Laminitis-related lesions and lameness detection in dairy cattle in Finland

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To be presented, with the permission of
The Faculty of Veterinary Medicine, University of Helsinki,
for public examination
in Walter Hall, Agnes Sjöbergin katu 2, Helsinki,
on 23rd April 2010, at 12 noon.

Helsinki 2010
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Helsinki University Print, Helsinki 2010
To my Heavenly Father and
my earthly father
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Abstract

During the last few years of structural changes in agriculture, lameness has become one of the most important farm issues in Finland. An estimated 90% of lameness is due to hoof problems. However, a national recording system for hoof diseases of cows did not exist in Finland prior to 2002, nor have analyses of risks been investigated. The co-operation project Healthy Hooves (HH) between The Finnish Hoof-trimmers’ Association, Suomen Rehu and Vetman was established in 2001 to attempt to improve national hoof health.

White line disease (WLD) or sole ulcer (SU) constituted the predominant (lameness-producing) hoof problems in Finland according to the results of the HH pilot year in 2002. Haemorrhages, WLD and SU were the lesions focused on here.

The HH project on one farm included e.g. a regular hoof-trimming and recording system, data collection and national incidence reports by Suomen Rehu Ltd. The full HH dataset for 2003–2004 consisted of 74 410 observations on 41 087 cows from 1 430 farms, (each cow trimmed 1–8 times). The final dataset of haemorrhages and WLD (without Finnish breed) included 11 220 cows from 552 tie-stall (TS) herds and 5 490 cows from 149 loose-housed (LH) herds. The final dataset of SU included 11 303 cows from 554 TS herds and 5 854 cows from 149 LH herds. Multivariable random effects logistic regression models were carried out and all models were evaluated with both hoof-trimmer and farm as random effects using both quasi-likelihood and maximum-likelihood estimation procedures. Lactational risks of hoof diseases were calculated and risk factors for haemorrhages, WLD and SU were analysed.

In addition to specific lameness-related hoof lesions and their incidences/prevalences, increasing interest has been directed towards the lameness detection itself. One aim of this study was to develop an automatic lameness detection system operating in a milking robot by force plates and compare it with lameness scoring (LS) and hoof-trimming data. In the final stage, a neural network model was established to detect/identify lame cows.
In WLD and SU cases that produced lameness, acute phase proteins were investigated to determine whether an acute phase response (APR) was connected to these hoof lesions, and to evaluate the severity of these reactions.

The HH project established a national recording system for hoof problems and identified the most important risk factors. According to the results, WLD and SU were important hoof diseases in Finland, which also might cause clear acute phase response in cows.

The lactational risks of WLD and SU, which are considered major causes of lameness in Finland, were strongly affected by the number of times a cow’s hooves were trimmed during lactation. In addition, the most important risk factors for WLD (in LH herds) and SU were breed (higher risk in Holsteins compared to Ayrshire), farm type (higher risk in LH than in TS) and parity, but neither high levels of milk yield nor feeding type were found to be risk factors. Parity and breed were dependent on each other in all-cow TS-model in WLD. The largest cooperative action was seen with older Holstein cows, that had huge risk to get WLD compared to young Ayrshire cows (OR= 7.92). Hard flooring in cubicles, compared with deep bedding or mats, was clearly a risk factor for both diseases. In addition, a strong effect existed between other hoof lesions and WLD/SU, especially in TS herds.

While carrying out the HH project, I concluded that the effect of feeding on laminitis-related lesions is probably overestimated in Finland. Laminitis-related lesions are multifactorial problems, with breed, parity (including growing heifers) and cow comfort having the greatest impact. However, when already a risk for laminitis exists, e.g. because of the environment, inappropriate feeding may further increase the risk.
This thesis is based on the following accepted articles (I–V). These articles are referred to in the text by their Roman numerals. These articles have been re-printed with the kind permission of their copyright holders. In addition, some unpublished material has been presented.


### Abbreviations

<table>
<thead>
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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>AP</td>
<td>Ante partum</td>
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<td>APP</td>
<td>Acute phase protein</td>
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<td>APR</td>
<td>Acute phase response</td>
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<td>AUC</td>
<td>Area under curve</td>
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<td>DD</td>
<td>Digital Dermatitis</td>
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<tr>
<td>FABA</td>
<td>Finnish Animal Breeding Effect</td>
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<td>HH</td>
<td>Healthy Hooves</td>
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<td>Hp</td>
<td>Haptoglobin</td>
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<td>LH</td>
<td>Loose housing</td>
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<td>LS</td>
<td>Locomotion scoring</td>
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<tr>
<td>LWR</td>
<td>Leg weight ratio (%) between lighter and heavier hind leg</td>
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<td>PNN</td>
<td>Probabilistic neural network</td>
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<td>PP</td>
<td>Post partum</td>
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<td>SAA</td>
<td>Serum amyloid-A</td>
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<td>SSHY</td>
<td>Finnish Hoof-trimmers’ Association</td>
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<td>SU</td>
<td>Sole ulcer</td>
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<td>WL</td>
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**1 Introduction**

**Lameness** has been a crucial welfare and health issue worldwide for a long time. During the last few years of structural changes in agriculture, lameness has become one of the most important farm issues, also in Finland. Tie stalls (TSs) have been a major farming system in Finland, where cows stand upright in cubicles and are usually let to pasture in the summer. Loose-housing (LH) systems are rarer and typically comprise free stalls with cubicles, where cows are allowed to walk on hard floors with two-metre-wide alleys. Since TS stables have developed to LH systems in Finland, (as has happened elsewhere in Europe before), cows are subjected to walk on hard concrete and seem to suffer more lameness problems.

In Sweden and Norway, researchers have been working towards improving the hoof health of cows and compiling prevalence databases and risk factors for a longer time. In Finland, however, no national hoof-trimming recording system for hoof diseases of cows existed prior to 2002, nor have risks been investigated.

Although some hoof-trimmers had kept regular recordings of lesions for their clients, national records of lameness (= the main way of collecting disease information of the cows in Finland), has consisted only of clinical cases diagnosed by veterinarians. Until 2002, approximately 10% of Finnish farms were within regular hoof-trimming (Jouni Niemi and the trimmers of the government of the Finnish Hoof-trimmers’ Association (SSHY), oral communications 2001).

The Healthy Hooves (HH) project was established in co-operation between The Finnish Hoof-trimmers’ Association (SSHY), Suomen Rehu and Vetman Ltd. All participants took care of their own area of expertise and the team developed ways of improving hoof health. At the beginning of this programme, our main concern was the overall hoof health in Finland. Teaching of farmers, studying the occurrence of hoof diseases and associated risks in Finland, and improving the detection of hoof lesions – were the first areas of interest. This research part followed the main project.
An estimated 90% of lameness is due to hoof problems (Murray et al., 1996), although all hoof lesions do not cause lameness (Smits et al., 1992; Logue et al., 1994; Manske et al., 2002; Logue et al., 2004). Sole ulcers (SUs) are generally considered the most important cause of lameness in cattle (Murray et al., 1996), and they also have the longest lasting effect on milk yield (Amory et al., 2008). According to the HH pilot project in 2002 (Kujala et al., 2004) and reports from Scandinavia (Manske et al., 2002; Sogstad et al., 2005b), infectious hoof diseases were not as serious a problem here as they were in other parts of Europe and the US. (Clarkson et al., 1996; Wells et al., 1993; Murray et al., 2002; Somers et al., 2003; Capion et al., 2008a, Capion et al., 2008b).

At the beginning of the HH project, non-infectious diseases and lameness due to SU or white line disease (WLD) appeared to be the biggest hoof problems in Finland. In addition, the most prominent lesions were haemorrhages (Kujala et al., 2004). The results of Healthy Hooves Project yielded abundant information, especially on non-infectious hoof diseases, found by trimmers. We evaluated lactational risk of SU, WLD and haemorrhages; and the effects of age, breed, milk-yield, housing type along with other hoof diseases and several management factors on the risk of the two diseases. Given the changes taking place in the Finnish dairy industry, it is particularly critical to look at the effects of breed and housing type on the risk of these three diseases. It is also important to identify important management factors which may reduce the risk of the conditions.

Accordingly, haemorrhages, WLD and SU were the lesions we studied more extensively.

In addition to specific lameness-related hoof lesions and their occurrence, an increasing interest is lameness detection itself. The bigger farming systems made it more difficult to detect animals and to identify lame cows early enough. Different lameness detection systems are in use worldwide, the most widespread being the 5-stage lameness scoring (LS) system established by Sprecher et al. (1997). More recently, before these trials, some technological approaches were developed to detect lameness in a more objective way (Rajkondawar, et al., 2002a; Rajkondawar, et al., 2002b; Tasch and Rajkondawar, 2004; Flower, et al., 2005). However, the use of objective, technological methods to detect lameness and comparisons with hoof health and LS has just begun.

In this thesis, I concentrate on non-infectious hoof diseases, especially laminitis-related lesions manifesting as haemorrhages, WLD and SU.
2 Review of the literature

2.1 Importance of hoof diseases and lameness

Lameness raises important questions about economic aspects and welfare issues in agriculture. Lameness due to hoof lesions is one of the most common diseases reported in modern dairy production (Bergsten and Herlin, 1996), and 90% of lameness is due to hoof problems (Murray, et al., 1996). The predominant hoof problems causing lameness in cows and reducing milk production are SU, white line (WL) abscess, interdigital phlegmons and digital dermatitis (DD) (Warnick et al., 2001; Hernandez et al., 2002; Amory, et al., 2008).

In addition, many researchers have found a correlation between laminitis (Pododermatitis aseptica diffusa), associated with the presence of haemorrhages (e.g. Greenough and Vermunt, 1991; Le Fevre et al., 2001), and such hoof lesions as SU (Pododermatitis circumscripita), WLD (Pododermatitis zona alba), and abscesses in the subsole (Pododermatitis septica) (Bradley et al., 1989; Greenough and Vermunt, 1991). Thus, laminitis is widely regarded as a major predisposing factor in lameness and SU (Bradley, et al., 1989).

2.1.1 Cow welfare

Lameness is a crucial production and welfare issue in modern dairy husbandry. Welfare of the cows refers to ethical quality of production, and lameness is one central issue (Laven et al., 2008). Lameness causes pain and suffering to cows. Improving cow comfort in cubicles and stables results in more sleeping time and positively affects lameness and hoof problems (e.g. Cook 2003; Cook et al., 2004; Cook et al., 2005, Cook and Nordlund, 2009; Dippel et al., 2009).

2.1.2 Economic aspects

Economic losses arise from e.g. decreased milk production, fertility problems and increased culling rates and treatment costs. Costs are usually costs calcu-
lated separately for each effect (e.g., Souza et al., 2006), but some studies calculated total costs (224–320€/case) (Guard 2001; Oszvari et al., 2007).

### 2.1.2.1 Milk production

Lame cows have clearly been demonstrated to produce less milk (Rajala-Schultz, et al., 1999; Green, et al., 2002; Hernandez, et al., 2002; Hultgren, et al., 2004; Hernandez, et al., 2005; Amory, et al., 2008; Bach, et al., 2007). Costs calculated in different studies range from 1.5kg/day to 2.8kg/day (Rajala-Schultz et al., 1999; Warnick et al., 2001; Green et al., 2002). In some studies, milk loss has been estimated at 270–440kg/lactation depending on the stage of lactation (Coulon et al., 1996). Amory et al. (2008) found an average milk loss of 574kg and 369kg associated with SU and WLD, respectively. They also observed that high-yielding dairy cows are more likely to become clinically lame with SU or WLD, and especially SU and WLD were associated with significant milk loss, while digital dermatitis (DD) was not linked to an economically significant reduction in milk production.

High milk yield itself is widely thought to be a risk factor for hoof problems (Enevoldsen et al., 1991; Barkema et al., 1994; Fleischer et al., 2001; Hultgren et al., 2004; Amory et al., 2008), although e.g., Dohoo et al. (1984) could not found such effect.

### 2.1.2.2 Fertility

Lameness also has effects on reproductability (reviewed by Fourichon et al., 2000 and Hultgren et al., 2004). Collick et al. (1989) and Barkema et al. (1994) noted that lameness extends the days open from 11 to 40 days.

When Hultgren et al. (2004) investigated reproduction and SU, regardless of any acute lameness; they found a clear negative effect to exist.

### 2.1.2.3 Culling

Hoof lesions cause most of the lameness in dairy cattle (Murray et al., 1996), and lameness is also an important cause of culling (Collick, et al., 1989; Barkema, et al., 1994; Sprecher, et al., 1997).

However, Hultgren et al. (2004) found no effect between SU and culling. Booth et al. (2004) discussed how the stage of lactation affects culling; a cow with lameness producing SU in late lactation is more prone to be culled than one that has it in early lactation.
2.1.2.4 Treatment costs
Other costs comprise the costs of the hoof-trimmer and/or veterinarian (Guard 2001). In Finland, the hoof-trimming cost of SU or WLD with shoe repair is approximately 50–100€ /individual cow + travel costs to the farm.

2.2 National databases and prevalence of hoof diseases

Despite the fact that hoof health has become an important welfare and economic issue for Finnish dairy producers, no national hoof-trimming recording system for hoof lesions of cows has existed in Finland prior to 2002. According to the HH pilot study carried out in 2002 (Kujala et al., 2004), laminitis and laminitis-related lesions, such as sole haemorrhages, WLD and SU, were the most common hoof lesions in Finnish dairy herds.

During the pilot year, the prevalence of infectious diseases, such as DD, was very low (0.2%), but higher for non-infectious, lameness-causing lesions, such as SU (3.3%) and WLD (8.8% for all herds and 3.3% for SU and 15.7% for WLD within LH herds) (Kujala et al. 2004).

2.3 Laminitis-related hoof lesions

The most investigated hoof disease over the decades has been laminitis.

Laminitis is generally accepted to be multifactorial (e.g. Greenough and Vermunt, 1991). These factors comprise management, housing (especially concrete floors), genetics (breed), nutrition and physiological stage (reviewed by Mülling and Lischer, 2002). The laminitis-related lesions are haemorrhages on the soles and on the white line, SU, WLD and deformation of the whole surface (Ossent and Lischer, 1998).

Haemorrhages alone as subclinical laminitis usually do not make cows lame.

Over the last few years, Lischer and Ossent (2002), Mülling and Lischer (2002), Lischer et al. (2002) have shown and discussed that cows differ from horses in the aetiology of laminitis. Alterations of the suspensory apparatus of the third phalanx, allowing the bone to sink, occur in the dermis of connective tissue, not in the dermo-epidermal junction as described in horses. In this area, collagen fiber bundles, which run between the bone and the dermo-epidermal junction, anchor the coffin bone. A loosening or stretching of these fibers causes a lowering or sinking of the pedal bone in the horn capsule (Mülling, oral presentation in Finland, 2003), and then the connective tissue segment of the suspensory apparatus is overextended (Lischer et al., 2002; reviewed by...
The result is increased pressure on the dermis, damage of blood vessels and finally necrosis of the tissue. In addition, contrary to horses, the digital cushion of the cows supports most of the body weight (Räber et al., 2004), and when there is a pressure load on the sole or chronic inflammation, it may lead to thinner fat pads (Lischer et al., 2002; Räber et al., 2004; Räber et al., 2006).

Lesions, such as sole haemorrhages and SUs, are due to focal ischemia and necrosis due to compression of the dermis, but it is not fully known how the compression occurs (reviewed by Mülling and Lischer 2002).

As described later with WLD, horn formation needs a nutrient and oxygen supply from blood vessels, and the underlying dermis and horn formation is very sensitive to any disruption in this supply. Whatever alterations occur arises from laminitis for instance, automatically have consequences for epidermal differentiation and horn formation.

Changes in the fibres of collagen tissue lead to contusions of the corium, mainly under the abaxial and plantar edges of the third phalanx, opposite to where ulcers develop. This could be seen as a higher pressure to WL area (WL haemorrhages) and in a walking cow in the SU area (Lischer, et al., 2002).

### 2.3.1 Haemorrhages

Laminitis (Pododermatitis aseptica diffusa), which is connected to the presence of haemorrhages on the sole (e.g. Greenough and Vermunt, 1991; Le Fevre et al., 2001), is generally thought to be the biggest predisposing factor for SU and WL lesions. Laminitis is one of the most studied hoof problems in dairy cows. Its aetiology and causes have been investigated for decades. However, haemorrhages in all laminitis-related lesions have a multifactorial aetiology. The different causative mechanisms have been discussed by Le Fevre et al. (2001). Theories about diet-induced inflammation (e.g. Ossent and Lischer, 1998), hard or uneven surfaces (e.g. Le Fevre et al., 2001) and hormonal effects (Leach et al., 1997) have been presented and thought to have a combined influence, although Le Fevre (2001) concluded after their trial that biomechanical aspects best explain that 75–79% of lesions are found in the outer hind claw and the differing sites (Logue et al., 1994; Clarkson et al., 1996, Le Fevre et al., 2001).

Researchers have discussed the difference in the causative mechanisms of haemorrhages between the WL and the sole (Leach et al., 1997; Le Fevre et al., 2001). Others have suggested that haemorrhages in WL and WLD are different developmental stages of the same lesion (reviewed by Mülling 2002). As described above, one explanation for haemorrhages in WL is sinking of the pedal bone, associated with laminitis (Lischer and Ossent, 2002; Lischer et al.,
Leach et al. (1997) described haemorrhages as their severest stage in the WL at 9 weeks, but in the sole at 14 weeks after parturition, and proposed that all initial damage to the corium affects the laminar region and that corium damage increases with a subsequent alteration in the physical forces on the sole.

![Image](image.png)

**Figure 1.** Widespread haemorrhages on the sole could indicate previous subclinical laminitis (Jouni Niemi, 2000).

### 2.3.2 White line Disease

The WL is built from different horn types located between the coronary horn (“wall”) and sole. It establishes a continuous connection between the sole and “wall”. The WL has an axial and abaxial part, and its width ranges from 3.5 to 6.5 mm. Within the WL, we can distinguish outer, middle and inner zones (reviewed by Mülling, 2002).
The horn of the WL is produced by the epidermis that covers the dermal surface in the wall region. In the terminal epidermis, which covers the terminal papillae of the dermis, the rate of horn production is highest. The three different parts (outer, middle and inner) all produce horn by different processes and the type of horn produced differs from hard to soft and crumbly. The heterogeneous origin of the horn makes the WL susceptible to fissures, penetration by foreign bodies and invasion by micro-organisms. Another reason for susceptibility of WL to disorders arises from the relatively small area where most of the horn is produced and microcirculation of this area being easily disturbed (reviewed by Mülling, 2002 and in oral presentation in Finland, 2003)

WL disorders manifesting as fissures, separations, abscesses or hollow wall are collectively called WLD, which contains lesions both with and without prior weakening, as described by Mülling (2002).

Figure 2. Complicated white line disease = white line abscess after opening (Minna Kujala, 2004).
WL abscess, which usually leads to obvious lameness, is described in this thesis as a penetration of the horn by a contaminated foreign body with or without prior weakening, leading to infection of dermis.

Lesions without prior weakening are those caused by physical, chemical or microbiological factors in the environment. They lead to WLD as a primary disease and come from outside. Lesions with prior weakening can develop either due to alteration of microcirculation (mechanical or metabolic), called multi-factorial secondary disease, or as a result of subclinical laminitis and haemorrhages in the WL area, called a secondary lesion. In case of microcirculatory disturbances, horn formation is disrupted and dyskeratotic horn is produced. The clinical lesions are often the result of an interaction of both processes (reviewed by Mülling, 2002 and in oral presentation in Finland, 2003).

2.3.3 Sole ulcer
Sole ulcer (Pododermatitis circumscripita) is perforation of horn capsule subsequent to ulcer in the sole. The distal phalanx and its displacement/sinking, as described above, are the most important factor in the development of SU (Lischer et al., 2002). However, the aetiology of SU remains somewhat unclear.

Although the prevalence of SU is not generally high, it has high priority among researchers because of its long duration and painfulness. SUs commonly cause clinical lameness (Murray et al., 1996; Lischer and Ossent, 2002; Hultgren et al., 2004); cows with SU have 6-fold higher odds of being lame than cows without SU (Manske et al., 2002), take a long time to heal (Lischer et al., 2002; Lischer and Ossent, 2002), adversely influence milk yield and affect reproductive performance and udder health (reviewed by Hultgren et al., 2004).
2.4 Lameness detection

In addressing the issue of lameness, researchers usually explore problems on the farm; e.g. how many cows are lame, why they are lame and how quickly lame animals, can be identified, especially in LH herds. In TS herds, cows do not walk, but they can be evaluated by observing their standing in cubicles (Figure 4, design for HH project by Minna Kujala and Jouni Niemi 2002).
Figure 4. Standing scale for tie stall cows in the Healthy Hooves project (Suomen Rehu). Healthy claws in the uppermost picture; both legs are straight and hooves bend only slightly in the lateral direction. In the middle picture, a cow is trying to avoid pain in the lateral claw, standing on the medial claw; the hock joint angle begins to resemble an x. In the lowest picture, the situation has worsened.
In LH stables, where cows move freely, locomotion scoring (LS) systems are widely used in different studies (Clarkson et al., 1996; Sprecher et al., 1997; Winckler and Willen, 2001; Flower and Weary, 2006). One of the most popular LS system (which uses a 1–5 scale), was developed by Sprecher et al. (1997) (Figure 5, page 30).

Different technological methods for automatic detection are continuously being developed (Rajkondawar et al., 2002a; Rajkondawar et al., 2002b; Tasch and Rajkondawar, 2004; Flower et al., 2005; Flower and Weary, 2006; Pastell et al., 2006; Rajkondawar et al., 2006; Pastell et al., 2008; Pastell and Madsen, 2008).

2.4.1 Locomotion scoring
LS is used worldwide to determine the status of farms or correlations between lameness and fertility (Sprecher et al. 2007), or to compare LS numbers between visits in an automatic milking system (Borderas, et al., 2008). Measuring reliability and repeatability of the scoring is crucial. Some studies have given a relatively good support for subjective lameness scoring (Winckler and Willen, 2001; Flower and Weary, 2006; Borderas et al., 2008), in contrast to Flower and Weary (2006, 2009), who critically discussed the lack of agreement among observers. March et al. (2007) concluded that an intensive training procedure was able to increase the inter-observer reliability. All lame cows do not, however, exhibit clear lesions on the hooves (Winckler and Willen, 2001).

2.4.2 Technological developments
Agricultural engineers and veterinarians have shown great interest in the new possibilities afforded by novel technologies. These technologies are independent of subjective observations and enable automatic measurements without a timetable. Validations of visual LS systems and especially reliability between observers have lately been the topic of much discussion (March et al., 2007; Flower and Weary, 2009). Technological developments allow objective and repeatable results, but unfortunately also have some drawbacks. Technological systems are under continuous development and the first farm systems are currently coming onto the market. Only some of these compare hoof or leg pathologies, so their validity is still of concern, as described by Flower and Weary (2009).

Rajkondawar et al. (2002, 2002, and 2006) were the first to identify lame animals with an automatic walk-through system. They used force sensors to measure step parameters and logistic regression model to detect lameness (Rajkondawar, et al., 2002a; Rajkondawar, et al., 2002b; Rajkondawar, et al., 2006). Lately, different types of image analysis systems based on track-way analysis have been used for analysis and automatic detection of lameness (Song, et al., 2007; Song, et al., 2008; Flower and Weary, 2009).
Good systems will improve possibilities for investigating lameness and following the healing process.

### 2.4.3 Acute phase proteins in cattle

Acute phase response (APR) is initiated by infection, inflammation, trauma and tumour or other tissue damage where soluble mediators that mobilize the defense response of the host are released (Stadnyk and Gauldie, 1991; Nikunen et al., 2007) and their secretion patterns are species-specific (Kushner and Mackiewicz, 1987; Hayes 1994; Petersen et al. 2004).

Two major bovine acute phase proteins (APPs), serum amyloid-A (SAA) and haptoglobin (Hp) (Eckersall et al., 2001; Ganheim et al., 2003; Eckersall 2007), are produced in the liver. In cattle, Hp has been widely used as a marker of several inflammation processes and bacterial infections in cattle (Skinner et al., 1991; Alsemgeest et al., 1994; Hirvonen et al., 1996; Hirvonen and Pyörälä, 1998).

SAA is delivered in APR in humans as well as in many animal species, including cattle (Steel and Whiteland, 1994; Petersen et al., 2004). Compared with Hp, SAA seems to be a better marker of more acute disease (Alsemgeest et al., 1994; Alsemgeest 1995; Horadagoda et al., 1999). Some studies have also shown that concentrations of SAA can increase with stress (Alsemgeest et al., 1995; Saco et al., 2008).

In the study of Laven et al. (2004), no increased concentrations of APPs were found in cattle with hoof haemorrhages. However, no reports of APPs in more serious hoof diseases have, to our knowledge, been published.
1. To determine the occurrence of laminitis-related hoof diseases in Finland, and to discover the most important risk factors for laminitis-related hoof problems.

2. To develop an automatic lameness detection system.

3. To evaluate acute phase response in lame cows with sole ulcer and/or white line disease.
The materials and methods for each study are described in detail in the original papers. Only a brief overview is provided here.

4.1 Healthy Hooves project

The HH project was established in co-operation between the Finnish Hoof-trimmers’ Association (SSHY), Suomen Rehu (now part of Hankkija-Maatalous Ltd.) and Vetman Ltd. in 2001–2002. Joining the programme was free for all farms, and during the pilot year about 10% of Finnish farms participated. Our co-operation team figured out practical ways to achieve a hoof health teaching programme, and “sold” these ideas to hoof-trimmers and farmers. At the beginning of the project, our main concern was overall hoof health in Finland, including recording hoof problems on farms, hoof-trimming, effects of housing, feeding and the lack of a national database. All participants were to attend to their area of knowledge (e.g. trimming, feeding, and environment) and improve it. The national database was used for the scientific part of the project.

4.1.1 Establishing a national recording system for hoof diseases (III, IV)

In the HH project, farmers filled in a questionnaire about herd management, and hoof-trimmers recorded lesions during all visits. Training events were carried out before the study commenced to ensure consistent recording of lesions across hoof-trimmers.

Diseases were categorized into the following 10 groups: sole haemorrhages, chronic laminitis, WLD, SU, interdigital dermatitis, heel-horn erosion, digital dermatitis, >90° corkscrew claw, other hoof diseases, and preventive hoof care (no hoof lesions in this category). All lesions were recognized and the information sent to Suomen Rehu, where it was entered into the national database and further researched.

4.1.2 Occurrence of laminitis-related lesions and their risk factors (III, IV)

For research purposes, we used data from record sheets, which were merged together with information on breed, parity, milk production data and calving
dates. The full dataset of 2003–2004 consisted of 74,410 observations on 41,087 cows from 1,430 farms, with each cow being trimmed 1–8 times. These data were restricted according to different specific criteria to make it as representative as possible, and the data was then split into two: one for TS herds consisting of 15,118 observations on 11,842 cows from 578 farms and one for LH herds consisting of 8,029 observations on 5,864 cows from 156 farms.

Lactational incidence risk was chosen as the measure of disease occurrence for two reasons. First, cows are generally free from hoof lesions during dry period and heifers are rarely trimmed in Finland, so observed cases were assumed to be new cases. Second, because many cows had multiple observations, lactational incidence risk is preferred to prevalence (which is usually based on a single observation).

4.1.2.1 The dataset
The data were reduced to one record per cow with the observation period for cows with a specific lesion being up to the time of diagnosis of the lesion, while the observation period for control cows was up to the day of the last examination during the lactation.

The final dataset of haemorrhages and WLD (without Finnish breed) included 11,220 cows from 552 tie-stall (TS) herds and 5,490 cows from 149 loose-housed (LH) herds. The final dataset of SU included 11,303 cows from 554 TS herds (average herd size 26.8 cows) and 5,854 cows from 149 LH herds (average herd size 50 cows).

Herd-level milk yield was computed as the average 305-day yield from the lactation previous to the study lactation. Cow-level milk yield was then computed as the difference between the cows’ 305-day yield in the previous lactation and the herd average. These cow-level yield values were a reflection of the cow’s genetic potential for milk yield, as the effects of herd-level factors (e.g. nutrition) were removed by the calculation. Because these yield data were only available for cows in their 2nd or higher lactation, two sets of analyses were carried out within each housing type: one using all data, and the other using data from a subset of cows with parity >2.
All data collected are described in Table 1 and in articles (III, IV)

**Table 1.** Description of predictor variables used in analysis of risk factors for sole ulcer (SU) and white line disease (WLD) in Finnish dairy herds.

<table>
<thead>
<tr>
<th>Cow-level variables</th>
<th>Description (Categories)</th>
</tr>
</thead>
<tbody>
<tr>
<td>parity</td>
<td>lactation number of cow (1, 2, 3 or 4+)</td>
</tr>
<tr>
<td>breed</td>
<td>breed of cow (Ayrshire, Holstein or Finnish)</td>
</tr>
<tr>
<td>parturition year</td>
<td>year in which lactation started (2003 or 2004)</td>
</tr>
<tr>
<td>season</td>
<td>season (autumn, winter, spring or summer)</td>
</tr>
<tr>
<td></td>
<td>– see text for details</td>
</tr>
<tr>
<td>yield-cow</td>
<td>milk yield expressed as the difference between a cow’s production in the previous lactation and the herd average value (’000 kg)</td>
</tr>
<tr>
<td>haemorrhages</td>
<td>diagnosis prior to, or concomitant with, diagnosis of sole ulcer (no, yes)</td>
</tr>
<tr>
<td>heel horn erosion</td>
<td>diagnosis prior to, or concomitant with, diagnosis of sole ulcer (no, yes)</td>
</tr>
<tr>
<td>corckscrew claw</td>
<td>diagnosis prior to, or concomitant with, diagnosis of sole ulcer (no, yes)</td>
</tr>
<tr>
<td>examinations</td>
<td>number of times a cow was hoof-trimmed during the study lactation (1, 2, or 3+)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Herd-level variables</th>
<th>Description and categories (or summary statistics for TS and LH herds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>herd size</td>
<td>number of milking cows in the herd</td>
</tr>
<tr>
<td></td>
<td>SU data: TS herds: mean = 26.8 range = 5 – 85</td>
</tr>
<tr>
<td></td>
<td>SU data: LH herds: mean = 50.0 range = 13 – 180</td>
</tr>
<tr>
<td></td>
<td>WLD data TS herds: mean = 26.9 range = 5 – 85</td>
</tr>
<tr>
<td></td>
<td>WLD data LH herds: mean = 50.2 range = 13 – 180</td>
</tr>
<tr>
<td>bedding</td>
<td>type of bedding in stalls</td>
</tr>
<tr>
<td></td>
<td>hard = hard floor with little straw or shavings</td>
</tr>
<tr>
<td></td>
<td>SU and WLD: 743 LH and 1 584 TS cows</td>
</tr>
<tr>
<td></td>
<td>mats = rubber mat with or without other bedding</td>
</tr>
<tr>
<td></td>
<td>SU 4 614 LH and 9 246 TS cows, WLD 4 625 LH</td>
</tr>
<tr>
<td></td>
<td>and 9 228 TS cows</td>
</tr>
<tr>
<td></td>
<td>other = deep bedding with straw, sawdust or peat</td>
</tr>
<tr>
<td></td>
<td>SU 133 LH and 473 TS cows, WLD 133 LH and 473 TS</td>
</tr>
</tbody>
</table>

.................
<table>
<thead>
<tr>
<th>Manure Type</th>
<th>Description</th>
<th>SU Herd Details</th>
<th>WLD Herd Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>Urine separated from manure</td>
<td>1,032 LH and 4,848 TS cows</td>
<td>1,032 LH and 4,830 TS cows</td>
</tr>
<tr>
<td>Wet</td>
<td>Urine mixed with manure</td>
<td>4,396 LH and 6,301 TS cows</td>
<td>4,385 LH and 6,301 TS cows</td>
</tr>
<tr>
<td>Missing</td>
<td>No information available about manure system</td>
<td>73 LH and 154 TS cows</td>
<td>4,396 LH and 6,301 TS cows</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Farm Floor</th>
<th>Description</th>
<th>SU Herd Details</th>
<th>WLD Herd Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold</td>
<td>Cold loose house with heavy straw beddings and large corridors</td>
<td>10 farms with 382 cows</td>
<td>10 farms with 382 cows</td>
</tr>
<tr>
<td>Warm slats</td>
<td>Typical warm loose house with slatted floor</td>
<td>97 farms with 3,388 cows</td>
<td>98 farms with 3,399 cows</td>
</tr>
<tr>
<td>Warm scraper</td>
<td>Typical warm loose house with scraper</td>
<td>42 farms with 1,720 cows</td>
<td>42 farms with 1,720 cows</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Feed Type</th>
<th>Description</th>
<th>SU Herd Details</th>
<th>WLD Herd Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial full</td>
<td>All concentrate from commercial source</td>
<td>1,983 LH and 4,575 TS cows, WLD 2,000 LH and 4,573 TS cows</td>
<td>1,948 LH and 3,853 TS cows, WLD 1,948 LH and 3,838 TS cows</td>
</tr>
<tr>
<td>Commercial half</td>
<td>Commercial minerals and protein with home-grown grain</td>
<td>1,945 LH and 3,853 TS cows, WLD 1,948 LH and 3,838 TS cows</td>
<td>1,948 LH and 3,853 TS cows, WLD 1,948 LH and 3,838 TS cows</td>
</tr>
<tr>
<td>TMR</td>
<td>Total mixed ration</td>
<td>1,082 LH and 82 TS cows, WLD 1,080 LH and 82 TS cows</td>
<td>1,082 LH and 82 TS cows, WLD 1,080 LH and 82 TS cows</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Yield-Herd</th>
<th>Description</th>
<th>SU Data TS Herds</th>
<th>WLD Data TS Herds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>Herd average milk yield in the lactation previous to the study lactation (‘000 kg)</td>
<td>8.6</td>
<td>8.6</td>
</tr>
<tr>
<td>Range</td>
<td></td>
<td>6.1 – 11.4</td>
<td>6.1 – 11.4</td>
</tr>
<tr>
<td>SU Data LH Herds</td>
<td></td>
<td>8.4</td>
<td>8.6</td>
</tr>
<tr>
<td>Range</td>
<td></td>
<td>4.7 – 10.6</td>
<td>6.1 – 11.4</td>
</tr>
<tr>
<td>WLD Data TS Herds</td>
<td></td>
<td>8.4</td>
<td>8.6</td>
</tr>
<tr>
<td>Range</td>
<td></td>
<td>4.7 – 10.6</td>
<td>6.1 – 11.4</td>
</tr>
<tr>
<td>WLD Data LH Herds</td>
<td></td>
<td>8.4</td>
<td>8.6</td>
</tr>
<tr>
<td>Range</td>
<td></td>
<td>4.7 – 10.6</td>
<td>6.1 – 11.4</td>
</tr>
</tbody>
</table>
4.1.2.2 Data analysis for all models (III, IV)
Descriptive statistics were computed for the outcome variable of interest (haemorrhages/WLD/SU present or absent in the cow during study lactation) and all potential predictors. The lactational risk of lesions was computed for cows by breed, by parturition and by number of trimmings during the lactation.

4.1.3 Variance estimates and model checking
The proportion of variance attributable to trimmer and herd was computed using the latent variable approach (Vigre et al., 2004). This assumes that at the cow-level, sole ulcer, WLD and haemorrhages represent a continuous condition only detected once they pass a certain threshold. It sets the variance at the lowest (cow) level to a constant value of 3.29.

Model diagnostics (evaluation of residuals) was carried out using MlwiN in order to take advantage of that program’s superior abilities in this area. The normality of hoof-trimmer level and farm-level residuals were checked and outlying observations were noted and the models re-fit without these outliers to determine whether these observations had a large influence on the model. Ultimately, the final models presented were those based on all observations. Extra-binomial dispersion was evaluated by fitting models with an additional dispersion parameter.

4.2 Lameness detection
These parts of the study were carried out at the Suitia research-farm, University of Helsinki. The farm had a typical Finnish loose-housing system with hard slatted floors with scrapers, and rubber mats in the cubicles. There were two 2-metre-wide manure alleys, one next to the feeding barrier and the other between the cubicle rows. Two separate departments were on the farm, with 45–50 cows per side.

4.2.1 Lameness detection and the measurement system (I, II)
The aim was to develop an automatic lameness detection system operating in a milking robot. The different stages of technological development have been described earlier (Pastell, et al., 2006; Pastell, et al., 2006; Pastell, et al., 2008)

A system for automatically measuring the weight distribution between all four limbs was installed in the floor of the milking robot. The system consisted of four strain gauge balances connected to an amplifier and a computer. The weight on each leg during milking was automatically recorded with dedicated measurement software by TestPoint (Capitol Equipment Corp., USA). The measurements were analyzed and the data stored on the computer together with recorded digital videos of milking. MATLAB was used to remove possible errone-
uous values from the data and to analyse the data, as described in detail earlier (Pastell, et al., 2006; Pastell, et al., 2006; Pastell, et al., 2008). Suitia research farm had two milking robots (DeLaval) used for 50 cows each. Only one of the robots was used in the trials.

4.2.2 Use of force sensors to detect and analyze lameness (I)

The basic idea in the analysis was to calculate a leg weight ratio (LWR) between the lighter and heavier hind leg and to compare problems in both legs with a single parameter. Leg weights were successfully recorded from almost 10,000 milkings for a total of 73 different cows. The difference in LWRs between healthy cows and cows with leg problems was evaluated using Student’s t-test. Also kicks, steps and SD (mean standard deviation of the weight of the lighter hind leg divided by the mean weight of the lighter hind leg during milking) were calculated.

LWR data were compared with a locomotion scoring (LS) system (Sprecher et al., 1997) (Table 2), with clinical inspections (following cows’ gait and moving behaviour and observation of other clinical signs) and with hoof-trimming information. Joint problems (in hock joint) and possible injuries were taken

<table>
<thead>
<tr>
<th>LS number</th>
<th>Description</th>
<th>Assessment criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Normal</td>
<td>The cow stands and walks with a level back posture. The gait is normal.</td>
</tr>
<tr>
<td>2</td>
<td>Mildly lame</td>
<td>The cow stands with a level-back posture, but while walking she has arched-back posture. The gait is still normal.</td>
</tr>
<tr>
<td>3</td>
<td>Moderately lame</td>
<td>The cow has a clear arched back posture while both walking and standing. The gait is changed, with shorter strides with one or more limbs.</td>
</tr>
<tr>
<td>4</td>
<td>Lame</td>
<td>An arched back is constantly present and remains all the time. The gait is best described as one deliberate step at a time and she favours one or more limbs are favoured.</td>
</tr>
<tr>
<td>5</td>
<td>Severely lame</td>
<td>The cow demonstrates an inability or strong reluctance to move or bear weight on one or more of her legs.</td>
</tr>
</tbody>
</table>
into account during trimming time. The results were used in the development of balances from 15 June to 7 December 2004 (Pastell et al., 2006; Pastell et al., 2008).

The second part of the LS trial was carried out in winter 2005–2006, when all 50 cows that were milked in the robot were subjected to LS (Table 2) and videotaped six times at 2-week intervals and the seventh time 2 months later. Cows with LS ≥ 2 and randomly some of the cows with LS 1–2 were hoof-trimmed. Data of hoof-trimming, weight graphs, LS and other clinical inspections were compared.

![Lameness scoring scale in Table 2 depicted in pictures](Healthy Hooves project, Suomen Rehu 2002).

**Figure 5.** Lameness scoring scale in Table 2 depicted in pictures (Healthy Hooves project, Suomen Rehu 2002).
4.2.3 Neural network model for lameness detection (II)

At the beginning of the study, the automatic alarm list used by the software (Pastell et al., 2008) and also the graphs described earlier gave too many false alarms.

To serve as an expert system for automatic lameness detection and for classification of lame and sound cows, a probabilistic neural network (PNN) model was chosen. The model was based on two possible outputs: sound and lame. Performance of the PNN in the classification was evaluated with the following criteria: 1) detection rate = percentage of lameness cases in the validation data detected with the network; 2) percentage of measurements causing false alarms; 3) earliness of the detection = detection date with the model – the earliest classification date; 4) percentages of measurements classified correctly as compared to clinical inspection and LS; and 5) sensitivity and specificity of the model at cow-level.

4.2.4 Acute phase response (V)

During the lameness trial we also took blood samples from cows with SU and/or WLD, but otherwise appearing clinically healthy. The animals were blood-sampled on days 0, 4, 7 and 14. Simultaneously (day 0) with a lame cow at least one clinically healthy cow that lame-scored 1 was chosen as a control and sampled. The study group consisted of 16 cows: 8 with SU, 6 with WLD and 2 with both SU and WLD. The control group included 15 animals. All cows in the study were 2–6 years old and the time to parturition was over 3 weeks.

Serum Hp was determined using the haemoglobin binding assay described by Makimura and Suzuki, (1982), with the modification of tetramethylbenzidine (0.06 mg/ml) being used as a substrate (Alsemgeest et al., 1994), and SAA concentrations in serum were measured with a commercially available ELISA kit (Phase SAA kit, Tridelta Development Ltd).

A linear random-intercept model was used for comparing concentrations of APPs in animals with hoof lesions on different sampling occasions with concentrations of APPs in control animals, as described in more detail in study V.
5.1 Healthy Hooves project

Initially, 43 different hoof-trimmers, representing over 50% of the members of the Finnish Hoof-trimmers’ Association were involved in the programme. After the cleaning process, the analyses included data from 37 hoof-trimmers. The number of cows at the start of the study represented nearly 10% of all Finnish cows.

5.1.1 National recording system for hoof diseases (III, IV)
A national recording system for hoof lesions was established. The data of this project have recently been moved from Suomen Rehu to FABA (Finnish Animal Breeding Effect). After the trial, hoof-trimmers continued to use recordings and contribute observations to the national database. Extensive data collection has occurred since 2003 and the data are available to farm health-system. In future, FABA is going to utilize data in genetic evaluations.

5.1.2 Lactational incidence risk of laminitis-related lesions and their main risk factors (III, IV)
The lactational risks by parity, breed and number of trimming are presented in Table 3 and 4. The main risk factors are presented in Tables 5 and 6. Main risk factors were number of trimmings, other hoof lesions, beddings in TS herd, breed and parity separately or depending on each other. (Interactions between breed and parity were observed in TS herds WLD model and in both haemorrhages all-cow models, other information in article IV).
### Table 3. Lactational risk of haemorrhages, white line disease and sole ulcer in tie stall cows by parity, breed and number of examinations.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Category</th>
<th>Haemorrhages</th>
<th>White line disease</th>
<th>Sole ulcer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parity</td>
<td>1</td>
<td>36.85%</td>
<td>4.81%</td>
<td>4.09%</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>23.25%</td>
<td>6.89%</td>
<td>2.82%</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>27.43%</td>
<td>8.12%</td>
<td>2.77%</td>
</tr>
<tr>
<td></td>
<td>4+</td>
<td>30.48%</td>
<td>13.42%</td>
<td>6.13%</td>
</tr>
<tr>
<td>Breed</td>
<td>Ayshire</td>
<td>29.07%</td>
<td>6.21%</td>
<td>2.72%</td>
</tr>
<tr>
<td></td>
<td>Holstein</td>
<td>38.15%</td>
<td>8.78%</td>
<td>6.90%</td>
</tr>
<tr>
<td>Number of</td>
<td>1</td>
<td>27.12%</td>
<td>5.44%</td>
<td>3.38%</td>
</tr>
<tr>
<td>examinations/</td>
<td>2</td>
<td>42.49%</td>
<td>11.00%</td>
<td>5.23%</td>
</tr>
<tr>
<td>trimmings</td>
<td>3+</td>
<td>55.42%</td>
<td>16.87%</td>
<td>10.84%</td>
</tr>
</tbody>
</table>

### Table 4. Lactational risk of haemorrhages, white line disease and sole ulcer in loose-housing cows by parity, breed and number of examinations.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Category</th>
<th>Haemorrhages</th>
<th>White line disease</th>
<th>Sole ulcer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parity</td>
<td>1</td>
<td>52.80%</td>
<td>17.20%</td>
<td>5.50%</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>34.84%</td>
<td>17.13%</td>
<td>2.93%</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>36.51%</td>
<td>17.43%</td>
<td>4.43%</td>
</tr>
<tr>
<td></td>
<td>4+</td>
<td>38.01%</td>
<td>31.05%</td>
<td>5.91%</td>
</tr>
<tr>
<td>Breed</td>
<td>Ayshire</td>
<td>43.76%</td>
<td>16.78%</td>
<td>3.24%</td>
</tr>
<tr>
<td></td>
<td>Holstein</td>
<td>48.29%</td>
<td>23.05%</td>
<td>8.44%</td>
</tr>
<tr>
<td>Number of</td>
<td>1</td>
<td>37.30%</td>
<td>14.58%</td>
<td>3.03%</td>
</tr>
<tr>
<td>examinations/</td>
<td>2</td>
<td>59.05%</td>
<td>25.30%</td>
<td>7.58%</td>
</tr>
<tr>
<td>trimmings</td>
<td>3+</td>
<td>72.19%</td>
<td>41.72%</td>
<td>16.56%</td>
</tr>
<tr>
<td>Variable</td>
<td>Category</td>
<td>OR for haemorrhages</td>
<td>OR for WLD</td>
<td>OR for SU</td>
</tr>
<tr>
<td>-------------------</td>
<td>----------------</td>
<td>---------------------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>parity – breed</td>
<td>1 – Ayrshire</td>
<td>1</td>
<td>1</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>1 – Holstein</td>
<td>1.27</td>
<td>1.11</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>2 – Ayrshire</td>
<td>0.43</td>
<td>1.56</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>2 – Holstein</td>
<td>0.75</td>
<td>2.56</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>3 – Ayrshire</td>
<td>0.50</td>
<td>1.81</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>3 – Holstein</td>
<td>1.17</td>
<td>3.88</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>4+ – Ayrshire</td>
<td>0.65</td>
<td>3.09</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>4+ – Holstein</td>
<td>1.27</td>
<td>7.92</td>
<td>–</td>
</tr>
<tr>
<td>parity</td>
<td>1</td>
<td>–</td>
<td>–</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>–</td>
<td>–</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>–</td>
<td>–</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>4+</td>
<td>–</td>
<td>–</td>
<td>1.86</td>
</tr>
<tr>
<td>breed</td>
<td>Ayshire</td>
<td>–</td>
<td>–</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Holstein</td>
<td>–</td>
<td>–</td>
<td>2.89</td>
</tr>
<tr>
<td>haemorrhages</td>
<td>no/yes</td>
<td>na</td>
<td>1.63</td>
<td>2.97</td>
</tr>
<tr>
<td>heel horn erosion</td>
<td>no/yes</td>
<td>1.55</td>
<td>1.77</td>
<td>2.10</td>
</tr>
<tr>
<td>corkscrew claw</td>
<td>no/yes</td>
<td>1.71</td>
<td>1.59</td>
<td>2.83</td>
</tr>
<tr>
<td>examinations</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.13</td>
<td>2.56</td>
<td>1.42</td>
</tr>
<tr>
<td></td>
<td>3+</td>
<td>3.06</td>
<td>3.42</td>
<td>3.42</td>
</tr>
<tr>
<td>bedding</td>
<td>hard floor</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>mats</td>
<td>0.80</td>
<td>0.57</td>
<td>0.49</td>
</tr>
<tr>
<td>yield – herd</td>
<td>–</td>
<td>not significant</td>
<td>not significant</td>
<td>0.78</td>
</tr>
</tbody>
</table>
**Table 6.** Main risk factors for haemorrhages, white line disease and sole ulcer in loose-housing herds. The eight final models are random effects logistic regression models with hoof-trimmer and herd as random effects; the most important results are presented.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Category</th>
<th>OR for haemorrhages</th>
<th>OR for WLD</th>
<th>OR for SU</th>
</tr>
</thead>
<tbody>
<tr>
<td>parity – breed</td>
<td>1 – Ayrshire</td>
<td>1.10</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>1 – Holstein</td>
<td>0.48</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>2 – Ayrshire</td>
<td>0.58</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>2 – Holstein</td>
<td>0.48</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>3 – Ayrshire</td>
<td>0.90</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>3 – Holstein</td>
<td>0.49</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>4+ – Ayrshire</td>
<td>0.77</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>4+ – Holstein</td>
<td>1.10</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>parity</td>
<td>1</td>
<td>–</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>–</td>
<td>1.16</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>–</td>
<td>1.28</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>4+</td>
<td>–</td>
<td>2.89</td>
<td>1.23</td>
</tr>
<tr>
<td>breed</td>
<td>Ayrshire</td>
<td>–</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Holstein</td>
<td>–</td>
<td>1.55</td>
<td>2.94</td>
</tr>
<tr>
<td>farm type</td>
<td>cold loose housing</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>warm loose housing with scraper</td>
<td>not significant</td>
<td>1.37</td>
<td>not significant</td>
</tr>
<tr>
<td></td>
<td>warm loose housing with slatted floor</td>
<td>not significant</td>
<td>2.31</td>
<td>not significant</td>
</tr>
<tr>
<td>haemorrhages</td>
<td>no/yes</td>
<td>na</td>
<td>not significant</td>
<td>not significant</td>
</tr>
<tr>
<td>heel horn erosion</td>
<td>no/yes</td>
<td>–</td>
<td>0.72</td>
<td>not significant</td>
</tr>
<tr>
<td>corkscrew claw</td>
<td>no/yes</td>
<td>1.61</td>
<td>1.60</td>
<td>not significant</td>
</tr>
<tr>
<td>examinations</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.37</td>
<td>2.32</td>
<td>2.77</td>
</tr>
<tr>
<td></td>
<td>3+</td>
<td>3.01</td>
<td>4.67</td>
<td>6.89</td>
</tr>
</tbody>
</table>
5.1.2.1 Feeding as a risk factor
Different feeding types did not appear to have a clear, significant effect on haemorrhages, SU or WLD. Some effects were seen on LH farms using grain (barley-oat) with supplementary protein (n=20) for WLD in the full model, but not unconditional effects. Telephone interviews revealed no explanation for the difference; the difference probably arose by chance.

5.1.3 Variance estimates and model checking
In TS herds, 25% of trimmers trimmed more than 20 farms (two trimmed more than 50 farms), and in LH herds only two trimmers trimmed more than 10 farms (one trimmed 20 and the other 27). Hoof-trimmer and farm variances of the total variance have been described in Table 7. The extra-binomial dispersion parameter fell in the range of 0.8–1.0 for all models, showing that extra-binomial dispersion was not present. Large residuals were also rare, and excluding them one by one from the model did not substantially change the model (III, IV).

### Table 7. Variance estimates in different models in tie stall herds.

<table>
<thead>
<tr>
<th>Variance</th>
<th>Category</th>
<th>Haemorrhages</th>
<th>White line model</th>
<th>Sole ulcer model</th>
</tr>
</thead>
<tbody>
<tr>
<td>explaining variation of total variation between hoof-trimmers:</td>
<td>23%</td>
<td>15%</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>between farms:</td>
<td>2.9%</td>
<td>11%</td>
<td>9%</td>
<td></td>
</tr>
</tbody>
</table>

### Table 8. Variance estimates in different models in LH herds.

<table>
<thead>
<tr>
<th>Variance</th>
<th>Category</th>
<th>Haemorrhages</th>
<th>White line model</th>
<th>Sole ulcer model</th>
</tr>
</thead>
<tbody>
<tr>
<td>explaining variation of total variation between hoof-trimmers:</td>
<td>30%</td>
<td>6%</td>
<td>4%</td>
<td></td>
</tr>
<tr>
<td>between farms:</td>
<td>4%</td>
<td>9%</td>
<td>9%</td>
<td></td>
</tr>
</tbody>
</table>
5.2 Lameness detection

5.2.1 Lameness detection and the measurement system (I, II)

An automatic lameness detection system was developed during the trial. The biggest challenge was to build a sufficiently durable measurement platform for continuous measurements. When the system was running properly, it was possible to follow lameness; especially those caused SU and severe WLD, by graphs produced by the system.

The measurements of LWR (%), standard deviation of the weight (%) of the lighter hind leg during milking and steps per milking assessed in sound (measurement n=9,499) and lame cows (measurement n=443) are described in study II. Because of overlapping in results and no value alone allowing us to judge whether a cow was lame or not, a PNN model was needed. Later taught and validated PNN model identified 100% of lame cows. Characteristics of measurement data for sound and lame cows are described in Table 9, additional details in study II.

Table 9. Measurement data for sound and lame cows.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sound</th>
<th>Lame</th>
<th>Sound</th>
<th>Lame</th>
<th>Sound</th>
<th>Lame</th>
<th>Sound</th>
<th>Lame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>80.1</td>
<td>64.9</td>
<td>2.6</td>
<td>7.2</td>
<td>3.7</td>
<td>9.9</td>
<td>26.4</td>
<td>34.5</td>
</tr>
<tr>
<td>SEM</td>
<td>0.2</td>
<td>0.8</td>
<td>0.04</td>
<td>0.4</td>
<td>0.04</td>
<td>1.0</td>
<td>0.3</td>
<td>0.8</td>
</tr>
<tr>
<td>SD</td>
<td>17.2</td>
<td>17.6</td>
<td>4.0</td>
<td>9.4</td>
<td>4.3</td>
<td>20.1</td>
<td>31.6</td>
<td>16.2</td>
</tr>
</tbody>
</table>

1 Leg weight ratio between the heavier and lighter hind leg
2 Number of kicks per milking
3 Number of steps per milking
4 Mean standard deviation of the weight of the lighter hind leg divided by the mean weight of the lighter hind leg during milking

**Different (p<0.01) from sound cows
5.2.2 Use of force sensors to detect and analyze lameness (I)
As stated earlier, the alarm list gave many false positives because while almost all of the cows with leg problems put less weight on the lighter leg, some of the healthy cows also put less weight on one leg for one reason or another. Thus, instead using numbers of weight distribution, graphs as in Figure 6 proved to be more suitable tools. With the graphs, it was also possible to follow the healing development. The graphs appeared to have a more accurate detecting rate than LS with SU3s and WLD problems, whereas joint problems were detected better with LS. Three hock joint problems were found only with LS and two of the hoof problems only with graphs. The graphs were also faster (1–8 days) in recognizing hoof problems every time.

![Figure 6. Measurements from the force sensors for a cow with a hock joint problem in its left hind-limb at the end of October and sole ulcers on both legs at the end of November. Its hooves were trimmed on 2nd December.](image)

5.2.3 Neural network model for lameness detection (II)
The PNN model was taught and validated as described in study II to classify lame and sound cows. The overall classifying ability of the model was 96.2% and the lameness detection rate 100%, including only 1.1% false alarms. Figure 7 shows with a ROC curve the model is performance as a diagnostic test for detecting lameness. The curve was created by calculating the sensitivity and specificity of the model classifications. With a sensitivity of 100%, a specificity of 57.5% was achieved.
5.2.4 Acute phase response

The results are shown in Figure 8. The mean concentrations of SAA were higher in lame cows due to SU or WLD than in control animals on day 0. The concentrations increased on days 4 and 7–8 and then decreased on day 14. No significant differences between groups in Hp were found.
Figure 8. Serum concentrations of serum amyloid A (SAA) and haptoglobin (Hp) in healthy cows (□) sampled on day 0 and in lame cows (■) sampled on days 0, 4, 7–8 and 14.

* = significant difference (p ≤ 0.05) and ** = significant difference (p ≤ 0.01) between healthy and lame cows.
6 Discussion

6.1 Recording systems for hoof health

National recording systems have traditionally been difficult to establish, and e.g. disease recordings are mainly available in Scandinavia. Recording hoof-trimming data is even more difficult because it requires voluntary recording from hoof-trimmers and extra money to implement the system.

In Sweden, hoof-trimming data have been collected by the Swedish Dairy Effect since 2003, and this information has also been used for breeding purposes. In 2009, Swedish hoof-trimmers collected 240 000 recordings (Emelie Tuffesson, oral communication, 2009), but in Norway, for example, no recording system of hoof-trimming was available until 2004, and a national recording system was only implemented in 2008 (Sogstad et al., 2008). In Denmark, only very few trimmers (3–4 of 109) are currently recording while trimming, but the Danish Cattle Federation with Danish vets and some hoof-trimmers are working on creating a recording system (Pia Nielsen, oral communication, 2009). There has also been co-operation for improving hoof health by breeding between Scandinavian breeding organizations. The results of the Finnish HH project will enable evaluations of success of this effort (information from Scandinavian co-operation meetings in FABA 2008).

Prevalence and risk factor analysis have been performed on data of randomly chosen farms and selected hoof-trimmers. In Sweden, questionnaires were sent to the farms, and selected hoof-trimmers carried out the trimmings (Manske et al., 2002). In Holland, Holzhauer et al. (2006) selected 15 trimmers from two private organizations. Programmes to improve hoof health have also been more local and project-centred e.g. in Norway through a claw health card (Sogstad et al., 2008).

During the HH program pilot year in 2001, Finnish hoof-trimmers began data-collecting and by 2001–2004 understanding of hoof-trimming and awareness of hoof diseases had grown among farmers. After the trial, hoof-trimmers continued to use recordings and contributed these to the national database.
We did not manage to uncover any specific feeding or hoof-trimming strategy that could solve the laminitis problems, instead we recognized better the multifactorial nature on laminitis-related lesions and the importance of management and the environment on farms.

Although the HH material may be little biased towards well-managed farms, the large dataset should be fairly representative of Finnish dairy cows. Much time was spent on data verification and cleaning to ensure the pressure of as few errors as possible prior to undertaking any analyses.

## 6.2 Laminitis-related lesions

Laminitis-related lesions, such as haemorrhages, WLD and SU, have been the most investigated hoof diseases during the last decade (e.g. Livesey and Fleming 1984; Livesey 1984; Bradley et al., 1989; Colam-Ainsworth et al., 1989; Greenough et al., 1990; Greenough and Vermunt, 1991; Bergsten 1994; Vermunt and Greenough, 1994; Logue 1995; Vermunt and Greenough, 1995; Bergsten and Frank 1996; Bergsten and Herlin 1996; Smilie et al., 1996; Ossent and Lischer, 1998; Smilie et al., 1999; Lischer et al., 2002; Bergsten 2003; Donovan et al., 2004; Thoefner et al., 2004; Hinterhofer et al., 2006; Danscher et al., 2009).

In the pilot year of the HH project 2002, the prevalence of digital dermatitis (DD) in Finland was only 0.2%, and very few infectious hoof disease problems existed. Large structural changes in agriculture, with e.g. new-built LH farms, growing herd sizes, moving of animals and new feeding strategies, have changed the environment for hooves, and during the last 5 years we have had some aggressive epidemics of infectious interdigital phlegmon on many new farms (oral communications with Finnish national cattle-disease group 2007–2009 and preliminary, unanalyzed material of the Finnish Food Safety Authority, 2009). However, in this thesis, we concentrated on those non-infectious, laminitis-related hoof diseases that easily make cows lame and increase economic effects. Automatic lameness detection, LS or APR, as described in studies I, II and V are mainly based on SU or WLD problems.

Lactational risk numbers differ from prevalence studies, in our study, they contain the whole lactation of the cows and we calculated lesions only once for each cow. When comparing the lactational risk of one time-trimmed cows in our study and prevalence e.g from Norway, Sweden, Holland and Ontario, USA (Manske, et al., 2002; Sogstad, et al., 2005b; Holzhauer, et al., 2008; Cramer, et al., 2009), the numbers of WLD in TS herds were similar to those in Norway (around 5.5%), but bigger in LH herds (14.6%) (Sogstad et al., 2005b), and also they were close to prevalence-numbers in Sweden (Manske
et al. 2002). Our numbers of SU were similar to those in Norway (around 3%) (Sogstad et al., 2005b), but slightly lower than in the other countries.

6.3 Important risk factors for laminitis-related lesions

6.3.1 Breed and parity

One of the most interesting risk factors that emerged during the epidemiological trial was breed. In Holsteins as compared with Ayrshire cows, an OR of nearly 3 was found for SU in both TS and LH herds, which is huge. Increased risk for SU and WLD in older cows and for haemorrhages in heifers were in accordance with other reports (Enevoldsen et al., 1991; Greenough and Vermunt, 1991; Smits, et al. 1992; Bergsten 1994; Wells et al., 1993; Hedges et al., 2001; Livesey et al., 2003; Potzsch et al., 2003; Sogstad et al., 2005a; Holzhauer et al., 2008; Barker et al., 2009; Hedges et al., 2001, Livesey et al., 2003; Potzsch et al., 2003; Sogstad et al., 2005a; Sogstad et al., 2005b).

An explanation for susceptible heifers and older animals could be the structure of fat pads or possibly sinking pedal bone. Heifers and primiparous animals suffer from a lack of a supportive fat pad on the sole. This may explain why sole lesions as haemorrhages tend to appear in heifers, especially on the sole (Reviewed by Lischer and Ossent 2002; Mülling and Lischer 2002). The fat of these fat pads also decreases after parity three and may explain the growing risk for older animals (Räber et al., 2004; Räber et al., 2006).

On the other hand, subclinical laminitis, seen as sole haemorrhages, loosens the collagen fibres in the dermis and produces sinking pedal bone and weakening of suspensory apparatus, which worsens over time. This makes cows susceptible to SU (reviewed by Lischer and Ossent, 2002; Mülling, 2002; Mülling and Lischer 2002). Haemorrhages in the WL make also a hoof susceptible to WLD and in laminitis and there are also alterations in horn production, and widening of WL.

In TS herds the effects of parity and breed also depended on each other with the highest risk being observed in older Holstein cows. This greatly elevated risk might be partially explained by the housing of Finnish TS herds. Older Holstein cows are usually large and stalls in old TS barns are often too small and short for them. Those cows probably stand on edges and on beams, which might damage the WL structure.

The effects of breed and parity also depended on each others in both the TS and LH haemorrhage models. The elevated risk associated with being a heifer is in agreement with older studies (e.g. Enevoldsen et al., 1991; Greenough and Vermunt, 1991; Wells et al., 1993; Livesey et al., 2003) and might be
related to lack of a fat pad in primiparous cows (Lischer et al., 2002). The interaction was a new aspect but associations seemed to remain similar to what was expected.

Effect of breed and parity are important since the whole agricultural system is changing to larger LH herds and a need exists for durable cows. Effect of breed did not change when milk yields were added to the model; thus the effect was not dependent on milk yield.

If Holsteins have the highest risk of becoming lame, we should put more effort into cow comfort (e.g. heavy beddings, rubber mats on floors (LH systems), cubicle lengths), or even prefer Ayrshire cows?

Altogether, it can be concluded that the most important time to prevent haemorrhages, WLD and SU is the first period, when heifers are growing and primiparous cows are lactating, or after the third parity, which is usually not happening in Finland.

6.3.2 Farm type
The effect of farm type was also clearly seen in lactational risk of WLD, SU and haemorrhages. The lower risk for non-infectious hoof problems in TS herds than in LH herds is in accordance with the results reported from Sweden (Bergsten and Herlin 1996), in which the incidence of clinical lameness was higher in cubicle systems than in TS herds. Also a Dutch study showed clearly better claw health in cows in straw yards compared with cows on concrete floors (Somers et al., 2003); the lack of exposure to hard corridors probably accounts for some of the observed difference between our TS and LH herds. The worst farm type for laminitis-related lesions in Finland appeared to be warm LH with slatted floors. This is consistent with many trials (e.g. Bergsten and Herlin 1996; Sogstad et al., 2005b). Barker et al. (2009) also found that new solid grooved concrete floors were the worst for WLD and especially for DD.

Austrian researchers constructed a compute bond finite element model comparing slatted floors and solid floors and noted that cows claws on slatted floors undergo mechanical stress. Any kind of solid floor will give uniform support to the weight-bearing system of the claw and cause less stress than slatted floors (Hinterhofer et al., 2005; Hinterhofer et al., 2006), and all uneven flooring and edges should be avoided (Hinterhofer et al., 2009). The anatomy of the WL, with a weak lamellar region, especially in zone 3 (zones described in Greenough and Vermunt 1991), and different horn production in different parts of WL, makes it susceptible to this kind of mechanical pressure (reviewed by Mülling, 2002). Increased risk of slatted floor in LH systems was also reported in a Norwegian trial (Sogstad et al., 2005b). Moreover, on LH farms,
there is increased competition between cows and possibly narrow passages or crowding (Fiedler et al., 2000; Sogstad et al., 2005b).

Finnish cold LH systems seem to be preventive compared with warm LH with slats for WLD. A similar trend was seen in SU, but because of the low number of farms (n=10), this should be confirmed in further investigations. Cook (2003) and Cook et al. (2004, 2005) found more lameness in cows housed on hard floors than in LH herds. Soft flooring is also preferred by cows (Tucker et al., 2006; Telezhenko et al., 2007), and soft straw yards seem to prevent hoof problems (Webster 2002; Somers et al., 2003). This may partly explain the positive effects of cold LH systems because the heavy straw or peat-straw combination beddings are used in these systems, and straw-based bedding appears be the most preventive, as discussed by Cook et al. (2009). According to these results, attention should be directed to ensuring cow comfort when building floorings in new LH systems in Finland. Both factors – removing slurry effectively from corridors and building even and soft floors – are recommended. In the future, preventing laminitis by building workable cold LH systems with heavy sand-peat beddings is worth for investigating more extensively.

6.3.3 Cubicles
In TS herds, there was a significantly increased risk of haemorrhages, WLD and SU for cows standing in hard cubicles compared with those standing on mats. These results are in agreement with many earlier studies (Bergsten and Frank, 1996; Hultgren and Bergsten, 2001; Somers et al., 2003), where soft straw bedding or rubber mats had a preventive impact on laminitis-related lesions.

In LH herds, no effect of bedding type was found, but this was probably due to the very small number of cows exposed to pure hard cubicles. Deep-bedded cubicles were also quite rare in this data. The above-mentioned floor effect was also stronger in LH herds. To improve cow comfort and prevent the negative effect of hard corridors, LH farms require comfortable cubicles with, for example, sand beds or heavy mattresses. The cows should use at least 12 hours for resting; increased standing time (because of overcrowding, competition, or poor cubicles) worsens hoof health, as reviewed by Cook et al. (2009). The collection area environment and waiting time in milking parlours or in the robot in LH herds should also be explored.

6.3.4 Other hoof lesions
In TS herds, 11% of the cows that had WLD also had SU, as compared with 4% of the cows that did not have WLD. In LH herds, the corresponding proportions were 7% and 4%. The low numbers can partly be due to the lower prevalence of SUs in the whole dataset, but it was apparent that same cows have a tendency to have both diseases.
In TS herds, previous or concurrent other hoof lesions, such as haemorrhages, heel horn erosions and corkscrew claw, increased the risk of SU and WLD and the two latter ones also the risk of haemorrhages. This is consistent with earlier studies (e.g. Greenough 2001). All other hoof lesions increased most of all the risk of SU. Haemorrhages (subclinical laminitis) are also generally thought to be the biggest predisposing factor for SU and WLD, which result in clinical lameness (Bradley et al., 1989).

In LH herds, we observed no effect between haemorrhages and WLD nor did we generally find risk effects between any other lesions and SU.

We obtained no information on the site of haemorrhages, i.e. whether they were situated in the WL area or on the sole. This might have had an impact on the results; haemorrhages along the WL probably are predisposing factor for WLD, and differences may exist in the causative mechanism of haemorrhages between WL and the sole (Leach et al., 1997; Lischer 2002; Mülling 2002). In a Swedish trial (Hultgren et al., 2004) a different aetiology for haemorrhages in the sole as compared with those in the WL area was found, but both were associated with an increased risk of SU. The marked variation of haemorrhages between trimmers can also affect the results.

Two other differences in our findings between SU and other lesions are problematic to explain. According to Manske et al. (2002), an abnormal claw shape was strongly associated with SU. We expected to find effect also in LH, but we did not. However, we did find a mild effect between corkscrew claw and haemorrhages/WLD in LH herds, while in Sweden no effect existed between WL fissures and abnormal claw shape (Manske, et al., 2002). The low proportion of SU in LH herds can explain this negative finding, but in any case, the risk of corkscrew claw is logical because of mechanical pressure to the sole.

We also we found a negative effect between heel-horn erosion and WLD in LH herds, in contradiction to what we expected. However, it could have occurred by chance.

To sum up: other hoof lesions emerge as risk factors for WLD and SU, especially in TS herds, where other measured risk factors are possibly not so strong. The effects of hard floors, walking, own room and space stress are avoided in TS. Nevertheless, all hoof lesions should be seen and taken into account in efforts to improve health and prevent lameness.

6.3.5 Quantity and quality of trimmings
The number of trimmings seemed to have a strong effect on the risk of haemorrhages, WLD or SU in our HH dataset. This suggests that when cows are only examined once for lactational risk studies, risks of haemorrhages, WLD
or SU are probably underestimated or the trimming method may be sub-optimal.

The HH dataset was collected by trimmers of different backgrounds (from well-trained experienced trimmers to self-taught trimmers), so a risk probably existed in trimming itself, at least if the trimmer takes away the supportive mechanism of the horn with a grinder or the sole becomes too thin during trimming. Fjeldaa et al. (2006) found trimming to be a good means of preventative treatment in Norwegian TS herds, but observed no preventative effect in LH herds, where the trimming method is more critical. The trimming method was discussed as one reason for an unexpected result also Fjeldaa et al. (2006).

### 6.3.6 Feeding

As described before, one popular older theory of laminitis (and especially of haemorrhages) has been diet-influenced inflammation of the laminae of the wall region (e.g. Ossent and Lischer, 1998), but new findings have shown that the problem of sinking pedal bone originates from non-inflammatory alteration of the collagen fibres in the dermal laminae (reviewed by Mülling and Lischer, 2002). Le Fèvre et al. (2001) were more convinced about the effect of flooring and other surfaces on the development of laminitis-related lesions. Webster et al. (2001, 2002) found that keeping heifers on a soft area (sand) from two months ante partum (AP) to four months post partum (PP) could prevent nearly all lesions. The difference between housing types was clear, and feeding could only exacerbate the problem in cubicles (Webster 2001; Webster 2002). Offer et al. (2001, 2003, and 2004) investigated different effects of feeding in heifers AP and PP and found a difference between lesions when heifers were fed with dry or wet silage, but no differences after parturition.

In recent studies, Thœfner et al. (2004) and Danscher et al. (2009) observed experimental oligofructose overload to induce acute lameness. They also discussed whether it could induce laminitis as well and found some histological evidence of lamellar pathology and pain in claws. However, the biggest problems were seen in joints, which can also explain lameness.

In our studies, feeding did not have a considerable effect on any laminitis-related lesions. However, we had no detailed concentrate-percentage or silage information AP or PP in our models.

No revolutionary effects of feeding on hoof problems are likely to be found. Laminitis-related lesions are multifactorial problems, which seem to be more affected by breed, parity and cow comfort. However, as also seen in England by Webster (2001), when there is already a risk for laminitis in the environment, feeding will worsen the situation. One interesting point about fat pad
lipid composition was discussed by Räber et al. (2006). They thought that if fat pads could be affected by diet, it might make the sole more resistant to load and damages (Räber, et al., 2006).

Nearly all Finnish LH systems have been built with hard floors and cubicles with light mats, old TS herds usually comprise cubicles with light mats (≤6mm) or without mats. During and after the HH project, we tried to pass along our findings to farmers to change their thinking about PP feeding as the only and inclusive reason for laminitis. However, here is still work to do, especially in shedding light on the effects of the environment, cow comfort and AP feeding.

6.3.7 Milk production
Effects between milk yield and laminitis-related hoof lesions were interesting. High milk production is usually perceived as an obvious risk factor for lameness, but unexpectedly we found only herd milk-yield in TS herds to have a significant, but preventive effect on SU.

Before analysis, much time was dedicated to achieve effect of milk-yields to lesions and to avoid getting effect of lesions to milk yield. This was the reason we decided to compute herd-level milk yield as the average 305-day yield from the lactation previous to the study lactation, and cow-level milk yield was then computed as the difference between cows' 305-day yield in the previous lactation and the herd average.

After 1980, there was a strong belief that increasing milk yield is a risk for hoof problems (Enevoldsen et al., 1991; Barkema et al., 1994; Green et al., 2002), although some studies failed to find an effect (Aeberhard et al., 2001). Enevoldsen et al. (1991) showed that early lactation was associated with increased risk of sole ulcer and that this might have been due to high levels of production. More recently, Amory et al. (2008), found a higher risk for WLD and SU in high-yielding cows and also a risk for milk loss, although the effects of WLD were smaller than those of SU. Interestingly, Barkema et al. (1994) also observed an effect of milk yield with SU, but not with WLD. Our results that farms with higher milk yields had fewer SUs could probably be explained by better herd management.

We were unaware of the lesions present in the previous lactation. If lesions are commonly found in sequential lactations, we may have underestimated the effect of yield as a risk factor. Still, because in our analyses milk yield was entered both as the herd average and the cow’s deviation from the herd average and as an individual cow’ milk yield, it is difficult not to accept the result as it is. According to the HH datas, we suggest that the effect of milk yield on laminitis-
related hoof diseases is probably overestimated, although hoof diseases themselves have an effect on milk yield.

6.4 Variance effect for Healthy Hooves dataset

The extra-binomial parameter was in all quasi-likelihood models (MlwiN) between 0.8 and 1.0, indicating that the variance of a binomial distribution did hold, and we managed to take clustering into account in our model. No other goodness-of-fit test exists for multilevel logistic regression models when the Hosmer-Lemeshow test, which is used for simple logistic regression, does not work for multilevel models (Henrik Strychn and Ian R. Dohoo, oral communications, 2008).

As described in more detail in the articles, variance estimates were remarkable in all models. In TS models, where more hoof-trimmers trimmed cows, considerable variance was seen due to trimmers, but also inter-farm variance was present. This suggests that the earlier described role of hoof-trimming itself is crucial in preventing non-infectious hoof diseases (Kloosterman, 2004; Holzhauer, et al., 2006) and has an impact on the results. Although we asked lots of typical questions about management on farms, we did not get all of the information; the farmer him- or herself could be one reasonable explanation for the observed variation, especially for WLD and SU. Variance of haemorrhages is nearly completely explained by huge hoof-trimmer variation and also explains why we found no effects between haemorrhages and other hoof diseases in the LH dataset. In future, hoof health trials, we should recruit similar hoof-trimmers to avoid large variations arising from trimmers.

6.5 Detection of lameness

6.5.1 Locomotion scoring or novel technologies

In our lameness detection trials, severe WLD and SU were best found by force plates, while joint problems were discovered best by LS (I). Because of short cubicles, bad problems in the hock joint were common on the Suitia farm. With the final, complex PNN model, we managed to detect nearly all lame animals (II).

To identify lame animals as early as possible and prevent economic losses, it is useful to use LS on ordinary farms regularly. SU is more often bilateral than WLD (Le Fevre, et al., 2001), which makes its recognition more difficult in LS. Inter-observer reliability is also crucial in LS, but it is possible to increase accuracy by training, as described in March et al. (2007). This means much
work and motivation; they reported that at least 200–300 cows need to be used for training (March, et al., 2007). In any case, LS is the cheapest method for use by farmers and works well considering the huge variability in the people observing cows. Variability could be decreased by using more than one observer at a time, by combining methods (Flower and Weary, 2006) and by teaching observers (March, et al., 2007).

Novel technologies are currently under way worldwide, and we believe that the PNN model could be transferred to applications on farms with milking robots and help in the recognition of lame animals.

In the future, large farms will likely have bigger problems with lameness and new infectious hoof diseases will probably emerge. Novel technologies such as force plates can be helpful in recognizing problems quickly. Over 100 cows on one farm make it difficult to manually apply a locomotion score for each cow.

Besides being expensive, another drawback in using force sensors in any research or on farms is the need for personnel to check the equipment regularly. Here, the balances, for example, often broke down and computer problems occurred regularly. However, when the plates were working, they provided excellent coverage of cows.

These views about LS reliability and difficulties with novel technologies were described well by Flower and Weary (2009). They validated gait assessment methods and discussed the reliability and validity of measures used in both visual LS methods and technological implementations (Flower and Weary, 2009).

In conclusion: teaching vets and farmers to use LS properly and sufficiently often is crucial. Today, novel technologies, such as force plates offer a means of detecting lameness in research field and on farms.

However, to improve the use of technology for veterinary purposes, e.g. to follow treatment and improve lameness thereafter, intensive co-operation between vets and technologists is required.

6.5.2 Acute phase response

Despite the rather small sample size of the last trial in this thesis, it can be concluded that severe SU and WLD, which caused lameness in addition to local changes, caused a more generalized reaction, an APR, in cows (V). An increase in SAA concentrations was clear, unlike with Hp. SAA is known to be a more sensitive APP than Hp in cattle (Werling et al., 1996; Muller-Doblies et al., 2004), and therefore, Hp needs a stronger stimulation to induce an in-
crease. The APR highlights the marked impact on the cow of SU or lameness-producing WLD, in accordance with other effects of lameness such as decreased milk production and reproduction problems (Collick et al. 1989; Barkema et al., 1994; Rajala-Shultz et al., 1999; Fourichon et al., 2000; Green et al., 2002; Hernandez et al., 2002; Hultgren et al., 2004; Hernandez et al., 2005; Amory et al., 2008; Bach et al., 2007).

No relationship between APPs and hoof horn haemorrhages was found in heifers (Laven and Livesey, 2004). Haemorrhages alone do not usually cause lameness in cows.

### 6.6 Further considerations

Within the last few years, after these trials, infectious hoof diseases, such as interdigital phlegmons and mild digital dermatitis, have become more dominant, warranting our attention. Some preliminary investigations conducted by the Finnish national cattle disease group have revealed the growing concern about infectious hoof diseases among vets (Preliminary unanalysed material of the Finnish Food Safety Authority, 2009). Random design studies on the prevalence of infectious hoof diseases and national recommendations to deter these diseases are needed.

Well-designed cold LH systems to prevent hoof lesions should be considered and investigated more thoroughly.

Development of lameness detection is ongoing. Technologists at the University of Helsinki have continued to develop different detection methods to identify lame cows.
The occurrence of laminitis-related lesions (haemorrhages, WLD and SU), which were described as lactational incidence risks in this study, are strongly affected by breed, farm type, parity and the number of times a cow’s hooves are trimmed during lactation. Lactational risk significantly increased every trimming time, and may be underestimated if cows are trimmed only once. The quality of trimming is also considered as one concern after this thesis, in order to improve hoof health by hoof-trimming.

In addition to number of trimming, breed and parity, which were dependent on each others in WLD all-cow TS model and in haemorrhages-models, were the most prominent risk factors for all lesions. Hard beddings in cubicles (compared with deep bedding or mats) were clearly a risk factor for all diseases in TS herds too, but neither high levels of milk yield nor feeding type were found to be risk factors.

Novel technologies, such as force plates, potentially answer the need for both early and work-saving detection on growing farms and the need of objective detection in the research field. The older and more subjective LS system provides a useful aid in finding and taking care of lame cows. Extensive training improves subjectivity and helps to inter-observer variation.

SU and WLD were important hoof diseases in Finland, which can, in addition to lameness, also cause clear APR in cows.
Financial support from Suomen Rehu, the Walter Ehrström Foundation, the Finnish Veterinary Foundation, The Research Foundation of Veterinary Medicine in Finland and the Interrobo and Kartek projects is gratefully acknowledged.

Thesis years are usually a period of many challenges and achievements, with students looking forward to the future. These years for me also contained numerous challenges, a large learning process and lot of adventure, but because of a personal life crisis it was period of change, shadowed by deep grief and sorrow. My thanks therefore contain appreciation, gratitude and warm feelings towards the people who helped me to complete this work, but at the same time, I want to thank everyone being in my life in that life-saving way. You not only made this research work possible, but also left your fingerprint on my heart. Perhaps this is something that people do not write about in the dissertation book, but still, I love you guys.

I warmly thank my supervisor Timo Soveri. I always wondered how you could trust and believe me so strongly after seeing all of the problems and life changes that I went through during these years. I thank you for the help, trust and freedom that you always gave me.

I am indebted to Professor Ian R. Dohoo, who made possible all epidemiological parts of this thesis, supervised my two largest studies and offered me the most interesting learning process to the epidemiological world. I cannot think about this work without bursting to tears of thankfulness and appreciation, the help and support I got was nearly too much to handle. I will never forget you or beautiful Prince Edward Island with its Cavendish beach and red soil, and I thank God for you.

I sincerely thank the official reviewers of this thesis, Christoph Mülling and Päivi Rajala-Shulz, for valuable comments and improvements and evaluation at the final stage of this work. Thank you also Satu Pyörälä for critical and excellent comments on this thesis at the last moment before reviewing process. You really helped me gain more order and insight into the text.
Thank you Carol Ann Pelli for the linguistic revision of my manuscript. Because my poor English your work was important part of the thesis.

Thank you Pirjo Järvelä for lay out of this thesis book. Thank you also for your great patience and flexibility during the last time-pressure. Thank you also to Jere Pääkkönen for the most stylish cover illustration, it was a great pleasure to meet you Jere in Kuopio hoof conference.

Thanks are also due to Matti Pastell. Your patience, energy and technological ideas made our Suitia project not only possible, but also interesting and valuable. I thank you also for your assistance; your humble attitude and friendship.

Thank you Jouni Niemi and Pirkko Hämeenoja. Jouni, you are always the heart of Finnish hoof health, I thank you for taking me into the world of hoof problems and hoof-trimmers and into your life. I also want to thank Pirkko, Jouni’s wife and also a colleague and a good friend. Without you two my whole life would have been a darker place as well.

Thank you SSHY and especially to the trimmers of the Healthy Hooves project group: Harri Asikainen, Erkki Nivala, Mervi Niinimäki, Asko Klemola and Mara Aulio. I also thank all of the other hoof trimmers for great work and your contribution to the national database in Finland. Our national health system is indebted to you.

Thank you Eero Korhonen. Without you Eero, as the hoof-trimmer, it would have been practically impossible to conduct Suitia part of this thesis. I would never have found anyone, who could have made the work so nice, peaceful and comfortable. You did work with a big heart and a “good hand” and saved some cows with good hoof-trimming.

Thank you Suomen Rehu, especially Asko Haarasitla and Kari Hissa. I will always remember Suomen Rehu with warm thoughts. Without this learning process, I could not have started this project and Finland would have not gotten its national hoof database. I also thank you for the large amount of money. During these valuable years at Suomen Rehu, Asko, you really paved my way by trusting me and I learned many ways to develop visionary thinking. Thank you Kari for your patient efforts in teaching this green veterinarian the secrets of feeding and healthy cows. I still keep you as a feeding-guru.

Thank you Suitia farm, particularly Sakari Alasuutari, Daniel, Susanna and Kimmo. Working with all the Suitia staff was a positive experience and Sakari, you did a real work when You also half by taking blood-samples. As with hoof trimmers, we worked hard and still had a good time together. Daniel, contributed greatly to the pleasant atmosphere in Suitia; his sudden death in April 2006
left us in deep sorrow. I hope we will meet again some day, in eternity. Thank you also Toomas Orro, Sanni Kallio, Frans Lahdenranta for helping me a lot in the lameness study and analyses in Suitia.

Thank you Mari and Kalevi Heinonen. Mari, you are the one of the people I appreciate most. You saved my life numerous times and helped me to go on. You stood by me and were a real friend outside the University; but you also gave good answers to problems and helped me write cover letters to articles. I will also remember Kalevi for an exceptionally encouraging conversation about thesis writing and life tragedies in autumn 2004. This conversation helped me believe in the future.

Thank you Henrik Strychn for your kindness, your brilliance and your patient. Because of your great teaching, I learned something even with my poor English and that terrible lung disease. I am also grateful for the great advice I got from you by email when I was back in Finland and struggling with overdispersions and MIWin.

Thank you Mika Uusimäki. Although we have had very different stages in our friendship, I will never forget the way you supported me during lonely times and difficult moments in Canadian springtime. The foundation of all epidemiology in this book builds on that spring and I wonder if this “reddish blow-hat” would have survived all exams and troubles without those numerous emails we both sent. I learned something very special about deep friendship and trust from you, something that I will always cherish.

Thank you Hannu Saloniemi. Nearly all clinical theses dealing with dairy cows have something to do with you Hannu, and mine was no exception. I called or emailed you nearly every time when something “big” happened and always I got the encouragement that I needed.

Thank the Genetic Department of the University of Helsinki, especially Minna Laakso, for valuable help and for providing me with important data on parity, breed and milk yield. Minna, you enabled an accurate analysis when you transformed all individual cow data from paper to Excel. The work was enormous and you did it well and relentlessly.

Thank you Christian Schnier for all data analysis of the HH pilot year in 2002. I am also indebted to you for my first steps with Stata and epidemiology. I also thank you for your outstanding hospitality in England in 2005.

Thank you Kristiina Hakkarainen for being such a good colleague and also a friend. I have enjoyed sharing a workroom and life beyond that room with you.
Thank you AVC students, with special thanks to Kathryn, Peter, Signe, Charles, Ralph, Dieter and Annie. You should know what you meant to me, not only as AVC schoolmates but also as friends. Also without you I might not have survived for the Biostat final exam and gained ANOVA tables.

Thank you Riitta Niemi and Jussi Pirkkalaniemi. I want to thank you Riitta and Jussi for being in my life during these last years, for taking care of me and Valiente and for sharing many special moments as friends. Also you made it possible for me to go to Canada.

Thank you to Maria, Kaisa and Magnus Andersson. When someone travels around the world, e.g. to study epidemiology or to work, and that someone owns horses and dogs, she needs incredible neighbours to help. Especially You, Maria, were always there, thank you!

Thank you also to all of my other dear friends, who make life worth living and give special encouragement and prayers when needed; special thanks to Antti and Helena, Kyllikki, Nina, Marja, Saku, Susa, Satu, Pirjo, Lea, Maija, Maarit, Markus and Mikko. Sometimes you really kept me alive!

Thank you my dear father Rauno Kujala. You showed me the value of an honest and uncompromising way of life and taught me to appreciate work but also good relationships.

And, finally, I thank my Savior Jesus Christ, to whom I dedicate my life. He gave it all.


Original articles