowey, 1998).

The low variability attributable to between-herd variation (**Paper I**) indicates a relatively little opportunity for decreasing the prevalence of haemorrhages through changes in feeding, housing design or management. The only herd-level risk factor associated with the risk of haemorrhages in the present study was length of adaptation period (**Paper II**), which possibly reflects a longer exposure to dairy-herd housing, rather than a lack of an adequately long adaptation process. Whereas it is generally agreed that abrupt introduction to concrete surfaces, mixing of animals and addition of new animals to existing hierarchies contributes to the development of haemorrhages (Greenough & Vermunt, 1991), Vermunt & Greenough (1996b) found sole lesions to be more common in primiparous cows that had been introduced to the dairy environment at service, instead of just preceding calving, indicating that the length of exposure might be more important in the development of lesions than a long adaptation period.

The less positive effect of claw trimming on the risk of haemorrhages than for sole ulcers and separations in **Paper III** (OR = 0.9 *vs.* 0.6 and 0.7, respectively) indicates that trauma associated with overgrown claws might be of relatively less importance to the development of haemorrhages than intrinsic (circulatory) disturbances in the corium, and that trimming prevents contusion of the solar corium following a secondarily weakened dermal-epidermal junction. This notion is further supported by the lack of association between haemorrhages and hardness of stall and floor surfaces in **Paper II**. Heifer rearing on soft surfaces such as deep litter has earlier been reported to result in less severe haemorrhages in the heifers (Frankena *et al.*, 1992). Given the hardness of flooring in most dairy herds and a negative effect of an abrupt change of surface resilience at the time of first calving (Bergsten & Frank, 1996b), a beneficial long-term effect for the hoof health might, however, be expected if heifers were kept on a harder surface. Clearly, transferring heifers (especially with overgrown hooves) from a soft surface to a concrete flooring at calving will induce an appreciable risk of damage to the sole corium. Blowey (1998) suggested that high yielding dairy cows would benefit from being kept on a softer surface (straw yard) the first 4-8 weeks of lactation, before introduction to cubicles.

The lack of associations between different aspects of feeding and the risk of haemorrhages (**Paper II**) might be related to irrelevant or incorrect data on feeding, or undetected confounding or interactions with other herd factors such as flooring resilience or housing system (Bergsten & Frank, 1996b; Livesey *et al.*, 1998). Our results are, however, in agreement with those of a controlled experiment, in which no effect of the rate of increase in concentrate ration after calving could be shown (Peterse *et al.*, 1986). The difficulties in obtaining relevant good quality information on feeding in commercial dairy herds have been discussed by Østergaard & Sørensen (1998).

Sole ulcers

The prevalence of sole ulcers in **Paper I** (8.6%) was lower than the 14% reported by Andersson & Lundström (1981). Although sole ulcers were not associated with an increased risk of culling *per se* (**Paper IV**), sole ulcers were the most important cause of lameness (**Paper I**), and lame cows were prematurely culled. The lack of association between sole ulcer and culling (**Paper IV**) can partly be explained by the 479 kg higher 305-d ECM production in cows with sole ulcer. It is thus not surprising that the prevalence of sole ulcers in the study of culled cattle exceeds our estimates. Claw trimming significantly reduced the risk of sole ulcer (OR = 0.59) (**Paper III**). Andersson & Lundström (1981) estimated that 40% of dairy cattle were trimmed annually. With the increasing habit of claw trimming (Hultgren *et al.*, 1998) it is possible that our more recent estimate reflects a decreased prevalence of lesions. The high risk of lameness in cows with sole ulcers (**Paper I**) is in agreement with previous studies (Murray *et al.*, 1996; Philipot *et al.*, 1994a). The gradual onset and sometimes bilateralness of sole ulcers (**Paper I**) may, however, cause sole ulcers to go undetected until trimming (Logue *et al.*, 1994).

The positive effect of claw trimming in **Paper III** indicates a traumatic origin of lesions. Moreover, cows in herds where both dry and lactating cows were kept on a hard surface were at a 2.5 times higher risk of sole ulcers than cows in herds where dry cows were moved to a soft surface (rubber mats) after calving (**Paper II**). The lower prevalence of sole ulcers and white line fissures or double soles in primiparous cows that had calved at a relatively low age (<28 months) (**Paper II**) is probably related to a better general management of heifers, possibly also to a lower bodyweight at calving, with a consequently decreased risk of solar corium contusion (Vermunt & Greenough, 1994; Bergsten & Frank, 1996b).

Although most sole ulcers (85%) disappeared after corrective trimming and, if necessary, application of a block to the unaffected claw (**Paper III**), one-third of cows examined with a recorded sole ulcer in year 1 also had an ulcer in year 2; the risk of recurrence was even higher (75%) if a cow had repeated ulcer-records (both autumn and spring) in year 1. A high risk of recurrence of sole ulcers has earlier been reported (Alban *et al.*, 1996). Lischer (2000) explained the high risk of recurrence by irreversible damage to tissues within the claw capsule.

The high risk of lameness in cows with sole ulcers (OR = 6.0) (**Paper I**) is in agreement with earlier studies (Philipot *et al.*, 1994a; Murray *et al.*, 1996). Logue *et al.* (1994) studied 48 autumn calving cows and found that only lesions in the sole were significantly associated with locomotion score. They also noted that there was an association between lesion severity score and locomotion in primiparous, but not in multiparous cows.

Having a sole ulcer at claw trimming 60-180 days in milk was associated with a lower first-service conception rate during the first study year (OR = 0.59), a 2% longer calving interval, and a higher odds of receiving treatment for anoestrus (OR = 1.61); there was, however, no association with calving-to-first-service interval (**Paper IV**). The effect of lesions and disorders on reproductive performance, as estimated from observational studies such as our, is a combination of a biologic effect and the farmers' attitudes towards affected animals. The 2% prolonged calving interval in **Paper IV** for instance, might be caused by both a direct effect of the hoof disorder and also the farmers' wish to let the animal recover before service. Moreover, studies of possible associations between hoof disorders and reproduction are often biased by the fact that the predictors may occur any time during the lactation, and the risk of declaring spurious associations thus increases in cows with prolonged reproductive intervals. Records used in **Paper IV** were point-estimates of hoof health, considered indicators of impaired hoof health throughout the entire lactation; the risk of overestimating the associations between hoof health and fertility traits was thus eliminated.

Fourichon *et al.* (2000) reviewed the literature on the effect of disease on reproduction and concluded that although lameness was associated with an average of 12 more days to conception, the association between hoof health and reproduction remains undecided. The lower conception rate at first service in **Paper IV** is, however, in agreement with the results of Collick *et al.* (1989) and Hernandez *et al.* (2001). In Hernandez' study, lame cows with claw lesions (white line abscesses or sole ulcer) or multiple lesions (but not lame cows with interdigital phlegmone or digital dermatitis) were less likely to conceive. The more pronounced effect in lame cows with claw lesions was expected; in comparison with skin diseases, claw lesions take longer time to cure even if treated and the associated pain persists longer (Whay *et al.*, 1998).

There are several plausible ways to explain a negative association between hoof health and fertility: Pain-induced stress alters the precise events within the follicular phase – the pulsation frequency of the hypothalamic GnRh-secretion and consequently the LH-secretion (Dobson & Smith, 2000; Dobson *et al.*, 2001) – resulting in abnormal ovarian function. In cases of chronic stress (*e.g.* from severe lameness), the GnRH/LH-pulsation will not be adequate to bring about the final maturation of the follicle resulting in anoestrus; whereas in less stressful situations, oestrus and fertilisation may occur, but due to less viable oocytes, the conceptus will fail to develop into a pregnancy (Dobson & Smith, 2000). It is generally agreed that sole ulcers are a consequence of laminitis. Feeding is one often-mentioned cause of laminitis; specifically, the vasoactive effects of endotoxins released as a consequence of inadequate feeding routines (*e.g.* Singh *et al.*, 1994; Nocek, 1997). Endotoxemia in ruminants cause activation of the arachidonic acid cascade and increased synthesis of prostaglandin, clinically resulting in increased body temperature, ceased appetite, depression, altered posture and vocalisation (Königsson, 2001). The prostaglandin levels might be high enough to cause degeneration of *corpora lutea* (Kindahl *et al.*, 1990), with the subsequent termination of early pregnancies. Moreover, endotoxin induces a delayed ovulation, possibly through a delayed preovulatory LH-surge and suppresses oestrus signs through a suppression of the preovulatory estradiol rise (Suzuki et al., 2001).

The effect of nutrition on reproductive performance has been summarised by Butler (2000). In short, the negative energy balance that occurs spontaneously in dairy cows at the onset of lactation alters the pulsatile secretion of luteinising hormone (LH) and the ovarian responsiveness to LH. Additionally, plasma levels of factors important to follicular growth (insulin, glucose and insulin-like growth factor-1) are decreased during negative energy balance. Negative energy balance is enhanced in situation with decreased feed intake, such as in overconditioned animals. Overconditioned animals are also more likely to develop severe hoof lesions. Moreover, the feeding of high protein-levels, intended to support and maintain a high milk production, causes a decreased reproductive performance, possibly as a consequence of a lowered intrauterine pH. Painful locomotion and standing can cause a decreased feed intake thus exacerbating the negative energy balance.

White line fissures and double soles

Andersson & Lundström (1981) did not record the prevalence of white-line fissures or double soles. The prevalence estimates in **Paper I**, however, are lower than reported from international studies (Smilie *et al.*, 1996; Philipot *et al.*, 1994a). White-line fissures and double soles are caused by disruptions in the continuity of the claw horn. Double soles generally result from an aseptic discontinuation of sole horn growth, but might also be caused by abscesses in the white line (Mülling, 2002). Although we did not find any white-line abscesses, the relatively strong association between the two types of lesions at all three organisational levels (the hoof, cow, and herd level) (**Paper I**) indicate either a common pathogenesis, or that one type of lesion causes the other. Both white-line lesions and double soles have been considered secondary to circulatory disturbances, *i.e.* laminitis (Singh *et al.*, 1994b). Consequently, it is not surprising that the associations between white-line fissures or double soles and the studied risk factors in **Paper II** were similar to those for sole ulcers, another "third-phase lesion" secondary to laminitis (Ossent & Lischer, 1998). Interestingly, there was no association between white-line haemorrhages and white-line separations at the cow or herd level (**Paper I**), indicating that fissures do not emanate from a weakened integrity of the white line associated with haemorrhagic residues in the claw horn.

The proportion of variability due to between-herd variation was 40-42% for these lesions, indicating a somewhat higher relevance of individual-level factors for the development of lesions (**Paper I**). One important factor was parity; the risk of lesions appeared to increase linearly with increasing parity (**Paper II**). In primiparous cows, there was a strong association between calving age and risk of lesions, with heifers calving at <26 months-of-age at a significantly lower risk of lesions (OR = 0.37) than those calving at ≥31 months-of-age (**Paper II**). As for sole ulcers, this association might be due to a better general management of heifers calving at a relatively low age or (possibly) to a lower body weight at calving. Due to their transient nature, most double soles (97%) recorded at autumn trimmings had disappeared at the subsequent spring trimming (~4.5 months later), whereas the recovery rate for white-line fissures was slightly lower (87%) (**Paper III**). The positive effect of claw trimming (**Paper III**) on the prevalence of double sole or white line fissure can thus (at least partly) be related to the actual removal of double soles in autumn-trimmed cows. The interaction between toe length and claw trimming status (**Paper II**) indicates either that the risk of lesions increases with the length of the time period between trimmings, or that claws that are not trimmed to an adequately short length still are at an increased risk of lesions, albeit having been trimmed.

More white-line fissures or double soles and lameness occurred in herds with comparatively rough flooring (**Paper II**). It is possible that the rougher floor increases the shearing forces on the claw capsule of moving cows that have been associated with white-line lesions (Bergsten & Herlin, 1996).

Lameness

Although most (72%) examined animals had hoof lesions, only few (5.1%) were recorded as lame (**Paper I**). It is possible that the challenges to the hoof health were not large enough for the lesions to progress into a lameness-causing stage, or that management (*e.g.* claw-trimming routines) in the herds stopped the progression of lesions into the severity needed to cause lameness. The propensity for lameness was approx equally associated with individual- and herd-level factors (**Paper I**). The most important individual level risk factor was increasing parity (**Paper II**), which is in agreement with results from the US (Wells et al., 1993b; Boettcher et al., 1998). Most lameness cases (87%) recovered after trimming and treatment, as judged at the reexamination ~4.5 months after treatment (**Paper III**).

The risk of lameness was three times higher in dry cows that upon entering the lactating herd were transferred to a hard surface relative to those that were transferred to a soft (rubber mats) (**Paper II**). Uncomfortable lying surfaces result in altered lying behaviour with subsequent deleterious effects on the hoof health due to prolonged standing (Galindo & Broom, 1993; Singh *et al.*, 1993, 1994; Leonard *et al.*, 1994). Locomotion scores have been reported to worsen progressively the 10 first weeks after calving/housing (Boelling & Pollott, 1998) probably due to the lag phase between the initial challenge and the occurrence of lesions at the solar surface.

Lameness at claw trimming 0-180 days in milk was associated with higher odds (OR = 1.81) for terminating the lactation with culling (**Paper IV**). Among all lactations terminated by culling, hoof or leg disorders were the primary reason for culling reported in 21.1% of lame cows (*vs.* 2.0% of non-lame cows). The increased risk of culling in lame cows is in agreement with previous studies (*e.g.* Sprecher *et al.*, 1997; Hernandez *et al.*, 2001). The results of Rajala-Schultz & Gröhn (1999) suggest that dairymen consider diseases to be a cause of culling principally at the time of disease occurrence; for lameness, however, the effects on culling extend throughout the lactation, regardless of the time of disease occurrence. This may contribute further explanation to why no effect of sole ulcer on culling could be demonstrated (**Paper IV**), since sole ulcers are only recorded by the hoof trimmer and thus might influence the farmer's culling decisions less.

Claw measurements as indirect parameters of hoof lesions

Due to the cumbersome procedure of obtaining direct measurements of hoof health, indirect parameters (such as leg and hoof conformation, claw measurements and claw-horn pigmentation, ultra-structure and hardness) have been suggested or implemented as indicator-traits in the selection procedure for genetic improvement of hoof health. The associations between such parameters and hoof health are, however, not always straightforward. Baumgartner *et al.* (1990), for instance, found toe length, heel height and sole area to be negatively correlated with heel horn erosion in the hind hooves but positively correlated with the same type of lesions in the front hooves. We used hoof-health records and claw measurements from 5,013 dairy cows and heifers in 102 herds obtained at claw trimming to describe claw morphology and associations between measurements of the claw capsule and the hoof-health status. Most of the following results are not included in **Paper I-IV**.

Claw measurements from the lateral claw of the left hind hoof are presented in Table 3. The toe length ranged between 62 and 135 mm, the distal toe angle between –13° and 87°, and the proximal between 10° and 72°. The difference between proximal and distal toe angle (a measure of the concavity or convexity of the dorsal wall of the claw capsule) varied between -37° and 44°. A majority of examined feet (76%) had a concave front wall. Examined heifers and cows in parity 1 to 3 had successively longer and shallower claws, no further changes were found for cows of parity >3. Our results are concurrent with those of Offer *et al.* (2000) who followed 31 cows from first calving to the fifth lactation and reported increasing toe length from parity 0 to 4. In a cross-sectional study, Andersson & Lundström (1981) also reported longer and shallower toes with increasing parity.

Table 3. Claw measurements for cows in different parity groups in 98 Swedish dairy herds examined at claw trimming 1996-1998

Parity	*n*	Toe length	Proximal angle	Distal angle	Concavity
0	203-217	77 mm	48º	46º	3º
1	1955-2123	83 mm	47º	42º	5º
2	938-1054	87 mm	46º	40º	6º
3	546-621	88 mm	46º	40º	6º
>3	652-745	88 mm	47º	41º	6º
All	5013	85 mm	47º	41º	6º

There were, however, marked differences between measurements obtained in different seasons and between cows of different breeds (Table 4, page 46). Cows examined in autumn had on average shorter toes than those examined in winter and spring. Moreover, the proximal toe angle was steeper in autumn and winter than in spring, and the distal toe angle was steeper in autumn than in winter and in spring. Swedish Red and White (SRB) cows had on average slightly longer claws and shallower proximal angle than Swedish Holstein (SLB) cows but the distal angle was similar in the two breeds. SRB cows also had slightly less concave walls than SLB. The differences between SRB and SLB cows in toe lengths and angle are in agreement with earlier Swedish studies (Ahlström, *et al.*, 1986; Andersson & Lundström, 1981). In the present study, tied cows had longer and shallower toes than animals in cubicles but there was no association between housing system and the difference between proximal and distal toe angle (Table 4). The observed differences in claw measurements were probably due to different rates of wear: The average net claw horn growth rate between autumn and spring claw trimming (~4.5 months later) was 2.0 mm/month for animals in free-stalls, 2.6 mm/month for tied animals on concrete and 3.4 mm/month for tied animals on rubber mats (**Paper III**).

The net increase in toe length was greater in trimmed than in untrimmed cows (**Paper III**). Manson & Leaver (1988, 1989) showed that both an increased growth and a decreased wear of the capsule contribute to this net increase. Correctly shaped claws might have an improved circulation due to a more effective pump-mechanism and hence a better quality (more wear-resistant) hoof-horn. According to Vokey *et al.* (2001), the growth rate of claw horn is proportional to the abrasiveness of the flooring. A low-grade inflammation (caused by trauma to the corium) might be the cause of the compensatory extra growth (Gogoi *et al.*, 1982). Hahn *et al.* (1986) studied claw horn growth and wear eight times during 19 months and showed that periods of increased wear were followed by periods of increased growth.

To avoid confounding by season, associations between lesions and claw measurements were studied on data from cows examined in spring only. The claws of lame animals were longer (88 *vs.* 85 mm), had a shallower distal toe angle (38º *vs.* 42º) and more concave dorsal toe walls (9º *vs.* 5º) than the claws of non-lame animals. Cows with sole ulcer or haemorrhages had shallower distal toe angles and a larger difference between proximal and distal toe angle than cows without these lesions. Cows with dermatitis had longer toes, shallower distal toe angles, and a larger difference between proximal and distal toe angle than cows without (Table 5, page 47). Due to the study design, no conclusions on causality can be drawn.

Table 4. Toe length (mm), and proximal and distal angle (º) and concavity of the lateral left hind claw in 5013 Swedish Red and White (SRB) and Swedish Friesian (SLB) cows kept in tie-stalls or cubicles and examined in different seasons, 1996-1998. Between 84 and 695 observations per row

Housing	Season	Toe length		Prox angle		Distal angle		Concavity	
		SRB	SLB	SRB	SLB	SRB	SLB	SRB	SLB
Tie-stalls	Autumn	85	82	46	48	41	42	5	6
	Winter	87	87	47	48	42	41	5	7
	Spring	91	89	44	45	39	39	5	6
Cubicles	Autumn	80	80	49	50	45	45	4	6
	Winter	81	81	48	49	42	42	4	7
	Spring	84	82	45	48	41	43	5	6

Table 5. Association between hoof lesions and claw measurements (toe length, proximal and distal angle, and concavity of the lateral left hind claw) in 1,470-1,545 Swedish dairy cows examined at routine spring claw trimming, 1997-1998

Lesion type	Toe length	Proximal angle	Distal angle	Concavity
Haemorrhages				
Cases (n=511)	86 mm	46°	39°	6°
Non-cases (n=1034)	87 mm	45°	41°	5°
Dermatitis				
Cases (n=731)	88 mm	46°	40°	6°
Non-cases (n=739)	86 mm	46°	41°	4°
Separations				
Cases (n=182)	88 mm	45°	39°	6°
Non-cases (n=1364)	87 mm	46°	40°	5°
Sole ulcer				
Cases (n=166)	88 mm	46°	37°	9°
Non-cases (n=1380)	87 mm	46°	41°	5°

Toe angle and length have been suggested as indicators of hoof health (see Ral *et al.*, 1995). Upper angle is thought to better reflect genetic merit, since the lower angle is more affected by overgrowth and trimming (Wells *et al.*, 1993a). The results of the present study show that factors not directly related to hoof health (such as housing system and season) are associated with these measurements. Such differences in shape of the claws of cows in different housing systems and examined at different times of the year need to be addressed if claw measurements are to be included in breeding evaluation schemes. Our results indicate that concavity of the toe wall might be a good alternative indicator of hoof health. The toe wall becomes concave following a rotation of the claw bone or a decreased horn production at the proximal dorsal toe wall. Rotation of the claw bone between 1 and 14 degrees was the most common (~35% of cases) radiological finding in 179 cows with acute laminitis (Gantke *et al.*, 1998), and ridges of the toe wall have been considered a more reliable indicator of chronic laminitis than sole haemorrhages (Boosman *et al.*, 1989). Concavity is easy to score subjectively or measure directly and it is not affected by claw trimming. The associations between shape of the dorsal wall and hoof health merit further research.

Prevention and treatment of claw lesions through trimming

Functional claw trimming contributes to a maintained or restored correct weight bearing within and between the claws and protects the solar corium from contusion through dishing-out of the sole (Figure 5, page 48), thus preventing hoof lesions. In restoring claw shape, trimming also contributes to the curing of existing mild lesions that are due to excess pressure on sensitive tissues. In the present studies, claw trimming was associated with a positive effect on the prevalence of lameness and all hind-hoof lesions (at the cow level), except dermatitis or heel horn erosion, as recorded ~4.5 months after trimming (**Papers II** and **III**). Moreover, the risk of hoof lesions requiring veterinary treatment in the period between scheduled trimmings was reduced in trimmed relative to untrimmed cows.

Historically, claw trimming was primarily intended to shorten the claws, and tools were developed to do this in the standing animal with no need for hoisting the feet (Hess, 1904). In modern dairy production (especially in situations with moist and abrasive flooring), the dishing-out of the sole has become more important (Dietz & Heyden, 1990). A further beneficial effect of trimming is that the propensity to slip is reduced in cattle with newly trimmed claws (Phillips *et al.*, 2000). The increased friction might be due to altered angles of the horn tubuli towards the surface, an increase in surface area, or changes in the claw horn properties after trimming.

The ideal trimming frequency is likely due to both individual- and herd-level factors. The results of **Paper III** speak in favour of at least two trimmings per year. Tranter & Morris (1992) observed that sole concavity was lost 50 days after housing in a cubicle system, indicating a need for even more frequent trimmings. Thirty percent of the farmers replying to the initial questionnaire reported that claws were trimmed routinely at least two times per year; 44% reported trimming once annually and 22% "when needed". A small number of farmers (4%) did not respond to the question of claw trimming frequency, possibly indicating that they did not employ maintenance claw trimming. A larger proportion of tied cows kept on rubber mats (50%) were trimmed twice yearly or more often than among tied cows kept on concrete (16%). More than every second farmer that reported one annual claw trimming trimmed in spring (at the end of the housing-season) whereas 80% of the farmers that reported trimming twice annually trimmed in the autumn and in the spring.

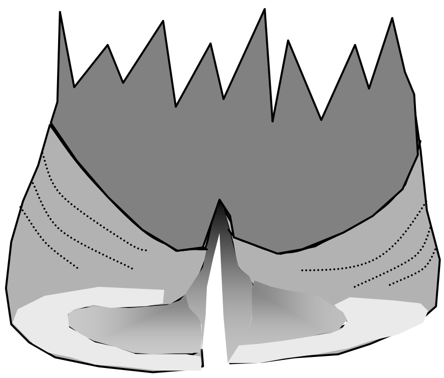


Figure 5. The soles are properly dished out – contributing to shock-absorption

In most (62%) of the herds, the trimming was done using a hammer (mallet) and a blade. In larger herds and in herds that routinely trimmed at least two times per year, the use of electrical angle grinders was more common. A professional hoof trimmer was contracted in 76% of the herds; in the remaining herds, the farmers made the trimming themselves. The situation in Sweden might be unusual; in contrast to our results, the results of a questionnaire delivered to 58 Somerset (UK) farmers indicated that farm personnel performed most trimmings, whereas only 16% of farm managers hired a professional trimmer (Weaver, 1997). Borsberry *et al.* (1999) reported from a smaller survey of dairy farms' claw trimming routines in the UK. It was estimated by veterinary practitioners that 45% of herds had incorporated a hoof-care programme with claw trimming. Trimming was reportedly performed 'when needed' (on 24 of 29 herds) or once per year (11/29); no farmer reported trimming two times per year or more often.

In the present study, there was no evidence of an association between stage of lactation at claw trimming and hoof health (**Paper III**); the magnitude of the beneficial effect of trimming was independent of when during lactation the trimming was performed. Intuitively, a preventive effect of trimming should be optimised if cows were trimmed before the peak of challenges. Whereas the negative effect of an unhygienic environment probably is more or less cumulative through the housing season, the peak occurrence of laminitis-associated lesions at 61-150 days in milk (**Paper II**) indicates that the relevant challenges to the claw health is most severe at the time around calving. For the individual cow, trimming in the dry period ought thus to be optimal. It should, however, be emphasized that the net growth of claw horn in cubicle housing is negative for a period extending from calving until 10-20 weeks after calving/housing (Leach *et al.*, 1997; Offer *et al.*, 2001). Trimming should thus be aimed at correcting the external shock-absorption, while retaining sufficient sole depth at areas exposed to abrasion. In a smaller herd, where individual trimming-programs are impractical, it would probably be preferable to trim all cows at the onset of the housing season, and in February-March; or (if trimming three times per year) in January and in April.

When claw trimming is performed incorrectly, there is a risk of severe damage, a risk that might have increased with the introduction of modern trimming methods (Kofler, 1999). The results presented in **Paper III** and in the previous chapter support earlier published observations (Hahn *et al.*, 1986; Smit *et al.*, 1986) that claw morphology differs between housing systems, indicating that the claw-trimming technique ought to be adjusted accordingly. In order to achieve a correct weight bearing, the claws of tied cows need to be trimmed relatively more at the apex of the toe than the claws of cows in cubicle systems. Kümper (1997) pointed out that, for cows in loose-housing, a need for trimming may pass unnoticed, since the overgrowth occurs rather at the sole than at the toe (and is invisible if the hoof is not examined from underneath). The claw-trimming technique also must accommodate for individual variation. For instance, with severe asymmetry between the claws, the smaller claw may not always need trimming (Kümper, 1997). Moreover, there is some evidence that hoof trimmers trimming in several herds and using dirty equipment can carry infectious organisms between herds and animals (Wells *et al.*, 1999). Hoof trimmers should clean and disinfect their tools and clothing between farms. Although recommendable, the cleansing of trimming equipment between single animals within a farm is hardly practical.

Recording of lesions should be an integral part of the claw-trimming routine (Weaver, 1997; Borsberry *et al.*, 1999). A well-educated hoof trimmer can assist in gathering quality data on the hoof health status of the herd, data that can prove invaluable to veterinary practitioners, feeding- and breeding-advisors (Ral *et al.*, 2001) – as well as to hoof-health researchers.

Conclusions

1) Most Swedish dairy cows had hoof lesions. Most lesions did not, however, cause lameness. Different hoof lesions were associated at the hoof, cow, and herd levels, but the patterns of association varied between levels. The correlation between the contra-lateral hind or front hooves was lower than the correlation between hind and front hooves. The correlation between lesion-status of the hind-hooves was particularly high for abnormal claw shape, heel horn erosion and dermatitis.

2) Hoof lesions and lameness were to a varying degree associated with animal- and herd-level factors. The variance component due to between-herd variability was relatively high (54-62%) for heel horn erosion and abnormal claw shape, but low for sole and white line haemorrhages (19%). The prevalence of most hoof lesions (except sole and white line haemorrhages) and lameness increased with parity and was highest in cows examined at 61-150 days in milk. Cows with high milk yield were at an increased risk of sole ulcers. Cows with dirty hooves were at an increased risk of hoof lesions and lameness. Cows in cubicle housing were at an increased risk of dermatitis or heel horn erosion relative to tied cows and cows in herds with soft flooring were at a decreased risk of sole ulcers and lameness.

3) By application of an adequately frequent and correct claw-trimming protocol, the prevalence of severe claw lesions (such as sole ulcers) and lameness can be decreased. Moreover, hoof-health records obtained at claw trimming are valuable tools in dealing with hoof-health problems at the individual and herd level, and might also be used in the genetic evaluation of breeding animals.

4) Cows with sole ulcers have a decreased reproductive performance, reflected by a lower first-service conception rate, a prolonged calving interval, and a higher risk of receiving treatment for anoestrus. Moreover, cows with sole ulcers tend to have a lower over-all conception rate and an increased number of services per pregnancy. Lameness is associated with a higher risk of culling and possibly higher milk-cell counts.

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