CHARACTERISTICS OF LAMINITIS AND ASSOCIATED CLAW LESIONS IN DAIRY COWS IN NAIROBI AND ITS ENVIRONS

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university

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DEDICATION

To

My wife Purity and our children Grace, Samuel and Titus. To God is the glory.

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ACRONYMS

AVAs: Arteriovenous anastomoses

AVs : Arteriovenous shunts

CHD : Claw horn disruption

C: F : Concentrate to forage ratio

DPX : Destrene 80 dibutyl Phthalate and Xylene

FAWC: Farm Animal Welfare Council

H & E: Haematoxylin and eosin

Ltd : Limited

MMP-2: Matrix metalloproteinase-2

MMPs: Matrix metalloproteinases

P3 : Pedal bone or distal phalanx or 3rd phalanx

SARA: Subacute ruminal acidosis

TMR : Total mixed ration

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ABSTRACT

Lameness in dairy cows causes vast economic losses by reducing production and reproductive efficiency. Claw horn lesions are the most common cause of lameness. Laminitis is an important condition due to its influence on the occurrence of other claw horn lesions. The extent of claw horn lesions and particularly laminitis and their contribution to dairy cow lameness in Kenya has not exhaustively been determined. In addition, pathomorphological changes associated with laminitis in cattle, and which would help in understanding its pathogenesis are not yet conclusively studied. The objectives of this study were therefore to: 1. Determine the prevalence of laminitis and other claw lesions in dairy cows in Nairobi and its environs, 2. Evaluate association between laminitis and other claw lesions and with risk factors in the study area, 3 Determine radiographic and pathomorphological characteristics of claw lesions.

The study was carried out in three phases. In phase 1, retrospective data on cases of dairy cows admitted for treatment of foot conditions in the Large Animal Hospital of the Faculty of Veterinary Medicine, University of Nairobi, Kenya in the period 1981 to 2006 were studied. Phase 2 was a prospective clinical study in which 29 zero-grazed smallholder farms and 3 large-scale pasture-managed farms were purposively selected. Farm-and cow-level data were collected. A total of 300 cows from these farms were examined for claw lesions in their hind limbs. A 1-2 mm thick layer of the horn was trimmed from the sole to expose any underlying lesion. Locations of lesions on the weight-bearing surface of the claw were categorized according to 6 conventional zones, while sole haemorrhages were categorized according to 5 conventional haemorrhage

scores. During phase three, 159 cow feet (318 claws) samples from two purposively selected abattoirs were collected. The claw samples were radiographed in dorso-palmar or dorso-plantar projections for examination of pedal bone changes. Examination of the claws for gross lesions was done as in phase 2. Sagittal section of each claw was made, after which the corium and the pedal bone were examined. Corium specimens were taken from claws with subclinical and chronic laminitis for histology and transmission electron microscopy. Controls for histological and electron microscopic examination were corium specimens from claws that did not show any laminitis. Analysis of all the data collected was done using descriptive statistics, tests of association, and stepwise logistic regression using SAS © 2002-2003.

Results of the retrospective study showed that interdigital necrobacillosis (foot rot) had the highest (35.7%) prevalence followed by interdigital fibroma (11.9%) and sole abscesses (11.1%), but prevalence of laminitis (0.79%) was low. Prevalence of claw lesions was computed based on number of cows affected (prospective clinical study), and based on the number of claws affected (abattoir study). Results of the prospective study indicated that most (88%) of the cows had claw lesions, of which 69% were subclinical. Prevalence of subclinical laminitis was 49.3% (prospective) and 34.6% (abattoir), while that of chronic laminitis was 21% for both prospective and abattoir studies. Among other claw lesions, sole bruising had the highest prevalence of 45% (prospective) and 78% (abattoir), followed by heel erosion at 27.3% (prospective) and 41.5% (abattoir). Claw deformities had prevalence of approximately 45% for both prospective and abattoir studies. Sole haemorrhages were present in 82% of the cows that had laminitis, of which

34.7% involved zone 4 of the sole and was significantly (χ^2 = 22.03, r = 0.3, O.R = 3.3, p < 0.05) associated with subclinical laminitis. Slight to moderate (scores 1 and 2) of sole haemorrhages were strongly and positively associated (χ^2 =18.01, r = 0.6, O.R = 39.3, p < 0.05) with subclinical laminitis. Chronic laminitis was significantly associated with more severe haemorrhages which occurred in zones 2 (r = 0.247, χ^2 =18.23, p < 0.05), 3 (r = 0.28, χ^2 = 23.45, p < 0.05) and 6 (r = 0.122, χ^2 =4.48, p < 0.05). Regular (≥ 2 times/day) concentrate feeding significantly (χ^2 = 3.84, r = 0.1, O.R = 1.9, p< 0.05) enhanced occurrence of subclinical laminitis. The risk factors that significantly enhanced occurrence of chronic laminitis were overstocking (χ2 = 12.09, r = 0.4, O.R = 1.6, p < 0.05) and having more than three parities (χ^2 = 5.36, O.R = 1.5, p < 0.05). Claw overgrowth (χ^2 = 91.83, r = 0.6, O.R = 14.1), horizontal ridges (χ^2 = 31.20, r = 0.5, O.R = 12.4), and concave claws (χ^2 = 11.98, r = 0.4) were strongly and positively associated (p < 0.05) with presence of chronic laminitis. High locomotion scores were invariably associated (χ^2 = 36.76, r = 0.6, O.R = 4.3, p < 0.05) with chronic laminitis compared to other associated claw lesions. Digital dermatitis (papillomatosis) was diagnosed for the first time in Kenya in the current study.

The main radiographic changes seen on the pedal bone were: dilated vascular channels (60.8%), prominent (but not dilated) vascular channels (24.1%), irregular margins (13.9%), exostoses (8.2%) and narrowing of the bone (5.7%). Outgrowths on the pedal bone had low (< 5%) prevalence but were a new finding. Key histopathological changes observed in the corium of laminitic claws were: arteriovenous shunts, vascular wall disruptions, vascular thrombosis, dermal-epidermal junction disruptions, epidermal hyperplasia, oedema in the dermis, spongiosis and degeneration in the connective tissue. Electron microscopy revealed presence of fibroblast degeneration, vacuolization within the cytoplasm of fibroblasts, vascular endothelial cell damage, degeneration and necrosis of fibroblasts as well as disoriented smooth muscle cells of the tunica intima within blood vessel walls..

From this study, it was concluded that: 1. Prevalence of laminitis (subclinical and chronic) was > 70.3%, in which subclinical laminitis was more prevalent than chronic laminitis, 2. Haemorrhages in the sole are the best sign to indicate presence of subclinical laminitis. However, when present together with claw deformities, it signifies that the deformities are laminitic. Hence differentiating them from deformities caused by regular overgrowth, 3. Concentrate feeding enhances occurrence of subclinical laminitis, while more than 3 parities and overstocking enhance occurrence of chronic laminitis, 4. Narrowing and outgrowths of the pedal bone, connective tissue degenerative disruption, epidermal cell spongiosis, epidermal hyperplasia, fibroblast degeneration and vacuolization in the cytoplasm of fibroblasts, which have not been recorded previously, were observed as new findings in laminitic claws. Further research needs to be carried out in different representative parts of Kenya to establish whether prevalence rates of laminitis and other claw lesions are similar to the ones found in the current study. In addition, progressive systematic research using longitudinal or case-control studies needs to be done to establish the actual pathogenesis of laminitis.

CHAPTER 1

1.0 GENERAL INTRODUCTION

The livestock sector in Kenya contributes over 40% of the agricultural Gross Domestic Products (GDP) (Draft National Livestock policy, 2006). Dairy farming in Kenya is mainly practiced in high potential areas as pasture-grazing and zero-grazing systems. Due to the increasing human population, there has been an inevitable reduction in per capita land-holdings, invariably diminishing the available grazing land and subsequently triggering an increase in smallholder dairy production systems particularly for the low income households (Mutugi, 2004). Small-scale farms contribute 80% of the national commercial dairy herd with an average herd size of 2-4 heads of cattle raised on $\leq$ 1.0 hectare (Wanyoike and Wahome, 2004). The annual contribution of the smallholder dairy herds is estimated at 3.2 billion litres of milk (Draft National Livestock policy, 2006). However, their average daily milk yield per lactating cow is 6 kg (Wanyoike and Wahome, 2004), which is considered low compared to other intensive production systems (Esslemont, 1990). This low productivity is due to diseases, poor nutrition as well as substandard husbandry and management practices (Gitau, 1994; Mutugi, 2004; Wanyoike and Wahome, 2004). Among the diseases contributing to low dairy productivity in Kenya are tick-borne and infectious diseases, mastitis, gastrointestinal parasitism and reproductive inefficiency (Odima, 1993; Gitau, 1997; Omore, 1997; Mutugi, 2004).

Lameness is also reported as another cause of lowered productivity and loss of economic output in dairy production systems (Hernandez *et al*.. 2005; Kossaibati and Esslemont, 1997). It causes this negative impact on dairy productivity through lowered conception rate and increased calving interval (Melendez *et al.*, 2003; Sogstad *et al.*, 2006), reduced ovarian activity during early postpartum period (Garbarino *et al.*, 2004), reduced milk yield (Hernandez *et al.*, 2005), discarding of milk due to antibiotic withdrawal period following intra-mammary and systemic treatment, cost of veterinary drugs and professional services, and premature culling (Enting *et al.*, 1997). Lameness has also been identified as a major welfare determinant in cattle, thus making it of increasingly important concern (Offer *et al.*, 2000).

More than 60% of lameness in cattle is caused by claw horn lesions (such as sole ulcers, heel erosion, white line separation and double soles) that result from insults or injuries to the corium, and are generally attributed to laminitis (Nocek, 1997; Manske *et al.*, 2002b; Belge and Bakir, 2005), which is very common in intensely reared systems (Smilie *et al.*, 1999). Laminitis is a diffuse aseptic inflammation of the corium, whose microvasculature is progressively damaged to the extent that production of good quality claw horn is compromised (Nocek, 1997; Bell, 2004). It has more recently been referred to as "claw horn disruption" (CHD), thus appropriately describing its main effect on the digital organ (Hoblet and Weiss, 2001). The development of laminitis is insidious and prolonged presenting late and protracted clinical symptoms at a stage when irreversible damage to the claw might already have occurred (Greenough, 1987; Nocek, 1997; Belge and Bakir, 2005).

The main pathomorphological changes observed in laminitis include arteriovenous shunts (AVs) in the corium (Hirschberg *et al.*, 2001; Christmann *et al.*, 2002), disruption of keratinocytes in the claw epidermis (Wattle, 2001), microvascular thrombosis in the corium, disruption of the dermal-epidermal junction (Nocek, 1997), and arteriosclerosis in all parts of the corium (Singh *et al.*, 1994). The most prominent radiographic changes in laminitis include "sinking" and rotation of the pedal bone within the claw capsule and dilatation of the vascular channels within the pedal bone (Boosman *et al.*, 1989b).

Laminitis has interactive and synergistic multifactorial risk factors that are related to nutrition (Cook *et al.*, 2004), housing type (Sogstad *et al.*, 2003; Cook *et al.*, 2004; Espejo *et al.*, 2006), floor type (Vockey *et al.*, 2001; Hinterhofer *et al.*, 2006), floor slope (Vockey *et al.*, 2003), environment (Borderas *et al.*, 2004; Vermunt, 2004), and body chemicals (Offer *et al.*, 2000; Hirst *et al.*, 2002).

Studies on lameness in Kenya are scanty and those done have not delineated its various causes (Gitau, 1994). A high number of dairy farming units are concentrated in Nairobi suburbs and the peri-urban districts of Kiambu, Kajiado and Thika owing to availability of good market for milk (Wanyoike and Wahome, 2004). Previous study in Kikuyu division of Kiambu district Kenya indicated that zero-grazed cattle in small-scale dairy farming units had a three times higher risk for lameness than cattle that had access to pasture-grazing (Gitau *et al.*, 1996). However, information on the status of laminitis in Kenya, and on the association of laminitis with other claw lesions and with cow-and farm-level risk factors is not available. Furthermore, radiographic and pathomorphological changes in laminitic claws are obscure. Therefore, it was imperative to carry out studies to establish the extent of laminitis and related claw lesions in dairy farming systems in Kenya, and to define radiographic and pathomorphological changes adduced to these claw conditions.

The overall purpose of the study is to describe the occurrence and distribution of digital lesions of dairy cattle in smallholder production systems and recommend curative and preventive measures against their occurrence.

1.1 Hypothesis of the study

The study was based on the following hypothesis:

High prevalence of claw lesions particularly laminitis in dairy cows in Kenya contributes significantly to lameness and associated pathology that is influenced by farm management systems.

1.2 Objectives of the study

The study was therefore carried out in Nairobi and its environs with the following specific objectives:

1.2.1 To determine the prevalence of laminitis and other claw lesions in dairy cows.

1.2.2 To evaluate association between laminitis and other claw lesions, and with risk factors.

1.2.3 To determine radiographic and pathomorphological characteristics of claw lesions.

To achieve the objectives, the study was carried out in three-phases. The first phase was a retrospective study of cases of dairy cows admitted for treatment of foot conditions in the Large Animal Hospital of the Faculty of Veterinary Medicine, University of Nairobi, Kenya from 1981 to 2006. The second phase was a prospective study of claw lesions and associated risk factors in smallholder and large-scale farms in Nairobi suburbs and the peri-urban districts of Kiambu, Kajiado and Thika. The third phase was radiographic and pathomorphological study of laminitic claws collected from abattoirs. The results provide useful information that can contribute to the fulfillment of the overall purpose of prevention of occurrence of claw lesions in cattle in the Kenyan smallholder dairy farming systems.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Clinical and economic importance of cattle lameness

In most parts of the world, cattle lameness ranks as the third most important health condition causing vast economic losses in dairy industry after reduced reproductive performance and mastitis (Kossaibati and Esslemont, 1997). The main ways in which lameness causes economic losses is by decreased feed intake leading to lowered milk yield (Greenough and Vermunt, 1991), discarded milk due to antibiotic treatment withdrawal period, premature culling, cost of veterinary services, increased labour, reduced reproductive performance causing infertility and prolonged calving interval (Enting *et al.*, 1997; Kossaibati and Esslemont, 1997).

A linear relationship between increasing degree of lameness and decreasing milk yield among cows in their second or later lactations has been reported (Hernandez *et al.*, 2005). Lame cows were reported to have a lower conception rate of 17.5% compared with 42.6% in non-lame cows at first service (Melendez *et al.*, 2003). They were also found to have significantly higher incidence (25%) of ovarian cysts compared to 11.1% in the controls (non-lame cows). Studies done by Sogstad *et al.* (2006) on lameness lesions and reproductive performance in first-lactation cows, showed association of moderate to severe heel horn erosions with increased calving interval, moderate and severe haemorrhages of the sole with a decreased calving to first service interval, and all haemorrhages of the sole (score 1, 2 and 3) with increased insemination return rates.

They concluded that claw disorders are generally associated with poorer reproductive performance.

Hernandez *et al.* (2005) found that non-lame cows became pregnant more quickly than lame cows. Lame cows had longer conception median time of 36 to 50 days than non-lame cows. Those with high cumulative locomotion scores had longer conception median time of 66 days than cows with low scores. Therefore early diagnosis and intervention might mitigate the effects of lameness and improve reproductive performance in lame dairy cows.

Lameness has been associated with delayed ovarian activity in Holstein cows during early postpartum period. These cows had 3.5 times greater odds of delayed ovarian cyclicity, compared with the non-lame ones. The delayed ovarian cyclicity in lame cows could be reduced by 71%, if lameness was prevented (Garbarino *et al.*, 2004).

Claw disorders are frequently reported in dairy cattle in variable frequencies of in Nairobi and its environs (December 2005-June 2006) occurrence all over the world. They are reported to contribute 90% of all lameness incidences (Weaver, 2000) and in 80% of the cows with sole haemorrhages (Bergsten, 1994), and 64.7% of the cows across a range of parities (Manske *et al.*, 2002b). Claw horn lesions are by far the most common and least understood causes of lameness in cattle (Clarkson *et al.*, 1996). Warnick *et al.* (2001) found claw horn lesions responsible for 23.3% and 33.1% of lameness in two U.S.A. herds housed in free-stalls. Generally, claw horn lesions account for 23 to 60% of lameness in dairy cows (Cook *et al.*, 2004) but could be higher when surveys include both lame and non-lame cows (Manske *et al.*, 2002b).

Lameness is characterized as a multifactorial condition. It is the result of an interaction between housing design, farm management, nutrition and animal characteristics (Clarkson *et al.*, 1993). These predisposing factors also influence occurrence of claw horn lesions. Claw disorders are distinguishable at clinical level (lameness) and at subclinical level (digital disorders recognizable at hoof trimming) (Clarkson *et al.*, 1996; Nocek, 1997).

Lameness was identified as an important and a major welfare determinant by the Farm Animal Welfare Council (FAWC) (Offer *et al.*, 2000). High producing mature dairy cows tend to have a higher incidence of lameness owing to the metabolic stress of high milk yield (Seagers *et al.*, 1998; Warnick *et al.*, 2001). Cows in poor body condition had a higher prevalence of clinical lameness than those in normal or in good body condition (Espejo *et al.*, 2006).

There is a higher incidence of lameness occurring in the hind limbs than the fore limbs, and 80% of the hind limb lameness occurs in the lateral claws (Tranter *et al.*, 1993). The difference in structure, shape and size between the outer and inner claws of the hind feet in cattle may contribute to the higher incidence of lameness seen in the outer claws (Russell *et al.*, 1982).

Modern dairy housing facilities predispose cattle to serious hoof problems. Smits *et al.* (1992) reported several claw disorders prevalent in Dutch dairy farms under zero-grazing environment. Zero-grazed cattle in small-scale Kenyan herds in Kikuyu division had a three times higher risk for lameness than cattle that had access to pastures (Gitau *et al.*, 1996).

2.2 Normal functional anatomy of the bovine foot

The foot is that part of the limb below the fetlock. In the bovine, it is divided into two digits and the ends of the digits are called "claws" or "hooves" and are surrounded by horny capsules. Each digit is comprised of four bones: the long pastern bone (proximal phalanx or P1), the short pastern bone (middle phalanx or P2), the pedal bone (distal phalanx or P3), and the navicular bone (distal sessamoid). The proximal and middle phalanges are outside the claw and the distal phalanx and navicular bone are inside the claw. There are two joints in the foot: the proximal interphalangeal (pastern) joint and the distal interphalangeal (pedal) joint (Berry, 1999).

The digital cushion lies below the pedal bone and has two functions: 1) to cushion the corium from pedal bone, and 2) to pump blood back up the leg when the cow walks. The two claws are divided by an interdigital space and connected by smooth, hairless skin. The interdigital space is narrow and can trap manure that predispose to some digital problems (Berry, 1999).

The horny capsule of the claw (hoof) is comprised of the wall, sole, heel, and white line. The wall consists of the toe and dorsal wall, the outside or abaxial wall and the inside or axial wall. The normal (non-laminitic) hoof wall has faint lines or growth rings on it. These growth rings slope slightly towards the heel indicating that the heel wears faster than the toe. The wall is the hardest horn, the sole is softer than the wall, and the heel is softer than the sole. The white line is the softest horn and forms the junction between the sole and the wall (Berry, 1999). In the claw, the epidermis is the horny part. The dermis (corium) contains nerve and blood supply and is inside the epidermis of the claw. The corium produces the horny claw and when it is damaged, it cannot produce healthy horn, thus lameness occurs. Healthy corium means healthy horn and diseased corium means diseased horn. The most common causes of lameness in cattle are from damaged corium. The perioplic corium forms the perioplic horn, which is visible on the dorsum of the hoof wall and wraps around the hoof to merge with the heel. So the heel is formed by the perioplic corium. The coronary corium produces the wall of the hoof, which grows downward from the coronary band at about 5 mm per month. The laminar corium produces the laminar horn that attaches the abaxial wall, dorsal wall and a small part of the axial wall to the pedal bone. Therefore, the pedal bone is firmly attached and suspended inside the toe of the normal hoof. The laminar corium also produces most of the white line. The solear corium produces the solear horn (Berry, 1999).

Arteriovenous anastomoses (AVAs) have been reported to serve as shunts that cut off perfusion of the capillary system and contribute to the regulation of the microcirculation. The densely innervated sphincteric arteries next to the papillae and laminae are the critical valves in the dermal microcirculation, which is controlled by neural regulation that is either related to autonomic or somatic nervous system. In addition to this regulation, other mechanisms exist triggered by different local as well as systemic vasoactive substances (Buda and Mülling, 2002).

The basic angioarchitecture of the papillae of the periople, coronary region, bulb, sole and the terminal papillae of the wall region consists of a centrally situated arteriole and venule surrounded by a network of subepidermal capillaries and venules. The central papillary vessels arise from the dense subpapillary corial plexus, which is, arranged parallel to the surface of the underlying distal phalanx. There exist peripheral arteriovenous loops in all papillae of the bovine claw. At the tip of the papilla, the arteriole drains directly into the venule, thus forming a peripheral arteriovenous loop (Hirschberg *et al.*, 1999).

Furthermore, it is reported that in the sole, the vascular papillae arising from the subpapillary plexus are uniform in size and shape. They are arranged in parallel rows that are a continuation of the lamellae and the rows of terminal papillae of the wall, and their tips are directed towards the apex of the claw. The capillary and venular network is very dense and reaches up to the tip of the papilla; at the sole, two or three units of arteriole, venule, and arteriovenous loops could be detected coiled around each other in one papilla. It is further reported that the breaking up of the plain dermal-epidermal surface into lamellae and papillae, and even further into secondary and side papillae, takes place in those areas with a high cornification rate and in the weight-bearing areas. An increase in dermal surface is thought to increase the epidermal-dermal bordering area, thus enabling a better supply of the dependent epidermal basal cells. It enables the capillaries, the site of cellular exchange, to get as near to the epidermal-dermal borderline, (the dependent basal epidermal cells,) as possible (Hirschberg *et al.*, 1999).

Finally, in zero-grazing, the cow has been taken from its natural environment which is pasture with soft yielding surface and has been put under confinement on concrete for most of her life. This predisposes to various claw problems. Nevertheless, by understanding the normal anatomy of the bovine foot, we can keep the foot functional and prevent many of the lameness problems (Berry, 1999).

2.3 Laminitis

Laminitis is a diffuse aseptic inflammation of the corium (lamina or pododerm). It affects the tissues of the hoof, especially the laminae and papillae (Bell, 2004). Some authors refer to it as disturbed claw (Somers *et al.*, 2003), haemorrhagic lesions, sole haemorrhages, claw horn lesions (Webster, 2002), and corium tissue damage (Bell, 2004). In Europe, 90% of lameness in cattle are localized in the claws of which laminitis contributes a high proportion. Laminitis is regarded as a major predisposing factor in lameness by causing claw lesions such as white line disease, sole ulcer and sole haemorrhages (Nocek, 1997).

The corium is a highly vascularized dermal tissue found between the horny capsule and the pedal bone. Irregular folds of the corium of the sole next to dermal-epidermal junction are referred to as papillae and the regular folds next to the hoof wall are termed laminae (the laminar corium). It serves three important functions: to absorb shock created when the claw impacts the ground, to attach the third phalanx (pedal bone) to the hoof wall and the sole, and to produce the horny tissue of the wall and sole of the claw. Its elaborate vascular network supplies nutrients and oxygen to the dermis and the epidermis of the claw. Anything that disrupts the flow of blood to the corium will result in damage to tissues and impairment of its functions especially that of the ability to produce high quality horn. When the damage is severe, the integrity of the tissues is compromised to the extent of detaching the pedal bone from the casing of the claw with alteration of its configuration within the capsule of the claw (Bell, 2004).

2.3.1 Aetiology and predisposing factors of laminitis

There are three forms of corium tissue damage: subclinical, acute and chronic (Nocek, 1997). The exact aetiology and pathogenesis of laminitis remains largely obscure, but has been categorized as multifactorial in nature with several interactive nutritional and managemental predisposing factors (Ebeid, 1993). It is postulated that the trigger for the process of corium damage is a dramatic decrease in ruminal and systemic pH that leads to altered blood flow to the feet. The vasoactive substances such as histamines and serotonin released into the blood stream during this process of decreased pH are thought to cause intermittent vasoconstriction and vasodilation that result in compromised blood flow as well as flow of unoxygenated blood to the claws (Nocek, 1997).

2.3.2 Nutrition

High yielding cows eat for approximately 3 to 5 hours per day (Grant and Albright, 2001). However, dairy cattle may overeat following a period of feed deprivation (Cook *et* *al.*, 2004). Nutrition is one of the critical factors initiating the process of laminitis as a result of the quantity and quality of feed intake that may influence ruminal fermentation (Peterse, 1985). Subacute rumen acidosis (SARA) plays an important role as one of the trigger factors for laminitis (Cook *et al.*, 2004).

Feeding diets that lead to a significant and prolonged drop in rumen pH will result in a dramatic increase in lameness due to increased incidence of laminitis (Vermunt, 2004). Excessive feeding of rapidly fermented carbohydrates and feeding finely chopped silage are common factors in the development of laminitis because of their propensity for initiating SARA. The risk of developing SARA is less when concentrate to forage (C: F) ratio of the diet is under 60:40 (Vermunt, 2004). Carbohydrates comprise approximately 70 to 80% of the dairy ration; therefore, its level and availability in various rations can have a significant impact on rumen metabolism. Furthermore, the amount of carbohydrate feed necessary to induce ruminal acidosis depends on the type of carbohydrate, adaptation period and nutritional status of the animal as well as the frequency of feeding (Nocek, 1997). Excessive protein feeding has also been associated with laminitis (Vermunt, 2004) and promotion of horn-growth (Somers *et al.*, 2005).

Transitional diets fed during the periparturient period have a high net energy and low effective fibre, and are likely to contribute to occurrence of laminitis (Donovan *et al.*, 2004). Other nutritional factors besides SARA may also be involved in enhancing laminitis. Heifers raised on a diet based on wet, fermented grass silage suffered higher rate of white line and sole lesions both pre- and postpartum compared with heifers raised on a diet based on dry, unfermented concentrate fed from weaning to one month prior to calving (Offer *et al.*, 2001 and 2003; Leach *et al.*, 2005). These results suggested that residual effect of prepartum feeding can precipitate development of claw lesions beyond parturition.

Environmental, dietary and management factors that promote onset of SARA provide a possible route of exacerbating the problem. The impact of SARA on claw health may be mediated through gelatinoproteases, which elongate collagen fibers and loosen the connective tissues of the hoof (Tarlton *et al.*, 2002). Work done using equine hoof explants model suggest an alternative method of metalloproteinase activation and subsequent laminitis. Mungall *et al.* (2001) demonstrated that streptococcal pyrogenic exotoxin B released from *Streptococcus bovis* might activate metalloproteinase-2 in dose-dependent manner and lead to the separation of equine lamellar explants. These results demonstrated a putative linkage between damage to the integrity of the hoof and *Streptococcus bovis*, an organism known to proliferate in the rumen during shifts to high grain feeding (Tajima *et al.*, 2001).

Biotin acts as a co-factor in glucogenesis, fatty acid synthesis and protein formation. It has been shown to be specifically required for the normal production and keratinization of claw horn tissue (Higuchi and Nagahata, 2001). Histological evaluation of the horn material from biotin supplemented animals revealed a reduction in the number of macro-cracks and reduced number of horn tubules with enlarged intercellular spaces. Mean serum biotin concentration from cows suffering laminitis was found to be significantly lower than the mean values from cows with sound hooves. It has also been suggested that claw horn disruption resulting in laminitis produces softer horn of higher moisture content which is more susceptible to damage, and reduced biotin availability may result in impaired horn keratinization, and horn quality (Higuchi and Nagahata, 2001). Evidence exists that acidic rumen environment reduces microbial biotin synthesis, which under normal circumstances in lactating cows far exceeds biotin supplied in the feed (Steinberg *et al.*, 1994; Da Costa *et al.*, 1998). Furthermore, it has been concluded that the overall effect of biotin supplementation results in improvement of the quality of claw horn, which promotes replacement of defective horn, improves healing, and reduces the likelihood of development of sole-horn lesions from laminitis in its early stages (Bergsten *et al.*, 2003).

Trace elements like zinc, copper, selenium and manganese contribute to the health of the claw. Significant synergistic interactions between these trace-minerals, makes their combinations in dairy cow diet more beneficial to claw integrity than supplying them as single trace-mineral supplements (Tomlinson *et al.*, 2004). Feeding trace-minerals tends to improve claw lesion scores and thus is associated with improved claw health and integrity. Tomlinson *et al.* (2004) have further stated that vitamins A, D and E play a role in the keratinization process and thus contribute positively to claw integrity, which is essential for decrease in the magnitude of claw lesions. In an investigation of risk factors for reduced locomotion in dairy cattle, Amory *et al.* (2006) found some of the risk factors for increased locomotion scores to be failure to supplement lactating cows with vitamins and minerals compared with supplementing them, and feeding corn silage to heifers compared with not doing so.

2.3.3 Housing

In a comfortable environment, dairy cows will lie down 12 to 15 hours a day and mostly when ruminating. Longer standing periods increase the loading on the claw and exposure to unhygienic conditions, particularly for the rear feet. Comfortable stalls have soft bedding and enough space for rising and lying down. In uncomfortable stalls, cows often stand halfway in the free stalls with their rear feet on the alley (Leonard *et al.*, 1994). Adequate room in the cow house allows for enough exercise, which is good for blood circulation in the claw (Sogstad *et al.*, 2005b). Animals in uncomfortable stalls have a high prevalence of sole haemorrhages reflecting that longer standing time is an exacerbating factor in the development of claw lesions (Leonard *et al.*, 1994).

The interaction behaviour of cows at the feeding bunk is influenced by the available size of feeding space and influences sole haemorrhage scores. In addition, more interactions among the cows are provoked by competition for feed and feeding space at the manger. Sole haemorrhage scores are higher in animals with high feeding space interaction scores (Leonard *et al.*, 1996).

Claw lesions were more prevalent in free-stalls than in tie-stalls (Sogstad *et al.*, 2005a). There is convincing evidence that the incidence of claw horn lesions is greater for cows housed in cubicles than in straw yards (Webster, 2001). This difference may partly be attributed to the physical surface of the lying and walking areas (Bergsten and Frank,

1996) and partly to the fact that cows in straw yards spend more time lying down (Singh *et al.*, 1993b). The severity of sole lesions is significantly reduced by housing the cows in a straw yard between 4 weeks before-and 8 weeks after-calving, before they are introduced to cubicle accommodation (Webster, 2000). There is less direct mechanical stress to the sole when cows stand on straw, and when they lie down longer in straw yards (Singh *et al.*, 1993b).

Neck-rail location is an important determinant of how cows behave in free-stalls. Cows stand for longer periods in the stalls that have higher neck-rails above stall surface. Furthermore, when the neck-rail is shifted nearer the rear curb, the standing behaviour of the cows changes and there is increased perching (meaning that fore feet rest on the platform and rear feet on the alley) (Gaworski *et al.*, 2003). However, neck rail location does not affect lying behaviour. When the lower divider rail is mounted too high it prevents side lunging in a stall that is too short to allow forward lunging (Nordlund *et al.*, 2001). For the cow to rise on her rear limbs safely, she must transfer weight over the front knees, creating a point of balance, which requires the cow's head to almost touch the ground in an area referred to as the "bob zone". Stall designs that inhibit this lunge and bob movement of the head may reduce stall usage by the cows for fear of slippage of the rear feet on the stall surface because of inadequate weight transfer. This fear explains why cows are reluctant to change position on a stall surface that increases the risk of slipping (Cook *et al.*, 2004).

Aspects of stall design such as lack of surface cushion, low divider rail (< 0.34m), limited lunge space, and high rear curbs (> 0.16 to 0.2m) have all been related to an increased risk of lameness or claw horn lesions (Leonard *et al.*, 1994; Philipot *et al.*, 1994; Faull *et al.*, 1996). The prevalence of lameness was lower in free-stall herds with sand stalls (17.1%) than in free-stall herds with mattress stall (27.9%) surfaces (Espejo *et al.*, 2006).

Hard floors increased the risk of subclinical laminitis and higher scores of sole lesions (Bergsten, 1994). A positive correlation exists between long period spent on concrete surface and development of claw horn lesions (Somers *et al.*, 2003). More white line haemorrhages were found in animals housed on concrete floors compared to those on rubber mats and slatted floors (Bergsten and Herlin, 1996). In Dutch dairy cows exposed to several floor systems, over 80%, and 55% to 60% of the cows exposed to concrete flooring and straw yard respectively had at least one claw disorder though the disorders were subclinical and were only diagnosed at claw trimming. Those raised on slatted floors had the lowest prevalence of claw infections. There was higher prevalence of white line separation in cows on straw yards, which was attributed to excessive hoof growth, lack of preventive hoof trimming, and subsequent overloading of specific regions of the claw (Somers *et al.*, 2003). Housing on hard concrete floors stimulates faster claw growth. Prolonged disorderly claw horn growth could lead to malformations of the claw that makes it vulnerable to mechanical injury and penetration of infectious agents (Somers *et al.*, 2005). Abrasiveness of the concrete floor, floor hygiene and moisture content on the floor are all important elements in the aetiology of claw disorders (Vokey *et al.*, 2001). Presence and severity of claw lesions decreases on rubber floors (Hultgren and Bergsten, 2001).

Concrete stall surface with a small quantity of finely chopped bedding material, and a variety of surface options such as hard rubber mats, mattresses consisting of rubber crumbs, foam, air or water cushioning, and deep, loosely bedded stalls typically using sand, soil or sawdust, are currently available for both free-stalls and tie-stalls (Cook *et al.*, 2004). Cows show preference for lying down on deep loosely bedded stalls compared to mats or mattresses (Tucker *et al.*, 2003; Wagner-Storch *et al.*, 2003). Stall preference study is an area needing further work.

Floor surface type does not seem to influence horn growth-and-wear. However, horn growth was greatest when cows were removed from pasture to confinement (Somers *et al.*, 2005). Providing soft walking areas such as rubber or straw enables a more natural weight-bearing on bovine claws, and it leads to better claw health that prevents occurrence of claw lesions predisposed by overloading (Van der Tol *et al.*, 2003).

Mechanical stress levels on a model claw under different types of flooring showed that the stress was highest when the claw was not supported under the abaxial wall and a clear distinction was detected between the solid floor with full claw contact and the slatted floors. From the point of view of the mechanical stress exerted, a large contact area between the claw and floor as occurs in solid floor surface is preferred (Hinterhofer *et al.*, 2006). When use of slatted floors is unavoidable, direction of the slats should run perpendicular to the direction of the walkway to prevent worse mechanical impact in certain footing situations. A claw bearing weight on the edge of a solid floor has higher mechanical stress (Hinterhofer *et al.*, 2006). Further, when claw horn quality is compromised, effects of poor flooring surfaces may be compounded. The structure of the white line and the quality of the horn produced is weakened at calving (Kempson and Logue, 1993) and during laminitis (Mülling, 2002), and may result in increased likelihood of white line disease when the claw is subjected to rough surfaces. Vokey *et al.* (2001) did not find any significant difference in lameness indices between different stall and alley configurations.

Although not much study has been done on the effect of floor slope on lameness, Vokey *et al.* (2003) reported that standing for 45 to 90 minutes on a 5% slope (rising from tail to head), had beneficial effect on claw health. This was probably due to drainage of moisture away from the claws rather than any effects on claw wear.

The risk factors of heel horn erosion were associated with poor hygiene, while subacute laminitis was linked to uncomfortable housing conditions such as high steps and slopes, and discomfort when lying down and getting up. No risk factors related to livestock building, were associated with chronic laminitis (Philipot *et al.*, 1994).

2.3.4 Environment

There is evidence suggesting that environmental factors play a significant role in influencing the rate and development of laminitis and associated lesions (Bergsten and Frank, 1996; Webster, 2001). Environmental factors appear to operate in 3 main areas. First they influence lying and standing behaviour, which may worsen claw horn lesions already triggered by changes at parturition or by the onset of SARA. Secondly they promote the onset of SARA during lactation, and thus trigger processes that may lead to laminitis and other claw lesions. Thirdly they influence claw horn growth and wear, and the resulting ground reaction forces on different walking surfaces (Cook *et al.*, 2004).

The environment in which the cow is housed is very important. Resistance of the horn of the claw to environmental effects depends on its hardness as this influences the rate of horn wear and erosion (Vermunt and Greenough, 1995). Wet underfoot conditions increase claw horn moisture that softens the horn of the sole, and predisposes the sole to easy penetration and claw lameness. Under these wet conditions, concrete causes abrasions of the claw more easily with more horn-wear of the weight-bearing surface (Vermunt, 2004). It has been shown that water content of the claw horn is related negatively to its hardness (Higuchi *et al.*, 2003). Cows kept on slatted floors, which reduce exposure of the claw to water, tend to have harder claws. Higuchi and Nagahata (2001) found greater water content in claws of cows with claw problems compared with healthy cows.

Moisture content of the horn of the sole for both thin-soled and normal-soled rear claws is significantly higher than that of front claws. The thin-soled claws have higher moisture levels than claws with normal sole thickness in the same herd. Moreover, an increase in sole horn moisture may result in increased rate of horn-wear because of increased softness (van Amstel *et al.*, 2004).

Studies done by Borderas *et al.* (2004) indicated that claws absorb water rapidly. When comparing water absorption as a percentage of the total water absorbed, they found that almost 30% of total water was absorbed into the claws during the first hour and approximately 50% during the first 4 hours. On the other hand, water loss when claws are allowed to dry occurs at a slower rate. By the 4^{th} hour of drying, claws had lost about one-third of total amount of water and approximately 50% by the 8^{th} hour. In addition to this, it has also been shown that as claw tissue absorbs water, its hardness decreases proportionately. There are marked differences in hardness between different regions of the claw, with the wall of the claw being the hardest region, and the sole-heel junction the softest. These findings are important when considering the slurry or manure accumulation in the cow house walk-ways. Furthermore, there is evidence that cows with softer claws tend to have more severe claw lesions. However, change in claw hardness does not necessarily lead to more claw lesions. Nevertheless, to reduce the chances of injuries, dairy cows should be kept in conditions that allow their claws to remain as dry as possible (Borderas *et al.*, 2004).

2.3.5 Parity, periparturient period and stage of lactation

There are mechanical changes that alter the biochemistry of the connective tissue. Around the periparturient period, connective tissue of the hoof suspensory apparatus weakens, leading to increased susceptibility to clinical lameness such as sole ulcers and white line disease (Tarlton *et al.*, 2002). Haemorrhagic lesions of the sole and white line typically start to develop around the time of parturition and tend to be most severe in early weeks of lactation (Bergsten and Frank, 1996).

Experimental data suggest that systemic changes at first calving in heifers appear to be a trigger factor for claw horn lesions, setting in motion a chain of events that are further influenced by environmental and dietary factors (Cook *et al.*, 2004). Cows suffering lameness during the first lactation are more susceptible to lameness in subsequent lactations, especially the lameness that is due to claw horn lesions during the second lactation, thus making lameness episodes at first parturition important determinants of future lameness incidences (Hirst *et al.*, 2002).

Primiparous cows were found to be more prone to sole lesions and had higher scores of sole haemorrhages than multiparous cows (Bergsten, 1994: Bergsten and Herlin, 1996). Incidence of lameness in cows was observed to be highest in the early stage (first 120 days) of lactation and reduced with progressing lactation, attaining lowest levels in the last three months of lactation, and this was suggested to be due to stress of heavy milk production in the early stages that exacerbates subclinical lameness (Rowlands *et al.*, 1985). A strong positive association between 61 to120 days post-partum and the presence of claw disorders is attributed to the fact that this period coincides with a high level of energy intake and negative energy balances (Vermunt, 2004). In a study done in Minnesota on high-producing Holstein cows housed in free-stall barns, prevalence of lameness in first-lactation cows was 12.8%. This prevalence was found to increase on average at a rate of 8% units per lactation (Espejo *et al.*, 2006).

White line lesions are initiated around 16 weeks and sole lesions around 26 weeks after calving and in both categories, the total lesion scores become progressively more in subsequent lactations (Offer *et al.*, 2000). These observations particularly concur if the cows are housed before and after calving. However, the difference between the initial lesion score and the maximum lesion score is lower in 3rd and 4th lactations than in the first two lactations. Furthermore, lesion and locomotion scores are significantly higher by the 4th lactation (Offer *et al.*, 2000).

It has also been reported that four weeks after calving, the scores of sole haemorrhages and white line lesions were very similar whether in cubicle accommodation or straw yards. This observation provides strong support for the hypothesis that the primary insult to the structural integrity of the foot is systemic and associated with physiological changes occurring around the time of calving and in early lactation. These changes occur synergistically with external stresses such as concrete floors and trigger the events that may in lead to development of sole lesions and severe lameness. Furthermore, these changes could also be attributed to hormonal (such as relaxin) or nutritional effects (Webster, 2002).

In Norwegian red dairy cattle housed in free-stalls, Sogstad *et al.* (2005b) found correlation between parity and stage of lactation with lameness. They found the relationships as follows: heel erosion, was related to lactation stage between 5-7 months after calving; haemorrhages of the white line related to lactation stage 3-5 months after calving; haemorrhages of the sole related to the first parity and lactation stage between 5-7 months after calving. They found that heifers housed in pens or free-stalls had more heel horn erosions, haemorrhages of the sole and white line fissures than heifers in tie-stalls.

2.3.6 Claw trimming

Healthy locomotor apparatus are crucial elements for normal cow behaviour and social activity. Poor horn quality and overgrown claws predispose the cow to development of claw conditions. The bovine claw capsule undergoes continuous turnover process, and under normal conditions, growth and wear occur at approximately equal rates (Vermunt and Greenough, 1995).

The main purpose of regular hoof trimming is to restore weight to the correct weight-bearing surfaces of the foot. All cows undergo a period of "negative net hoof growth" in the immediate post-partum period which means that hoof growth slows but hoof-wear increases. Therefore, it is paramount that an adequate thickness of the sole be present during hoof trimming of such cows to avoid excess thinning (Blowey, 2002). In addition, excessively thin soles can lead to bruising of the corium and subsequent formation of sole horn defects. Furthermore, great care needs to be taken to avoid removing excess wall; otherwise the sole will end-up bearing most of the weight rather than the claw wall which anatomically should be the main weight-bearing surface (Blowey, 2002).

Accelerated growth of the horn in the outer claws of the hind feet and subsequent overloading is thought to be due to irritation of the corium, which is caused by greater changes in weight distribution during locomotion for the outer claw compared with the inner claw in dairy cows (Toussaint-Raven *et al.*, 1985). The anatomical differences in the length of the medial and lateral hind claws may also contribute to the overloading of the outer claws (Paulus and Nuss, 2002).

The medial claws of the fore limbs and the lateral claws of the hind limbs bear most of the weight since they are usually more overgrown than the contra-lateral claws. Common faults in hoof trimming have been cited (Blowey, 2002). First is the excessive shortening of the toe, and if the sole is trimmed at the same time, it becomes too thin that the corium becomes compressed and subsequently bruised leading to severe lameness. This could also lead to excess weight-bearing on the white line. It is suggested that if the toe is trimmed too short, then the sole should not be trimmed. At the toe the corium is surrounded mainly by the horn and hence it will not become compressed. This could lead to excess weight-bearing on the white line and caudal rotation of the foot. Second is when the toe is left square-ended such that weight is taken on the sole and white line and not on the wall. Third is the removal of axial wall which destabilizes the claw and predisposes it to rotation. The axial wall is also an important weight-bearing surface (Blowey, 2002).

When deformities become excessively advanced, such that gross distortion of the foot occurs before being corrected, they will cause secondary stretching of the support ligaments and tendons. Claw trimming decreases horn-wear and increases horn-growth because artificially removing horn from the sole stimulates a natural compensatory reaction of increased horn production, thereby balancing wear (Manson and Leaver, 1989). The new horn may be of better quality than the one removed. Therefore, it is suggested that regular claw trimming to stimulate growth of healthy horn may help in the control of lameness (Vermunt, 1999). Moreover, it has been shown that trimming of claws significantly lowered lameness, haemorrhages of the sole or white line, sole ulcers, white line disease and double soles (Manske *et al.*, 2002a). On the other hand, inadequate or unskilled claw trimming are recognized risk factors of lameness (Vermunt, 2004). The conclusion reached is that "claw-trimming can be beneficial, but not always."

A Study done to compare sole thickness on the medial and lateral claws, showed that if the soles of the two claws were trimmed to equal size (Dutch claw trimming technique), the sole on the lateral claw was on average 1.6 mm thinner than on the medial claw and in some parts up to 4.1 mm thinner (Paulus and Nuss, 2002). It is therefore prudent to conclude that when trimming the claw, it would be necessary to leave the sole of the lateral claws larger than that of the medial claws.

In order to prevent evolving of claw disorders from subclinical to clinical stage, preventive trimming is applied as the most routine management practice. The goal is to promote natural loading by increasing the weight-bearing contact area of the claws and improving balance between the medial and lateral claws (Toussaint-Raven, 1985). It appeared that preventive trimming of the hind limbs brought the claws slightly more in balance (Van der Tol *et al.*, 2004). They found that before trimming, 80% of the total force is taken up by the lateral claws and 20% by the medial claws. However, after trimming, this becomes 70% for lateral and 30% for medial claws respectively. In this, a significant increase in the weight-bearing contact area from 27.5 to 40.0 cm^2 was achieved, resulting in a remarkable decrease in average pressure. Moreover, the main focus of claw trimming should not be force balance, but should be targeted at reducing local maximum pressures at the contact areas in such a way that the strongest parts of the claw capsule (mainly the wall) bear the highest pressures (Van der Tol *et al.*, (2004).

A study done in Norwegian dairy herds found that in tie-stalls with concrete base, herds trimmed occasionally had more haemorrhages of the white line than herds trimmed routinely. In addition, herds never trimmed had more heel horn erosions than herds trimmed routinely, and less haemorrhages of the white line and the sole than herds trimmed occasionally (Fjeldaas *et al.*, 2006). They also found that in free-stalls, herds with routinely trimmed had higher number of lesions than those not trimmed. Furthermore, results of hind claws on concrete base in free-stalls showed that herds never trimmed had less haemorrhages of the white line and the sole as compared with herds trimmed routinely. These herds that were never trimmed also manifested scanty haemorrhages of the white line and fewer white line fissures compared to the herds trimmed occasionally. The conclusion was that routine trimming performed in Norwegian free-stalls has not had the desired effects on claw lesions and abnormal claw shapes. However, routine claw trimming in tie-stalls seemed to have prevented claw disorders (Fjeldaas *et al.*, 2006).

Manson and Leaver (1989) found out that locomotion was positively correlated with the length of outer toe and negatively correlated with outer toe angle. These correlations suggested the need for shorter toe lengths and steeper angles for improved locomotion.

2.3.7 Genetics and conformation

Certain lameness conditions are genetically predisposed. Bazeley and Pinsent, (1984) found daughters of certain bulls to have higher incidence of sole ulcers and white line lesions. Friesian cows were reported to be more prone to laminitis than other breeds (Brochart, 1987). Andersson and Lundstrom (1981) reported that Swedish Friesians were more prone to sole ulcers and sole haemorrhages than Swedish Red and White cattle. The cow-hock conformation (hocks being adducted while the distal ends of the limbs stand base-wide) is considered as a predisposing factor to sole lesions. But it is not clear whether this is the cause or the result of claw lesions (Vermunt, 1999).

2.3.8 Age

It has been observed that first-calf heifers have a higher incidence of laminitis (Moser and Divers, 1987), as well as high frequency and severity of sole lesions (Greenough and Vermunt, 1991). Acute laminitis has been reported to be more common in heifers and chronic laminitis in older cows (Russell *et al.*, 1982; Bradley *et al.*, 1989). Andersson and Lundstrom (1981) reported that sole haemorrhages, ulceration and chronic laminitis are more common with increasing age. Rowlands *et al.* (1985) found that incidence of white line disease also increased with age.

2.3.9 Biomechanics of weight-bearing

Overloading of the claw is suggested to be the main cause of claw lesions, and on a flat ground, the lateral claws of the hind limbs bear more weight than medial claws (Ossent *et al.*, 1987). The total load and pressures exerted during locomotion are twice as great as those exerted while standing (Van der Tol *et al.*, 2003).

The painful claw is almost always held higher than the adjacent claw, particularly at the heel area, which means that it takes a greater percentage of the load. The extra height originates from hypertrophy and swelling of the horn of the sole. To some extent, hypertrophy manifests as an overproduction of the horn in which the sole horn and bulbar horn becomes thicker and the wall relatively higher (Toussaint-Raven, 1985).

Dairy cows shift weight from a limb in response to limb discomfort and redistribute it primarily to the contra-lateral limb. The variation in weight over time applied to a pair of contra-lateral limbs increases in response to discomfort in one hoof (Neveux *et al.*, 2006). Cows have only limited ability to shift weight from front to back limbs. In this regard, lameness may be detected through manifestation of how cattle distribute their weight among the four limbs. However, this requires an understanding of how cattle redistribute weight in response to pain in one or more limbs (Neveux *et al.*, 2006).

The type of floor determines how claws bear weight. On soft surfaces, more parts of the claw wall and heel sink into the ground and thus increasing the weight-bearing surface on the axial part of the sole (Sagues, 2002). Furthermore, weight is distributed uniformly on the main surface of the sole in order to reduce excessive distribution to the specific critical zones of the claw. Moreover, on hard surfaces, any change in gait and weight-bearing leads to an abnormal distribution of weight that disrupts normal function of the claw and causes discomfort, claw lesions and lameness (Sagues, 2002).

On a hard flooring surface, the lateral hind claw becomes overloaded. This excess loading causes the corium to be over-compressed by the distal phalanx against the horn capsule creating a blood pumping system since there is no room for outward expansion of the corium. In addition, the overloading of the lateral claw mobilizes more blood into its peripheral blood pumping system as compared to the medial claws (Sagues, 2002). Furthermore, the increase in blood flow to the corium of the lateral claw leads to a higher rate of horn production that aggravates weight imbalance and pressure of the distal phalanx on the corium. This causes irritation of this sensitive tissue, leading to hypertrophy and hyperplasia of the affected areas and consequently asymmetry of the claws becomes more apparent (Sagues, 2002).

2.3.10 Pathogenesis of laminitis

Laminitis is a systemic disease with a primary manifestation in the claw due to its unique morphology. Pododermal microvasculature plays a key role in the physiological function of the bovine claw and in the pathogenesis of claw diseases (Hirschberg and Plendl, 2005). Anatomical studies have shown that there are three critical structures in the claw, these are: the dermal vascular system, differentiating epidermal cells and connective tissue system in the suspensory and the supportive apparatus (Bergsten and Mülling, 2004).

2.3.10.1 Dermal vascular system of the claw

The dermal vascular system of the claw is unique in its three-dimensional arrangement, complexity and density, which is the reason for its high susceptibility to structural damage and disturbances of microcirculation (Hirschberg *et al.*, 2001). Structural peculiarities in the vascular system and arteriovenous anastomoses (AVAs) in particular have been described as having a central role in development of laminitis. It has been hypothesized that AVAs play an important role in the initial stages of bovine laminitis (Vermunt and Leach, 1992). However, more recent studies, have demonstrated that there are almost no AVAs in the vascular system of healthy claws (Hirschberg *et al.*, 2001). Although AVAs are needed in normal skin tissue for thermoregulation, they are not functionally required and do not even develop in the modified skin of the claw. Nevertheless, there is evidence that the increased number of AVAs detectable in diseased claws is an adaptive structural change (Bergsten and Mülling, 2004). In a study using grain overloaded steers with initial laminitis-like events, it was further demonstrated that there was an increase in capillary pressure and post-capillary resistance that facilitated transvascular fluid movement and increased tissue pressure. Digital venous constrictions are thought to be the initial step in these events (Christmann *et al.*, 2002).

2.3.10.2 The differentiating epidermal cells

Formation of claw horn (cornification of the epidermis) is the result of proliferation and cellular differentiation (keratinization and programmed cell death) (Mülling and Budras, 1998). This process is controlled by a variety of bioactive molecules such as growth factors and neuropeptides provided by the dermis and/or the vascular system. There is evidence that disruption of the differentiation of keratinocytes in the differentiating hoof epidermis is the major reactive event during the pathogenesis of laminitis that occurs secondary to dermal alterations and results in disruption of appropriate epidermal supply. Most of what is seen in laminitis on the claw is related to or a result of the reactive changes in the epidermis (Wattle. 2001).

2.3.10.3 Weakness of connective tissue in the suspensory apparatus

Hypotheses have been developed on aetiology of the postulated weakness of the connective tissue part of the suspensory apparatus. One hypothesis favours the central role of the enzyme matrix metalloproteinase-2 and its activation through a novel gelatinolytic protease "hoofase" (Tarlton and Webster, 2002). Increased connective tissue strength from dorsal to ventral hoof segments was correlated with protein, proteoglycan, pro-and activated matrix metalloproteinase-2, and tissue inhibitors of metalloproteinases. It was found to be inversely correlated with fat, water and collagen content. This implies that mechanical changes reflect alterations in the biochemistry of the connective tissue (Tarlton *et al.*, 2002). Furthermore, the primary causal events are associated with calving and weaken the connective tissue of hoof suspensory apparatus, leading to increased susceptibility to clinical lameness associated with sole ulcers and white line disease. The other hypothesis incriminates the effects of hormones particularly relaxin present in the periparturient period (Tarlton *et al.*, 2002).

2.3.10.4 The phases of pathogenesis of laminitis

The phases of development of laminitis are related to metabolic and subsequent mechanical degradation of the internal foot structure. The initial insult that triggers the process of laminitis is associated with metabolic alteration in systemic pH, which leads to impairment of microvasculature of the corium due to action of vasoactive substances (Nocek, 1997; Shearer and van Amstel, 2000; Lischer and Ossent, 2002). Factors that encourage ruminal acidosis particularly highly fermentable carbohydrates will subsequently lead to reduced systemic pH. Lowered systemic pH then activates a mechanism that causes release of vasoactive substances such as histamine, which is formed by decarboxylation of histidine in several lactobacilli species (Nocek, 1997). Different reports show that histamine increases capillary permeability and arteriolar dilatation (Brent, 1976; Merc Index, 1976)).

Rumen acidosis causes lyses of gram negative bacteria in the rumen with release of endotoxins. Endotoxins are extremely potent and when absorbed into circulation, they trigger a prostaglandin cascade (chain reaction). In addition, an imbalance of the prostaglandin thromboxane and prostacyclin is evident, and thrombi are prodded, which obstruct the small blood vessels (mainly capillaries) of the laminar corium (Bergsten and Mulling, 2004). Furthermore, blood circulation deteriorates locally and the end results can be compared to a “heart attack” of the feet. The decreased oxygen and nutrient supply damages the corium’s horn-producing cells.

A good description of vascular processes that take place leading to development of laminitis is documented (Nocek, 1997). He indicated that endotoxins in combination with histamine intermittently initiate vasodilation and vasoconstriction processes within the microvascular system of the corium. This leads to initial increase in blood flow and pooling within the corium capillary-bed causing a build-up in local blood pressure that ruptures the vessel and eventually ends-up with serum seepage and haemorrhaging. Nocek (1997) further stated that the fluid forced out of the microvessels into the interstitial tissue spaces within the corium causes pressure ischaemia. There is also development of several unphysiological arteriovenous shunts (AVs) that further aggravate the local blood pressure. Furthermore, the function of the musculature of the corium blood vessels is affected such that blood does not return into circulation normally, and the anatomical features of the corium vascular network also play a very important role in the development of various stages of laminitis (Mortensen, 1994).

In laminitis, vascular thrombosis develops in the microvasculature of the corium. The solear corium expands as a result of oedema and this causes pain on the affected claw. However, when vascular oedema occurs, ischaemia ensues and causes hypoemia (local anaemia) of the local internal digital tissue, followed by tissue hypoxia, and subsequently fewer nutrients and less oxygen reach the epidermal cells (Nocek, 1997). In addition, ischaemia can trigger further increase in arteriovenous shunts. The specific mode of action for these events can be associated with smooth muscle contraction as well as dilatation of capillary beds and contraction of arterioles (Nocek, 1997). Another mode of action is associated with increase in capillary pressure and post-capillary resistance which facilitates transvascular movement of fluid inevitably resulting in corium tissue oedema and an increasing tissue pressure (Christmann *et al.*, 2002). Digital venous constriction is thought to be a trigger of these events. During the forementioned processes, histamine and other vasoactive agents are also released. Production of histamine can be caused by a variety of factors including nutritional, environmental stress, concussion and trauma associated with concrete floors, overcrowding and infectious diseases causing tissue breakdown. These processes are particularly prevalent during the early days of lactation (Rowland *et al.*, 1985). Furthermore, events around parturition are associated with hormonal increases that have an effect in vascular dynamics (Altura and Altura, 1977). In this connection, oestrogen is one of the hormones incriminated and has peripheral vascular dilatation activity that enhances catecholamine-mediated vasoconstriction and an overall significant impact on haemodynamics.

Examination of pathologically altered claws revealed changes in the vasculature (number and direction of primary and secondary branches of the terminal arch, increased arterial anastomosing in the heel of the claw) and circulation of the diseased claws (Hirschberg and Mülling, 2002). These authors stated that the subcutaneous, subpapillary and sublamellary plexuses were poorly filled. This was true especially in claws with heel horn erosion, double sole and solear haemorrhages.

There is evidence of mechanical damage associated with corium microvasculature and fewer nutrients reaching the epidermal cells. The stratum germinativum in the epidermis breaks down. The corium becomes degenerated and eventually there is breakdown of the dermal-epidermal junction, which results in separation of the strata germinativum and corium (Nocek, 1997; Belge and Bakir, 2005). This separation results in the breakdown between dorsal and lateral laminar supporting of the hoof tissue. The laminar layer separates and the pedal bone takes a different configuration in relation to the dorsal claw wall and the corium. It drops and compresses the corium against the horn of the sole resulting in further thrombosis, haemorrhage, oedema and ischaemia. Eventually, necrotic areas appear within the solear region of the foot and scar tissue forms in these sites, and this scar tissue might be the trigger lesion for the formation of double soles (Nocek, 1997).

All the processes affecting or damaging the corium lead to production of poor quality horn with compromised integrity (Nocek, 1997). Other external lesions seen in corium microvascular damage are red bloody patches of the sole, sole and heel bruises. Moreover, owing to its anatomical location between the hoof capsule and third phalanx, the corium is particularly vulnerable to inflammatory insults. In addition, any increase in size of the corium due to fluid accumulation (blood, lymph or oedema) will inevitably increase tissue pressure and subsequently cause tissue damage (Shearer and van Amstel, 2000).

Furthermore, there is histological evidence of destruction of dermal-epidermal junction with consequences of laminar separation. As the laminae separate, the distal phalanx begins to "sink" within the horny capsule, resulting in compression of the corium between the phalanx and the horn of the sole, which then sets the stage for development of sole ulcers (Shearer and van Amstel, 2000). These authors reported that in some cases, the "distal phalanx-sinking phenomenon" involves severe rotation of the toe of bone downwards towards the sole such that if compression of the corium by the toe is severe enough, a toe ulcer develops. If on the other hand the sinking of thel bone is such that the rear portion sinks furthest, then a sole ulcer is likely to develop in the area of the heel-sole junction (known as the "typical ulcer site" or the site that is commonly associated with sole ulcers. All these processes in the corium can result in acute, subclinical or chronic laminitis (Shearer and van Amstel, 2000). Sole necrosis could result and the site of necrosis depends on the angle of pressure from the "sinking" pedal bone (Nocek, 1997).

2.4 Acute laminitis

This type of laminitis is triggered by a high level of ruminal acidosis. In acute laminitis, the cow is systemically ill and is prone to recurrences if the metabolic insult persists (Nocek, 1997). Vascular congestion is present due to vessel seepage, oedema of the capillary bed and arteriovenous shunts. This then results in major clinical signs of acute laminitis and intense pain, swelling and warmer than normal coronary band area when one touches the soft tissues (Nocek, 1997).

2.5 Subclinical laminitis

Subclinical laminitis can be a prolonged, slow, insidious process depending upon persistence of low-grade insults (Nocek, 1997). It has been reported to be the most important factor predisposing young dairy cows to future lameness in subsequent lactations (Smilie *et al.*, 1999). Changes in animal posture or gait are not usually discernible, thus making its recognition and diagnosis difficult. Sometimes the soles of affected claws are softer and warmer but normally subclinical laminitis lesions are only clearly discernible at hoof trimming (Nocek, 1997; Belge and Bakir, 2005).

Softening of the horn, yellow waxy discolouration of the sole, haemorrhagic stains of the solear area (particularly the white line zones, apex of the sole and the sole-heel junction), white line separation and erosion of the heel are the clinical signs seen during trimming (Nocek, 1997; Smilie *et al.*, 1999; Belge and Bakir, 2005).

Frequent dorsal wall ridges, and a slight shifting of the pedal bone configuration are characteristic internal manifestations. Other internal characteristics are ischaemia, hypoxia and epidermal damage which are main aspects associated with this stage of laminitis. Arteriovenous shunting also becomes increasingly a progressive occurrence (Nocek, 1997).

Subclinical laminitis is considered a major predisposing factor in development of sole ulcers, white line separation, heel erosion, and double soles (Nocek, 1997; Smilie *et al.*, 1999; Belge and Bakir, 2005). Development of heel cracks and double soles may be triggered by walling-off the haemorrhagic areas during subclinical laminitis. These walled-off areas then become good environment for growth of anaerobic bacteria which produce gases and exudates. Subsequently, the gases and exudates are forced by pressure to points of least resistance, which often are at the junction of the sole and heel bulb. Eventually, these areas of least resistance give way to separation of the horn and double soles ensue (Nocek, 1997).

2.5.1 Sole haemorrhaging in subclinical laminitis

Initially claw horn lesions develop as haemorrhages of the sole and white line. They may progress to solear ulceration and white line separation (Vermunt and Greenough, 1996). Sole haemorrhaging is very common and is normally related to the incidence of subclinical laminitis. Smilie *et al.* (1999) found sole haemorrhages (scores 1-4) in 62.1% of the cattle examined, and it was widespread in all the herds that were examined. Enevoldsen and Gröhn (1991) found that 29.7% of first lactating cows and 24.7% of cows in second and third lactations had sole haemorrhages in more than one foot. Other researchers found more than 25% incidence of sole haemorrhaging (Mgassa *et al.*, 1984). Smilie *et al.* (1999) found 0.3% of the cows with exposed corium or ulceration (score 4).

Belge and Bakir (2005) while conducting a survey in Turkey found 61.4% of the cows examined to have sole haemorrhages.

Laminitis process is associated with haemorrhaging and oozing of the serum from capillary beds within the corium of the claw. The oozed blood and serum seep gradually to discolour the internal layers of the horn of the sole. The horn of the sole grows outwardly at a given rate per month. As the inner layers of the horn tissue of the sole grow to the surface, the haemorrhagic and serum discolourations become externally visible as a clinical sign that internal haemorrhage has occurred (Nocek, 1997). The interval between occurrence of sole haemorrhages and their external appearance on the surface of the sole depends on the growth rate of the horn. Growth rate of the horn is approximately 5-6 mm/month (Greenough and Vermunt, 1991). Sole thickness ranges from 10-12 mm and therefore depending on trimming objectives, the time expected for haemorrhage to externalize is about 2 months (Nocek, 1997). The severity of haemorrhages is related to the intensity and duration of the insult that caused the vascular disruption. Nocek (1997) further suggested that the haemorrhagic site on the claw could indicate whether the haemorrhages are laminitic, traumatic or mechanical in nature. He suggested that diffusely occurring haemorrhages on the sole are likely to be caused by laminitic process. On the other hand, localized haemorrhages are likely to originate from traumatic or mechanical causes

Bergsten (1994) observed that primiparous heifers were more prone to sole haemorrhages than were multiparous cows. He further stated that higher haemorrhage scores were found in cows on hard concrete floor with little or no use of beddings. Sole haemorrhages were more prevalent on the lateral than medial claws of the hind limbs and on medial than lateral claws of fore limbs. He also indicated that sole haemorrhaging was associated with feeding practices particularly involving concentrates. The conclusion was that sole haemorrhages can be used to gain information relating to the aetiolgy of subclincal and clinical laminitis. The incidence and severity of sole haemorrhages tend to be high in the periparturient period but decreases dramatically 3 months postpartum (Bergsten, 1994).

2.6 Chronic laminitis

In chronic laminitis, the growth of keratinized horn is disrupted and the shape of the digit is altered, becoming more elongated, flattened and widened (Nocek, 1997). The dorsal (toe) angle is reduced from about 55° to between 35° and 45°, and the dorsal wall may become concave, while the coronary band looks flakey and the periople loses its shiny appearance (Weaver, 1993). Horizontal ridges on the dorsal wall become more prominent giving a rippled appearance (Weaver, 1993; Nocek, 1997). Internally, there may be separation of the pedal bone from dorsal aspect of the wall; double soles with yellow discolouration may be present, destruction of capillary beds, development of arteriovenous shunts, separation of dermal-epidermal junction and arteriosclerosis. In addition to this, ulceration can be demonstrated at the solear region, while in severe situations the distal portion of the pedal bone can protrude through the corium and horn of the sole. Severity of chronic laminitis depends on the intensity and damage caused by each preceding acute episode as a result of the initial metabolic insult (Nocek, 1997).

2.7 Gross pathological features of laminitis

Pathological picture of acute laminitis has been described and it includes congestion at the toe extending up to the anterior wall, the coronet and over part of the solear laminae. Furthermore, on vertical transverse section, the congestion surrounds the os pedis to about one inch behind the point of the toe; but on sagittal section, there is an increase in the amount of fat in the os pedis, and purpler colour than normal, with prominent vessels. In addition, a slight deviation of the bone from its normal position in relation to the hoof was seen in a case of 5 days duration (Nilsson, 1963; Maclean, 1965).

In subacute laminitis, Maclean (1966) found on sagittal section, varying degrees of distal phalanx rotation in all cases and in all claws. He noted that the space left by the deviating os pedis formed a long triangle with the point of the toe and the base of the anterior wall of the os pedis. This space was filled with large quantities of new soft waxy horn. Furthermore, the os pedis was severely atrophied especially in the lateral claws and had a pink discolouration, which was most obvious at the posterior edge (Maclean, 1966).

Greenough (1987) stated that in both subacute and subclinical laminitis, the hoof texture became softer than normal, the white horn took distinct yellow tinge and haemorrhages appeared in the sole and wall. He noted that haemorrhage of the wall, sole or heel was an important sign of subclinical laminitis and was attributed to bleeding from the capillary pegs of the corium into the tubules of the horn. He further described that haemorrhage was seen as a thin layer of discrete or diffuse reddening in the keratinized portion of the hoof. In addition, these haemorrhages of the sole might be encountered when the horn is pared and frequently resembles a brush stroke. He noted that a range of changes could be observed in the white line, from haemorrhage or exudation of yellow serum to a major avulsion of the sole from the wall, sometimes with secondary infection.

Description by Nilsson (1963) and Maclean (1966) is that in chronic laminitis, the claws are much taller and more boxy than normal. The abaxial wall is convex from side to side, and in the lateral claw there may be a shallow depression. The anterior part of the wall is concave from above to below, longer than normal and the wall-sole angle is usually around 60°. The transverse lines are well marked, which proximally run parallel to the coronet, but distally they diverge and run more vertically. The heel bulbs are very long, usually the same length as the anterior wall, which gives long upright appearance to the foot.

Nilsson (1963 and Maclean (1966) further found that on sagittal section, the distal phalanx is likely to be severely deviated. and atrophied in all cases. The bone might attain the shape of an equilateral triangle. In addition, the fat content of the os pedis appears to be increased, and the space between the anterior wall of the bone and the anterior horny wall is filled with a large amount of new horn. This horn is pale, slightly yellow and soft. while below it (between this horn and the sole), there is likelihood of a deep curved haemorrhagic line marking the junction of this horn and the solear horn. They additionally stated that the sole is thick and crescent-shaped and containing areas of dark brown discoloration, which represent old haemorrhages in the laminae. while the horn of the sole splits and fissures longitudinally.

Greenough *et al.* (1981) also indicated that in chronic laminitis, the dorsal claw-wall border forms a small angle with the ground with a possible drop of the pastern and fetlock joints closer to the ground. The position of the pedal bone is also altered relative to the wall and sole, with the dorsal surface pointing downward so that the dorsal wall forms a more acute angle with the ground.

Further to this, Greenough (1987) also reported that chronic laminitis in cattle is often mistakenly regarded as mere hoof deformity, and the clinical condition at this stage is referred to as "slipper foot" because the deformed hoof is shaped like the Persian slipper. Greenough (1987) also listed several characteristic changes in the hoof as a result of chronic laminitis. These are: hard, rough appearance of the coronary band and a marked irregular ridging of the hoof, flattening and widening of the hoof, development of a concave dorsal hoof border, dulling of the normally shiny periople and extreme softening of the sole which often contains channels of necrotic material

2.8 Histopathological changes in laminitis

Vascular changes are part of the key histopathological features in laminitis. In this regard, proliferations of tunica intima, hypertrophy of tunica media and fibrosis of tunica adventitia of arteries and arterioles have been reported (Andersson and Berman, 1980). Typical changes suggestive of chronic laminitis include hyperplasia of the epidermis of the laminae, thrombus formation, arteriosclerosis in the solear and coronary corium as well as the laminar corium (Singh *et al.*, 1992)

In a study involving endotoxin-induced hoof lesions in cattle, it was reported that endotoxins can induce diffuse aseptic pododermatitis (laminitis) which is characterized histopathologically by initial degenerative changes in the papillae and laminae followed by proliferative changes in the laminae and arteriosclerosis in all parts of the corium (Singh *et al.*, 1994).

Chronic degenerative changes have been found in the pododerm of cattle with chronic laminitis. These changes were reported to be associated also with age rather than chronic laminitis alone (Boosman *et al.*, 1989a). Furthermore, Boosman *et al.* (1989a) found that arteriovenous shunts increased significantly with age. In another study, they histologically examined radiographically abnormal arteries in chronic laminitis and found features indicative of arteriosclerosis. From the results, they concluded that chronic laminitis develops subsequent to a subclinical laminitis attack as long as hypoperfusion of the digit persists.

Vacuolization of the stratum basale, lymphocyte and leucocyte infiltration as well as thrombosis have been reported in endotoxic-induced acute laminitis in cattle (Boosman *et al.*, 1991). Vermunt and Leach (1992) observed numerous arteriovenous anastomoses throughout the entire dermis of the claw that were situated predominantly at the base of the dermal papillae and lamellae. They suggested that the anastomoses and focal capillary enlargements may influence the blood flow in normal claws and could play a significant role in the pathophysiology of bovine laminitis and sole ulceration.

Continuous hypoperfusion of the digits is incriminated as an important factor that influences development of chronic laminitis. This hypoperfusion is associated with altered haemodynamics in the underlying claw even in the absence of specific pathological events (Boosman *et al.*, 1989a). Furthermore, the pododermal haemodynamic changes are influenced by age, hypertension, mechanical stress and hypoxia. These factors also precipitate arteriographic changes and they are more pronounced in chronic laminitis. Consequently, there follows loss of vascular integrity, sole haemorrhaging, poor quality horn tissue, and dorsal wall concavity (Boosman *et al.*, 1989a). Mural thrombosis that causes arteriosclerosis and dilatations of capillaries and venules is also reported in laminitis (Maclean, 1971; Boosman *et al.*, 1989a).

2.9 Radiographic changes in laminitis

A downward rotation of the pedal bone is reported in chronic laminitis (Bargai *et al.*, 1989; Greenough *et al.*, 1990). Well delineated vascular channels have been observed within the pedal bone in laminitis and the bone bounding them was found to be sclerotic (Maclean, 1970). Maclean (1970) further reported occurrence of exostosis in the pyramidal process of the pedal bone and at the heel, but the overall radiodensity of the pedal bone is reduced especially at the toe. Other radiographic changes seen in chronic laminitis are atrophy and deformation of the pedal bone coupled with absence of the bone apex (Greenough *et al.*, 1990). In contrast, deviation of the pedal bone is a consistent finding in equine chronic laminitis, but in cattle, it is less pronounced and inconsistent in chronic laminitis (Weaver, 1988).

The most prominent arteriographic abnormalities of the claw artery in chronic laminitis include dilatation, tortous and irregular course, and constriction at the exit of the pedal bone. The primary branches of the claw artery are frequently constricted or dilated and the constrictions are predominantly seen in the toe area (Boosman *et al.*, 1989b). Furthermore, arteriographic lesions are severer in the lateral than in the medial claws. Other changes include relatively poor vascularization in the "typical ulcer site", widening of the medial branches of the claw artery, and widening of the well-delineated vascular channels of the claw artery as well as primary branches in the pedal bone (Boosman *et al.*, 1989b).

2.10 Management of laminitis

In acute laminitis, the primary aim of treatment is to promote improved circulation within the claw. Hosing the feet with cold water and forcing the animal to make movements may improve this circulation (Weaver, 1993). Hosing also helps to reduce tissue oedema (Baggott and Russell, 1981). The beneficial effects of medical treatment of laminitis are not elucidated. However, it has been observed that antihistamines have better results in acute than subacute or chronic laminitis (Nilsson, 1963). Corticosteroids administered intravenously or intramuscularly, and anti-prostaglandins have been recommended for early cases of acute laminitis (Weaver, 1993). In contrast, Nilsson (1963) found corticosteroids to give unsatisfactory results compared to other forms of treatments, but Maclean (1966) reported that corticosteroids yielded satisfactory results in cases which failed to respond to other forms of treatments. On the other hand, corticosteroids may not help alleviate the problem, but may prevent progression to the chronic form (Baggott and Russell, 1981). In addition, flunixin meglumine (a non-steroidal anti-inflammatory drug) given intravenously, phenylbutazone given orally every second day, and aspirins (acetyl salicylic acid) also given orally, have been tried but their benefits are not elucidated (Weaver, 1993). In addition, anti-prostaglandins have mainly been used for endotoxic pododermatitis (Weaver, 1993). Another form of remedy particularly for acute laminitis includes phlebotomy, which involves withdrawing a considerably large volume of blood from the jugular vein. It has been tried with some success although the mechanism of action is not known (Baggott and Russell, 1981).

Edwards (1982) and Greenough (1987) recommended that treatment of laminitis should be instituted as early as possible using the following protocol:

1. The underlying causative or predisposing factors be dealt with. For example the amount and type of feed which should be withdrawn or reduced; acute infections such as metritis or mastitis which should effectively be treated.
2. Early administration of parenteral antihistamines.
3. Normal circulation in the foot is restored by bathing the foot in warm water.
4. Inclusion of methionine in the diet for a week provides a disulphide-bond substrate for maintenance and repair of hoof-pedal bone bond.

Anatomical changes caused by chronic laminitis cannot be reversed. Nevertheless, paring the affected claws to a more normal shape could alleviate some of the effects of the condition. However, care must be taken to avoid trimming the sole excessively since it is already thinned during this condition (Baggott and Russell, 1981). Only repeated and careful trimming can assist to alleviate chronic laminitis. But in doing it, attempts must be made to restore normal weight-bearing to the walls of the claws and take it off the heels by removing excessive growth at the toe and on the surface of the sole in order to increase the dorsal angle (Weaver, 1993).

2.11 The outcome of laminitis

Some of the animals with subclinical laminitis might recover completely, others are cured partially, and still others do not improve at all. In those that partially heal, or fail to heal at all, the disease becomes chronic particularly in those affected during the periparturient period (Nilsson, 1963). Weaver (1993) stated that with or without treatment, many cases fail to recover and are culled owing to poor production or to development of secondary complications. In addition, some of the laminitic lesions may get infected with *Bacteroides necrophorum* or *Actinomyces pyogenes* (Weaver, 1993).

In chronic laminitis, poor quality horn is produced and this may lead to other foot lesions such as heel erosion, underrun heel, underrun (double) soles, white line disease, sole ulcer, sole bruising and sole foreign body penetrations (Weaver, 1979; Baggott and Russell, 1981).

2.12 Prevention of laminitis

Prevention of laminitis depends on good husbandry (Ebeid, 1993; Weaver, 1993). New feeds especially concentrates should be introduced gradually and the forage level made high in risk-exposed herds (Weaver, 1993) Particular attention should be paid to heifers to give them adequate room for exercise, the claws trimmed twice per year and great attention paid to all cows with dorsal (toe) angle less than 45° (Weaver, 1993).

Weaver (1979) recommended the following events as preventive against development of laminitis:

1. Down-calving heifers should enter concrete floored yards several weeks beforehand to become accustomed to the surface.
2. There should be plenty of exercise for the stock in the prepartum and immediate postpartum months.
3. There should be a relative reduction in the rate of concentrate feeding after calving so that peak yield is reached at about 6 weeks and not 3-4 weeks. Feeding of concentrates in several small quantity rations per day (more than 2 times daily) to freshly calved cows rather than fewer larger quantity rations, will minimize the risk of rumen acidosis.
4. There should be free access to salt-lick to ensure an increase in saliva flow and improve the pH buffering capacity of the rumen.
5. Approximately 1% sodium bicarbonate added in the on-farm-mixed rations will improve rumen pH.

2.13 Prognosis of laminitis

The prognosis of acute and subclinical laminitis is guarded because it usually progresses to the chronic form. Chronic laminitis produces irreversible changes and is a major predisposing cause to many foot conditions and this makes its prognosis poor (Baggott and Russell, 1981).

2.14 Laminitis associated lesions

Manske *et al.* (2002b) in a study of Swedish dairy cows, found the prevalence of lameness to be 5.1% but most of the hoof lesions encountered did not cause lameness

The lesions encountered were heel horn-erosion (41%), sole haemorrhages (30%), abnormal claw shape (21%), white line haemorrhages (14%), white line fissures (8.8%), sole ulcers (8.6%), and double soles (3.3%). Among all the cows examined, 72% had at least one hoof lesion. Sole haemorrhages were found in all the herds examined. Herds with high prevalence of sole ulcers also had high prevalence rates of sole haemorrhages and abnormal claw shapes. These researchers suggested the importance of maintaining correct claw shape for prevention of claw horn lesions.

2.15 White line disease

White line disease is characterized by separation (widening) of the white line zone and its penetration by infected debris that often leads to abscessation (Baggott and Russell, 1981). The abaxial white line particularly in the lateral claws of the hind limbs is the most commonly affected, and the point of first impact is just distal to the bulb of the heel. The common predisposing causes of white line disease are unhygienic environment that softens the horn, claw malformations such as overgrowth and poor horn quality resulting from chronic laminitis and this reduces strength of the white line. It is most common in cows older than 3 years (Baggott and Russell, 1981). In a survey done in Uganda, the prevalence rate of white line separation in Kampala was found to be 5% (Okwee-Acai *et al.*, 2004).

2.16 Sole ulcer

Sole ulcer (pododermatitis circumscripta or Rusterholz ulcer) is a circumscribed lesion affecting the sole or sole-heel junction close to the axial margin of the hind outer claw (Baggott and Russell, 1981). It occurs invariably at the same site on the sole referred to as the "typical ulcer site". It starts as a bruise, develops into devitalized area, and later produces protruding granulation tissue and even osteoarthritis (Hull, 1993). Sole ulcer is characterized by presence of a mass of granulation tissue protruding through the sole and is more discernible after the horn of the sole is trimmed (Baggott and Russell, 1981; Hull, 1993). This granulation is the resulting piston-like effect of pedal bone forcing the sensitive laminae out through the defect in the sole. Sole ulcers are most common in the lateral claws of the hind feet in mature cows (Hull, 1993).

Though aetiology is not well understood, one of the main hypotheses advanced incriminate damage of the corium and softness of the horn that occurs in laminitis (Hull, 1993; Baggott and Russell, 1981). They are more common in animals confined on concrete floors and the incidence seems to be higher when such floors are wet (Hull, 1993). Chronic laminitis seems to be the chief predisposing factor by causing production of poor quality horn, increasing tendency of walking on the heel, and damaging the corium and the sole by impinging tuberosity of the pedal bone at the insertion of digital flexor tendon (Baggott and Russell, 1981; Hull, 1993).

Elevated levels of matrix metalloproteinase-2 (MMP-2) were reported to be present in the tissues of soles of claws that had an ulcer when compared with healthy sole tissues from the same animals as well as sole tissues of claws recovering from ulceration (Hendry *et al.*, 2003). In addition, there is evidence of basement membrane disruption at the ulcer sites and an increased potential for disruption in the diseased claw, and these changes are associated with abnormal epidermal keratinization. Furthermore, basement membrane disruption is in-turn associated with reciprocal changes in matrix metalloproteinases (MMPs) and their inhibitors, favouring extracellular proteolysis. As to whether MMPs activation is the primary cause of dermal-epidermal deterioration and how its activation is triggered, remains undetermined (Hendry *et al.*, 2003).

Sole ulcer causes severe lameness due to exposed corium tissue and the cow assumes adduction (cow-hocked, base-wide) posture especially when the ulcers are bilateral (Baggott and Russell, 1981). In such cases, the affected cows stand base-wide to relieve pressure from the ulcerated lateral digits (Hull, 1993). Untreated sole ulcers lead to weakness and necrosis of the deep flexor tendon near its attachment to the pedal bone. When this happens, the tendon eventually ruptures and the toe is tilted or tipped upwards due to lack of flexion of the pedal bone (Hull, 1993). Prevalence of sole ulcers in Kampala, Uganda was 14.4% in cows fed on excess grains and 2% in cows that were not fed on grains (Okwee-Acai and Acon, 2005). However, in Netherlands the prevalence rate of sole ulcers was found to be 10.4% in the second month of lactation (Smits, 1992).

The first steps in treating sole ulcer are to trim the undermined horn of the sole to expose the protruding granulation tissue which must be cut off (Hull, 1993). All necrotic tissues present must be debrided and this process requires regional nerve block or intravenous regional analgesia (Baggott and Russell, 1981). Fixing of a thin wooden-block (shoe) on the sound claw in order to raise the ulcerated claw off the ground is a necessity for the ulcer to heal in 3-6 weeks, but bandaging is not recommended (Hull, 1993).

2.17 Heel erosion

Heel erosion starts with pitting of the horn of the heel, followed by small craters joining together to form areas of black, rotten horn. Erosion of the heel horn continues until stability of the claw is compromised and the heel becomes sore (Greenough, 2005). The cause of this condition is not well known but is most prevalent in wet, cold and filthy under-foot conditions. Subclinical laminitis may enhance the occurrence of this condition. The areas of black horn have undergone bacterial erosion and necrosis (Nocek, 1997).

The condition is treated by trimming-off the black necrotic horn and subsequent spraying or dipping of the claw in an antimicrobial chemical solution. Footbath with 5% formalin or 5-7% copper sulphate is preventive. Okwee-Acai and Acon (2005) found a prevalence rate of 79% in grain-fed cows and 83% in non-grain fed cows in Kampala, Uganda. But Gitau *et al.* (1994) reported an incidence rate of 4.4% in dairy cows in Kikuyu division, Kiambu district, Kenya. while Blowey *et al.* (2004) found incidence rate of heel erosion in U.K. to be 0.27%.

2.18 Sole bruising (erosion)

A bruised sole has patches of dark-blue discolourations visible beneath the horn of the sole, which can be confused with haemorrhagic discolourations of laminitis. A bruised sole is thin following excessive wearing of the horn and is vulnerable to mechanical damage (Greenough, 2005). Furthermore, it can physically succumb to pressure depression, to which the animal manifests painful responses as the pressure is transmitted to the underlying corium. In addition, excessive claw trimming will also cause sole erosion and the stony terrains will increase risk of developing the condition. However, careful paring to transfer weight-bearing to the claw walls as well as housing the cows in well strawed stalls may assist alleviate the problem (Greenough, 2005). Removal of causative factor should be endeavoured. This condition was not been reported in the previous study in Kenya (Gitau, 1994).

2.19 Double (underrun) soles

A double sole phenomenon implies presence of a superficial outer horn of the sole and a deeper underlying horn of sole on the same claw. Occasionally multiple (more than two) soles are encountered. The space between the soles is filled with blackish fluid and/or other debris. Double sole can be predisposed by sudden change in nutrition and therefore it has a "laminitic-like" component. Traumatic components such as sudden introduction of cows to concrete floors can also precipitate the condition (Greenough, 2005). When not trimmed off, it takes about three months for a double sole to wear away naturally. However, during trimming to remove the superficial layer of the sole, care must be taken to ensure that weight-bearing is shifted to the walls to avoid injury of the thin soft horn of the underlying sole which easily succumbs even to thumb-pressure. This horn will harden in one or two days after removal of the superficial sole, depending on the temperature and humidity of the environment. After trimming, the cow should be housed in well bedded stalls or well strawed yards. Double soles can be either unilateral or bilateral (Greenough, 2005).

Gitau (1994) reported an incidence rate of 1.2% for underrun soles in dairy cows in Kikuyu division, Kiambu district, Kenya; and Okwee-Acai and Acon (2005) reported prevalence rates of 29.6% for double soles and 28.5% for underrun sole as two separate conditions. The distinction of the two conditions named as double soles and underrun sole in the latter report is not clear. However, the reported cavities in the soles with prevalence rate of 4.9% at second month of lactation could imply double soles (Smits *et al.*, 1992). Blowey *et al.* (2004) reported a 2.14% incidence of double soles.

2.20 Sole foreign bodies

A foreign body could mean any object such as a stone, piece of glass, thorn, or nail which penetrates mainly into the sole or white line of the claw. It penetrates accidentally when the cow treads on injurious objects and is predisposed by softening of the sole which is caused by slurry in the animal environment or laminitis (Greenough, 2005).

A foreign body can cause pressure in the sensitive tissue inside the claw, penetrate the sole, or inject infection into the sensitive tissues inside the claw. When it penetrates the front part of the sole, it causes a sudden development of acute lameness. It gradually and progressively causes sole abscess which must be drained of pus for it to heal. In comparison, a foreign body that penetrates the heel region causes slow development of relatively less severe lameness. This eventually causes heel abscess that ultimately ruptures at the coronary band area culminating into "underrun heel". The treatment of sole foreign body is physical removal and subsequent management of underlying complications (Greenough, 2005). Control is by removal of foreign bodies from the cows' environment.

Okwee-Acai and Acon (2005) reported a 2.4% prevalence rate of foreign bodies in Kampala, Uganda, but Gitau (1994) in the Kenyan study in Kikuyu division, Kiambu, did not report any sole foreign body occurrence. Blowey *et al.* (2004) reported incidence of 3.1% for foreign bodies in dairy cattle in the U.K.

2.21 Horizontal ridges of the dorsal wall

Horizontal ridges (grooves or growth rings) are common on the dorsal walls of claws, but vary in appearance and depth. The more the number of claws seen with prominent and deep grooves in a herd, the greater is the nutritional problem being experienced in that herd. A groove grows away from the coronary band at the rate of 4 mm per month in a herd that is experiencing the problem. This makes it possible to calculate the time a predisposing insult or nutritional change occurred. Ridges are considered as areas of weakness around which claws bend or from which cracks of the walls of claws start. Sometimes they are so deep that they penetrate through claw walls, and are referred to as 'fissures" (Greenough, 2005). While a few grooves can be tolerated, the widespread appearance of this "acquired abnormality" should be considered as an indicator of a problem in the herd that requires investigation. Okwee-Acai and Acon (2005) reported prevalence rate of 61.6% for horizontal ridges in grain fed cattle and 31.5% in non-grain fed cattle in Kampala, Uganda.

2.22 Claw deformities

There are a number of conditions of the foot in which the claw grows abnormally and either directlty causes lameness or predisposes to other foot lesions (Rhebun and Pearson, 1982). These lesions could eventually lead to necropurulent pododermatitis or be part of the laminitis syndrome that causes abnormal horn production (Toussaing Raven, 1985). There is hoof overgrowth and increased length of the wall or sole that misshapes the claw. This occurs when cattle are raised on soft surfaces where little hoof wear occurs

(Rhebun and Pearson, 1982). Toussaint-Raven (1989) suggested that heel horn erosion causes local irritation to the corium which contributes to excess production of the horn. However, Bradley *et al.* (1989) reported that heel horn erosion was not present in all cattle with overgrown soles.

A study carried out on hind limb claws collected from abattoirs with overgrown soles of outer claws classified them into two categories (Singh *et al.*, 1993a). These categories were: 1. Those with thick, broad and flat soles, with a steep dorsal wall. They had haemorrhages at the weight-bearing surfaces and some had discolourations. Sagittal sections of these claws showed that the corium was straight.

2. Those with thick, broad and flat soles and had a sloping dorsal wall. A close examination of their dorsal walls revealed appearance of a notch on them and an altered direction of growth. Some of the soles manifested yellowish discolourations of haemorrhages at the weight-bearing surfaces particularly the sole-heel junction. Still in a few others, a clear ring of discoloured horn was present below the plantar process. Sagittal sections of some of these hooves revealed that the corium was compressed at the plantar process of the pedal bone.

Heel horn erosion was an inconsistent finding in both categories, but when present, the sole was much thicker. Histopathological examination of overgrown claws did not show any evidence of laminar involvement. The only histological change seen was thickening of blood vessels in the solear corium, but with very little evidence of inflammatory cells and no thrombi (Singh, 1993a).

In two studies carried out, Okwee-Acai and Acon (2005) reported a prevalence rate of 15.2% for overgrown claws in Uganda, while Blowey *et al.* (2004) reported an incidence rate of 2.95% for overgrown claws in the United Kingdom. Some of the claw deformities may be predisposed by congenital factors that lead to abnormal limb conformation. "Beak claw" is a claw deformity in which the dorsal surface of the claw is concave, the weight-bearing surface is convex, and the toes are turned upwards (Rhebun and Pearson, 1982). Corkscrew claw is characterized by medial spiraling of the abaxial claw wall towards the axial plane of the normal claw. The condition is normally bilateral affecting the lateral claws of the hind feet and it is mainly seen after the third year of life. It is believed to be an inherited condition (McCormack, 1978; Rhebun and Pearson, 1982). Another claw deformity is "Scissor feet" which manifests as an overlapping of the toes and is also reported to be an inherited condition (Rhebun and Pearson, 1982).

The treatment of inherited claw deformities consists of trimming. However, this is reported to be only palliative because the underlying cause cannot be removed and furthermore, it is difficult to reshape the affected claws. It is therefore recommended that cattle with inherited claw deformities should not be bred but culled (Rhebun and Pearson, 1982). The acquired (non-inherited) deformities are exacerbated by confinement and heavy feeding of concentrates (McCormack, 1978).

It has been reported that in lameness, almost a painful claw is higher (more overgrown) than the neighbouring claw. The highest part in such claws is normally the heel. For such cases, the affected claw bears a greater percentage of the weight and the locomotion load (Toussaint-Raven, 1985). In addition, the extra height is caused by hypertrophy and swelling. In addition, hypertrophy manifests as an overproduction of the horn underneath the claw in which the horn of the sole and the bulbar horn become higher than the wall of the claw (Toussaint-Raven, 1985). Overgrowth of the horn of the sole of hind lateral claws transfers excessive weight to the corium of the same claws and causes secondary lesions such as haemorrhages, white line separation and sole ulceration (Toussaint Raven, 1973). In addition to local corium injury, biomechanical factors may play a significant role in the development of other sole lesions following overgrown sole.

2. 23 Foot conditions not directly associated with laminitis

There are other common foot conditions that are not directly associated with laminitis. Most of these conditions are infections of the digital region that commonly cause lameness in cattle (Farrow, 1985). Cattle affected by these conditions are normally from 1 to 10 years of age. Physical inspection of the infected part usually reveals one or more of the following abnormalities: varying degrees of altered weight-bearing, localized swelling, heat and hair loss proximal to the coronet, as well as granulation tissue and drainage in the proximal part of the interdigital space. Furthermore, granulation tissue may also protrude from vertically oriented cracks in the hoof wall. The hooves may be overgrown and spread out laterally if there is a large swelling in the interdigital space (Farrow, 1985).

Some of the commonest foot conditions well documented are: sole abscess, vertical and horizontal hoof wall cracks (Hull. 1993); interdigital and digital dermatitis, interdigital phlegmon (interdigital necrobacillosis) (Weaver, 1993); and interdigital fibroma (Welker, 1993). A cow with a sole abscess is reluctant to bear weight on the affected claw or foot and is noticeably lame, but those with interdigital necrobacillosis manifest acute lameness in one or more limbs. However, if interdigital necrobacillosis is untreated, several unfavourable sequalae might occur. The commonest of these being, infection extending into pedal or pastern joints causing suppurative arthritis. Others include abscessation of the interdigital space and osteomyelitis of the digital bones (Rhebun and Pearson, 1982).

Interdigital fibromas are fleshy smooth-surfaced protuberances in the interdigital space (Rhebun and Pearson, 1982). They progressively enlarge and become increasingly painful. They are common in heavy beef bulls and in cattle with splayed toes, which tend to have poor support in the interdigital area. Majority of affected cattle will have interdigital fibroma lesions in more than one foot and the hind feet are affected more often than the fore feet (Rhebun and Pearson, 1982).

Fractures of the pedal bone occur most of the times in heavy cattle raised on hard surfaces and more frequently in the front claws and occasionally bilaterally (Rhebun and Pearson, 1982). Superficial foot lesions may be adequately treated whether or not radiographic evaluation is done, but radiographic assessment of deeper disorders is a necessity in order to give guidance on the most appropriate treatment to be instituted and for drawing of accurate prognoses (Farrow, 1985).

Radiographic signs of foot infections in the bovine involve soft tissues, joint spaces and bones. Radiographic indicators of soft tissue infection of the bovine foot include soft tissue swelling, presence of gas in the tissues, soft tissue mineralization, presence of foreign bodies in the tissues, and soft tissue defects (Farrow, 1985).

An increase in soft tissue area and/or density is a reliable indicator of swelling. The swelling may be localized to one aspect of the foot, or involve the entire foot. Gas within the soft tissues may be associated with atmospheric air entry through an open wound or tissue defects. It may also result from microbial metabolism that produces gas particularly anaerobic bacteria, or it may be iatrogenic following aspiration, nerve block procedures, or taking of biopsies (Farrow, 1985). Mineralization of soft tissues is usually dystrophic in nature and often develops along natural soft tissue planes such as tendons and ligaments. It may also develop within or surrounding natural cavities such as joints and bursa. Foreign bodies within soft tissues must be metallic in order to be identified radiographically. Tissue defects could occur anywhere on the foot, but are commonest on the distal aspects. They occur from direct trauma or secondary to tissue devitalization (Farrow, 1985).

With regard to joint spaces, the radiographic indicators of joint space involvement in disease include widening, narrowing, subchondral lysis, fractures, subluxation, and luxation. Widening of the joint space is one of the earliest and most reliable indicators of joint lesions in cattle. It is most commonly seen in the distal interphalangeal joint. Initially widening is not easily recognizable but it tends to increase with time (Farrow, 1985). Comparison with adjacent normal joints is essential and when no radiographic abnormalities are found but suspicions are high, progressive radiographic examinations at certain time intervals are helpful. Subchondral lysis develops following extension of infection into the surrounding bone. It may be focal, regional or diffuse and often involves both sides of the joint but rarely to the same extent. Pathologic fractures often lead to destabilization of the involved joint with subsequent subluxation or luxation (Farrow, 1985).

Radiographic bone changes associated with infections are characterized by excess bone production, bone destruction and bone sequestration. Excess production of new bone is the most common alteration and may be localized, regional or diffuse (Farrow, 1985). Bone destruction could also be localized, regional or diffuse. It mainly involves the subchondral tissues but could develop in other osseous tissues. Bone sequestra may be a result of trauma or infection and are most frequently seen in the distal phalanges (Farrow, 1985).

In an abattoir study of radiographic changes of the digital region in cattle, Parizi and Shakeri (2002) reported prevalence rates of 27.83% for phalangeal rotation, 13.4% for anatomical changes, 18.54% for bone reaction and density changes, 10.30% for ossification of lateral cartilage of the third phalanx, 3.09% for osteomyelitis, 4.12% for displacement of distal sessamoids, 1.03% for fractures, 6.19% for bony ankylosis of joints, 4.14% for arthritis, 8.25% for degenerative joint disease, 2.06% for abscessation and 1.03% for polydactylia. They found 77% of the lesions to be osseous in nature and 19% joint related, and both forms were predominantly in the hind limbs. But in 29% of the cases, no radiographic changes were seen.

CHAPTER 3

3.0 GENERAL MATERIALS AND METHODS

3.1 Introduction

In this chapter, an overview of the methodology applied for this project is presented. The study was carried out in three main phases that included retrospective, prospective and abattoir data collection on dairy cow with laminitis and other claw lesions.

3.2 Study area

Nairobi occupies an area of 696 km^2 (Figure 3.1 and 3.2) and has a population of over 2.1 million people who live in over 649,000 households. The population density is estimated at over 3,017 persons per square kilometre It has maintained a population growth rate of approximately 4.7% for every decade in the last four decades (Population and housing census, 1999). This population has provided a ready market for milk and other dairy products, making it inevitable for presence of a high concentration of zero-grazed smallholder dairy farms in Nairobi suburbs and its peri-urban districts of Kiambu, Kajiado and Thika. Therefore, the area is suitable for smallholder dairy farm research such as lameness

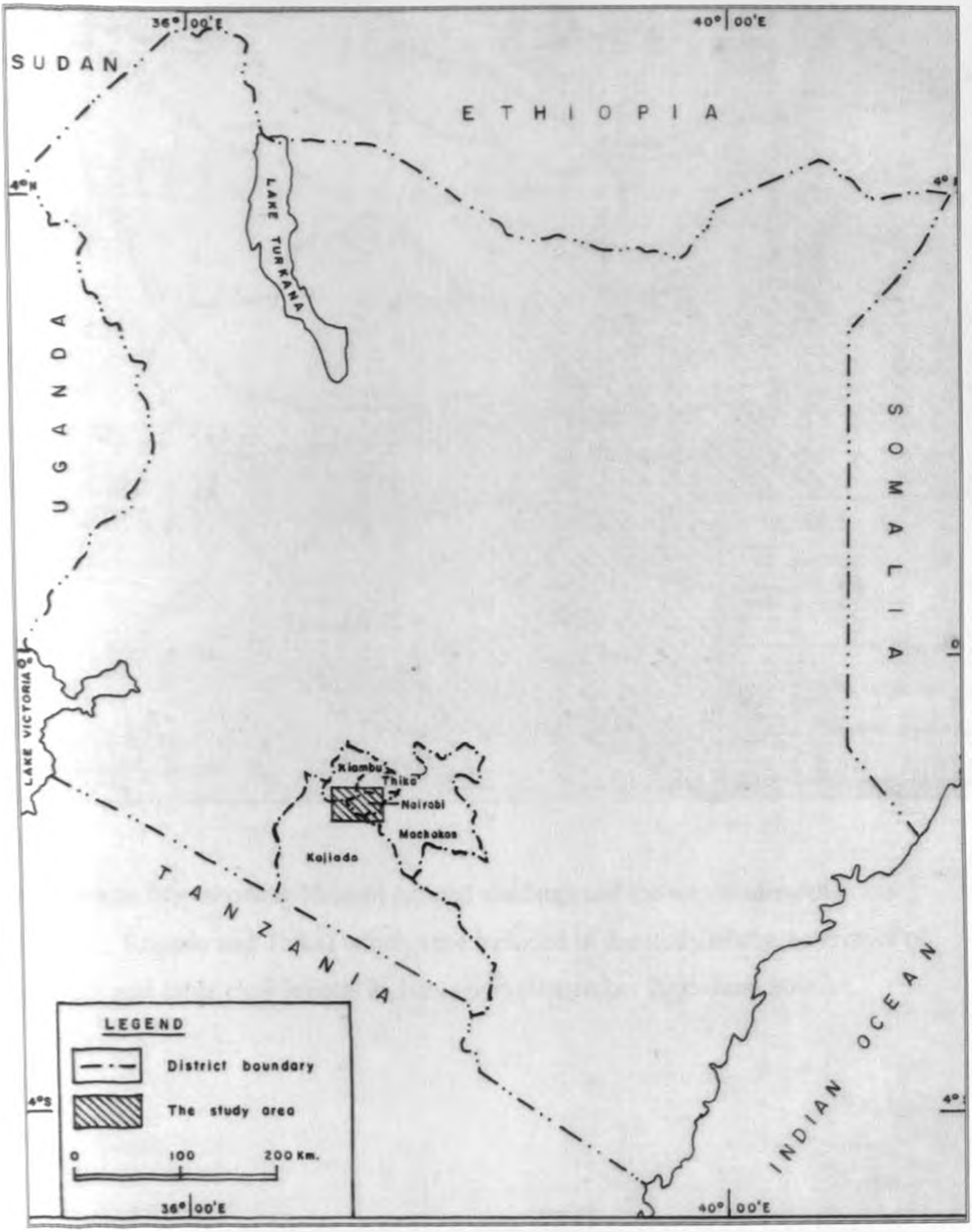


Figure 3.1: Map of Kenya showing Nairobi (shaded rectangle) and the surrounding districts which were included in the study of characteristics of laminitis and other claw lesions in dairy cows (December 2005-June 2006).

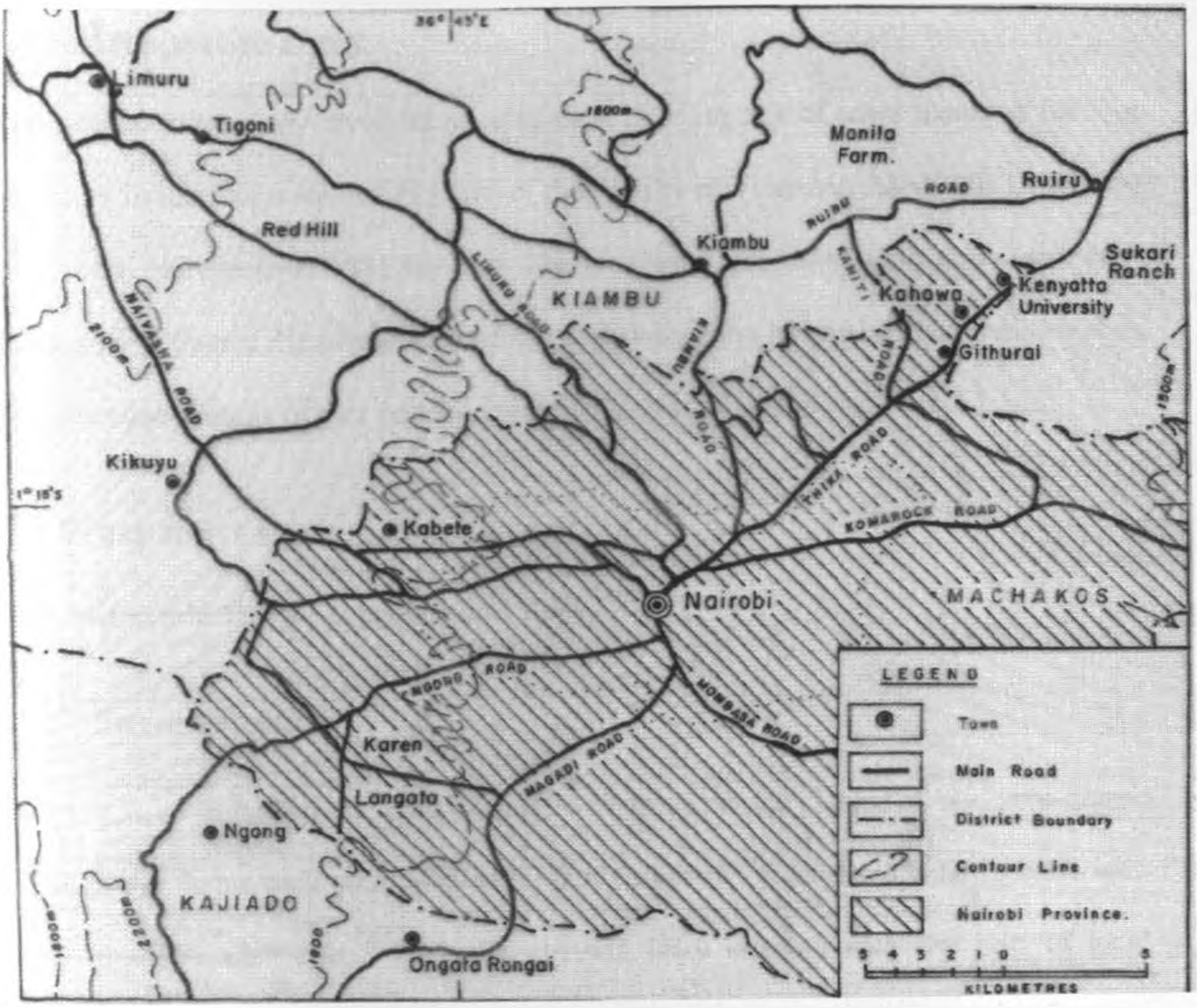


Figure 3.2: Map showing Nairobi (striped shading) and the surrounding districts (Kiambu, Kajiado and Thika) which were included in the study of characteristics of laminitis and other claw lesions in dairy cows (December 2005-June 2006).

3.3 Retrospective study

The retrospective study involved all admission case records of cows managed for foot lameness in the Large Animal Hospital of the Faculty of Veterinary Medicine, University of Nairobi, Kenya from 1981 to 2006. The total case records of adult cows were 625. Data were collected from details available in the daily entry hospital record cards for each specific case. Details of data collection are included in chapter 4 section 4.2.1.

3.4 Prospective study

This was conducted as a cross-sectional study.

3.4.1 Farm-selection

A purposive selection of dairy farms was done which included 29 zero-grazed smallholder farms each with 5-20 adult dairy cows and 3 large-scale farms each with more than 60 adult dairy cows. These farms were selected with the help of local veterinarians and animal health assistants; and selection depended on the farmers' consent for use of their farms and animals. The selected farms were located in Nairobi suburbs, Kabete, Kikuyu, Tigoni, Red-Hill, and Limuru area of Kiambu district, and Ngong and Ongata Rongai divisions of Kajiado district and Thika district. The chosen area has a high concentration of smallholder dairy farms necessitated by a high demand for milk and dairy products for its market.

3.4.2 Animal selection

The cows selected had one or more parities, and included lame and non-lame in any dairy breed, as cattle breeds varied from farm to farm. In all 32 farms selected, a total of 300 cows were picked for the study using simple systematic sampling. In each farm the cows that fitted into the study category were numbered serially as 1, 2, 3, to n, where n was the last serial number depending on the total number of cows in the farm. Every second cow from the serial numbers was selected. For example in the serial n_1, n_2, n_3, n_4, n_5, n_6, n_7, n_8, n_9, n_{10}, if the first cow selected was n_1. the next was n_3. n_5. n_7 and n_9. But if the first cow selected was n_2. then the next was n_4. n_6. n_8 and n_{10}. Therefore, the cows selected in any farm were either those with odd or even serial numbers. Alternate selection of the first serial number was made between the farms such that in the first farm the first serial number selected was odd and in the next farm it was even. This was alternated in a similar way until all the farms were covered.

3.4.3 Examination of cows for claw lesions

Each cow was observed as she walked on the alley and the gait evaluated according to a conventional locomotion scoring system (Table 3.1) adapted from Sprecher *et al.* (1997). In all the 300 cows, only the hind limbs were examined and that made a total of 1200 claws. The hind limbs were preferred because they are responsible for a higher percentage of foot lameness in cattle and were also easier to examine with respect to the available restraint farm structures. Each cow was restrained in a standing posture in the farm-crush with the head well fastened; the hind limb was tied with a long strong sisal rope and raised off the ground by fastening the rope to the wooden or metallic crush bars

(Figure 3.3). The claws were thoroughly washed and various claw measurements taken. They included claw length, claw height, heel height, claw diagonal, toe angle, claw width and digit width (Figure 3.4). The weight-bearing surface of the claw was examined for any gross claw lesions. after washing of the claws, those that were excessively overgrown were first trimmed using hoof shears to effectively reduce their sizes. It was then possible to use a quittor knife to trim the horn of the sole after the excessively enlarged horn was reduced. A thickness of 1-2 mm of the horn of the sole was trimmed with a quittor knife to expose any underlying claw lesions. Each claw lesion was photographed using a digital camera (Sony DSC-S80, 4.1Mega Pixels). Diagnosis of laminitis was based on presence of sole harmorrhages occurring alone or together with one of the laminitis associated claw lesions (such as sole bruising, sole ulcer, heel erosion, white line separation, and double soles) (Belge and Bakir, 2005; Nocek, 1997). A claw manifesting two or more of these lesions without haemorrhages was considered to have subclinical laminitis. Presence of sole haemorrhages concurrently with claw deformities (such as overgrown, flattened, concave and broadened or widened claws) was considered to signify chronic laminitis. Presence of one laminitis associated claw lesion or deformity without sole haemorrhages was concluded that such a claw suffered only the manifested lesion but no form of laminitis. Locations of lesions on the weight-bearing surface of the claw were categorized according to 6 conventional zones of the sole (Figure 3.5), and haemorrhages were also categorized according to 5 conventional haemorrhage scores (Table 3.2) both adapted from Greenough and Vermunt (1991). All the clinical examination and claw measurement data collected were recorded in specially designed and coded data entry forms for each cow (Appendix 1 and 2).

Table 3.1: A conventional locomotion scoring system adapted to evaluate the gaits of dairy cows in a cross-sectional study of digital characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).

Locomotion score	Clinical description	Evaluation
1	Normal	• Stands and walks normally. • All feet placed with purpose. • Back posture standing: flat. • Back posture walking: flat.
2	Mildly lame	• Stands with flat back, but arches when walking. • Gait is slightly abnormal. • Back posture standing: flat. • Back posture walking: arched.
3	Moderately lame	• Stands and walks with an arched back. • Short strides with one or more legs. • Back posture standing: arched. • Back posture walking: arched.
4	Lame	• One or more limbs favoured but partially weight bearing. • Back posture standing: arched. • Back posture walking: arched.
5	Severely lame	• Refuses to bear weight on one limb. • May refuse or have great difficulty moving from lying position. • Back posture standing: arched. • Back posture walking: arched.

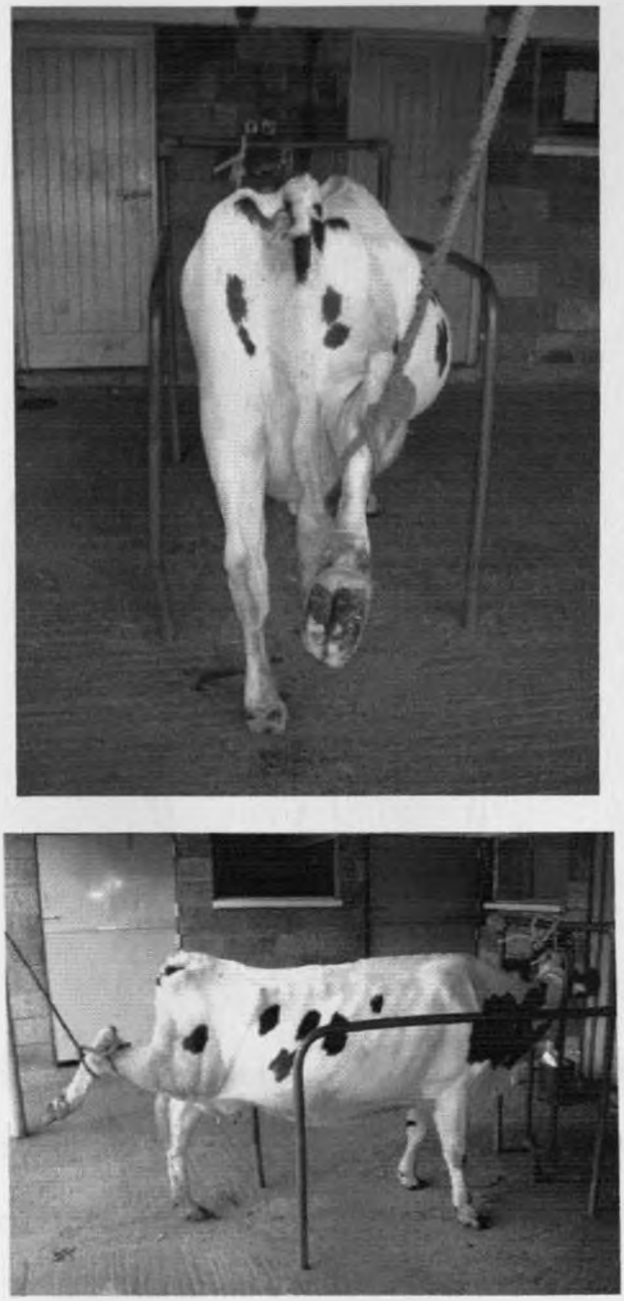


Figure 3.3: A back and side view of a friesian cow restrained in a crush with the right hind limb suspended for trimming to examine the weight-bearing surface of the claws for lesions during a cross-sectional study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December2005-June 2006).

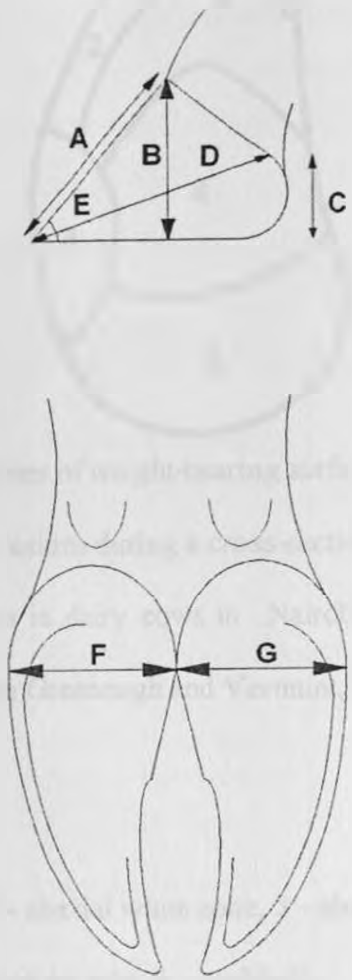


Figure 3.4: Shows the claw measurements taken during a cross-sectional study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006) (Adapted from Ishler *et al.*, 2005)

Key:
A-Claw length, B-Claw height, C-Heel height, D-Claw Diagonal, E-Toe angle, F and G –Claw width, F+G = Digit width)

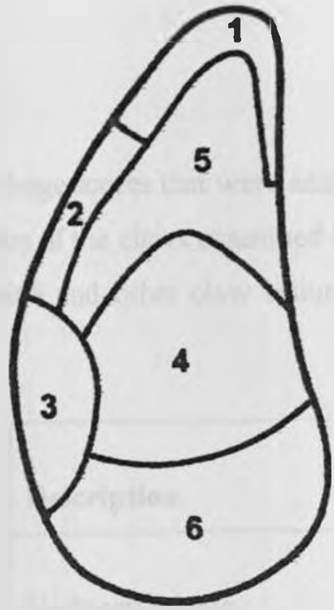


Figure 3.5: Six conventional zones of weight-bearing surface of the claw adapted to categorize location of the claw lesions during a cross-sectional study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). (Adapted from Greenough and Vermunt, 1991)

Key:

Zone 1-white zone at the toe, 2 - abaxial white zone, 3 - abaxial wall-bulb junction,

4 – sole-bulb juction, 5 – apex of the sole, 6 – heel bulb.

Table 3.2: Conventional haemorrhage scores that were adapted to categorize haemorrhages observed in the soles of the claws examined during a cross-sectional study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

Scale	Description
0	No haemorrhage
1	Slight discoloration
2	Moderate haemorrhage
3	Severe haemorrhage
4	Exposed corium

3.4.4 Evaluation of the cow- and farm-level risk factors

Cow-and farm-level data were collected by recording relevant information in specially designed and coded questionnaire forms. This information was obtained by direct respondence from farmers, farm managers or stockmen. The cow-level data included body condition, parity, lactation stage, and milk yield (Appendix 1). The farm-level data included housing, management, and nutritional factors (Appendix 3).

3.4.5 Controls

The prospective study was observational and therefore the cows that scored negative for laminitis and other claw lesions were considered as controls and compared with those that were positive. Comparisons were done directly on the farms as well as later on photographs. Presence of cow-and farm-level parameters was compared with their absence as a means of controls on the risk factors. Where risk factors were constituted by taking of actual measurements, they were compared with the known documented standards measurements.

3.5 Abattoir study

3.5.1 Selection of the abattoirs and collection of the samples

Kiserian abattoir and Wangige market slaughter-slab were purposively selected for logistic reasons. A pilot survey prior to the current study indicated that this abattoir and slaughter-slab were the only ones in the study area where dairy cows were slaughtered more regularly, thus making it possible to collect enough claw samples from them for this research. A total of 159 cow-feet (318 claws) samples were collected, of which 96 were from Wangige market slaughter-slab and 63 from Kiserian abattoir. Among these, 109 were hind limb claws and 50 were forelimb claws. More dairy cows were slaughtered in Wangige market slaughter-slab than in Kiserian abattoir during the study period. The difficulties of getting claw samples from dairy cows made it necessary to also include forelimb claws. These claw samples were collected from January 2006 to May 2006.

3.5.2 Macroscopic and radiographic evaluation of abattoir claws

The claws were thoroughly washed, examined for macroscopic lesions and claw measurements taken in a similar method to the prospective clinical examination (described in section 3.4.3). All the claws were radiographed for examination of pedal bone changes. The horn of the sole was trimmed to check for haemorrhages and any other underlying lesions. Sagittal section of each claw was made (Figure 3.6), after which the corium and pedal bone were grossly examined for physical changes. The data of the findings were collected and recorded in specially designed and coded data entry forms (Appendix 4).

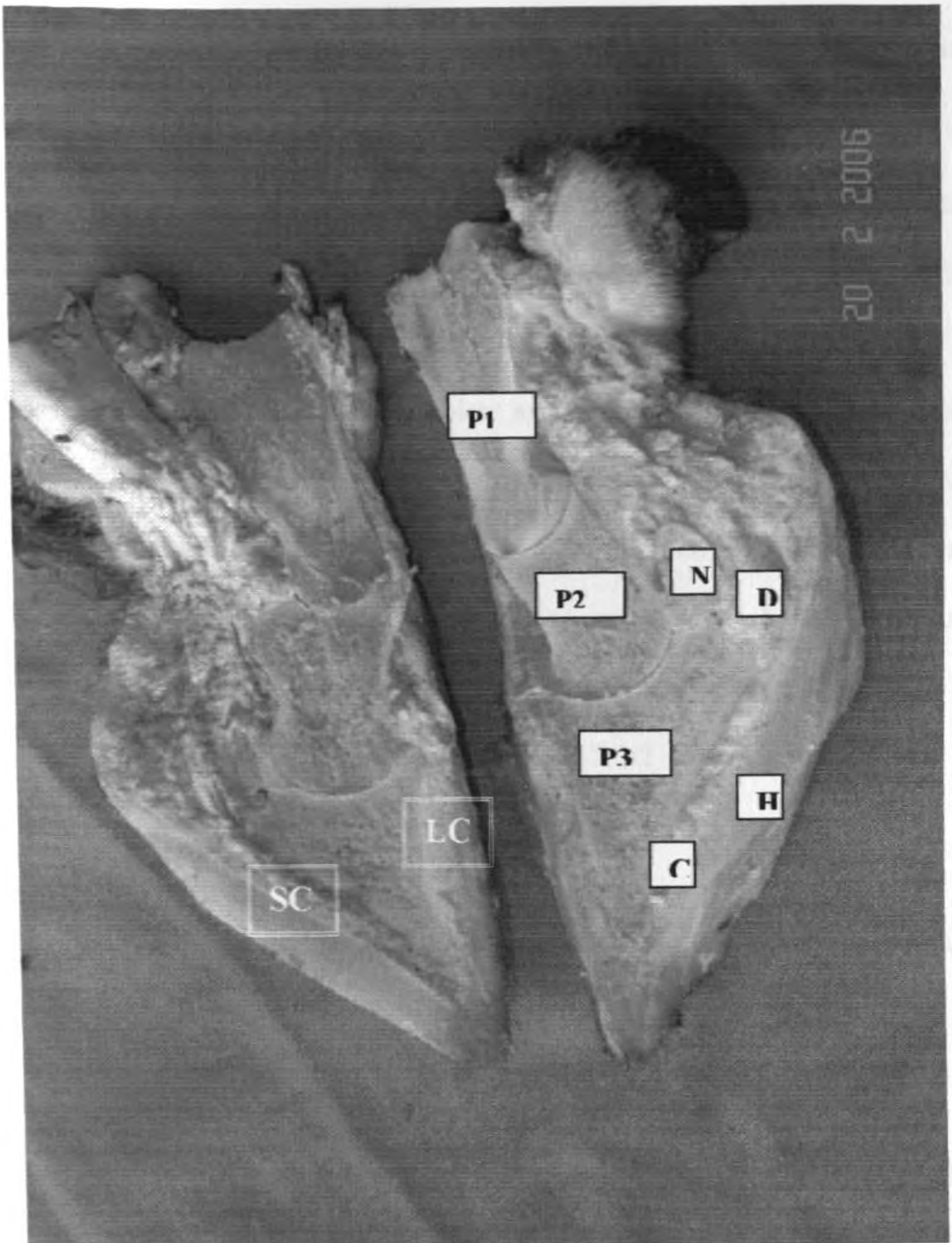


Figure 3.6: Sagittal section made through the digit for gross examination of the pedal bone and the corium and for collection of corium specimens during abattoir study of characteristics of laminitis and other claw lesions in Nairobi and environs (December 2005-June 2006). This digit was normal.

Key: P1-proximal phalanx, P2-middle phalanx, P3-distal phalanx (pedal bone), C-corium, H-horn of the sole, D-digital cushion, N-navicular bone, SC-solear corium, LC-laminar corium.

3.5.3 Histology and transmission electron microscopy of the corium

After the sagittal sections, corium specimens were taken from 10 claws with subclinical laminitis and 10 claws with chronic laminitis for histological examination. Further corium specimens were taken from 5 claws with subclinical laminitis and 5 claws with chronic laminitis for transmission electron microscopic examination. The corium specimens were harvested from solear and laminar corium (Fig. 3.6). The specimens were either from medial or lateral claws whichever had the gross lesions. The specimens were processed following the standard histological (Luna, 1968) and electron microscopic (Glauert and Phillips, 1965) procedures. Histological and electron microscopic data were recorded. Details of the histological and electron microscopic procedures are included in chapter 7, sections 7.2.1.2 and 7.2.2.

3.5.4 Controls

Controls for histological and electron microscopic examination were corium specimens from claws that did not show any form of laminitis.

3.6 Data management

For most of the parameters, the data collected indicated presence or absence of a particular disease or disease and were recorded as "1" (meaning "Yes" for presence of a claw lesion or a risk factor), and "0" (meaning "No" for absence of a claw lesion or a risk factor). Data was recorded and managed per cow (retrospective and prospective study) and per pair of claws from the same limb (abattoir study). The data were stored in Microsoft Office Excel 2003 (Microsoft Corporation, 2003). It was validated and verified to be correct as per the entries from the record sheets.

3.7 Data analysis

The data were imported into SAS © 2002-2003 (SAS Institute Inc., Cary, NC, USA) and into GENSTAT for Windows Discovery Edition 2 (VSN International). Descriptive statistics and tests of association were computed for: subclinical and chronic laminitis, other claw lesions, deformities as well as cow- and farm-level risk factors.

3.7.1 Descriptive analyses

Prevalence of the claw lesions was computed as: Proportion of the number of positive observations of each lesion type to the number of cows (retrospective and prospective study), or claws (abattoir study) examined. Correlation matrix for correlation coefficient (r) was used to determine unconditional associations between laminitis and other claw lesions. It was concluded that there was an association when $r \geq 0.3$ and the association to be significant at the level of $p < 0.05$. Chi-square (χ^2) statistic was used to determine unconditional associations between risk factors and laminitis at the level of $p < 0.05$. Odds ratio (O.R.) was also calculated by 2 x 2 contingency tables for prediction of probability of occurrence of chronic laminitis against some claw lesions (Kirkwood, 1992).

3.7.2 Multivariate analyses

Stepwise multiple logistic regressions were done using SAS by forward selection and backward elimination of eligible predictor risk factors in order to model for occurrence of laminitis against the potential risk factors. The logistic modeling controlled the effects of confounding and interactions between the risk factors being considered. The factors that were found to be significant were retained in the model while the rest were eliminated.

The Odds ratio (O.R.) was also included as a measure of strength of association between the significant ($p < 0.05$) predictor risk factors (Kirkwood, 1992).

CHAPTER 4

4.0 RETROSPECTIVE STUDY OF FOOT CONDITIONS

4.1 Introduction

The effect of foot diseases on the claws of cattle leading to lameness with low productivity, reduced reproductive efficiency, subsequent negative economic impact and animal welfare concerns, makes them of great importance particularly in dairy cow production (Greenough and Vermunt, 1991; Enting *et al.*, 1997; Kossaibati and Esslemont, 1997; Offer *et al.*, 2000). Poor hygiene precipitated by wet conditions and slurry soften the horn of the claw, weaken and disrupt the interdigital skin barrier and even corrode the horn. These events promote entry of bacteria and cause infectious diseases of the foot (Somers *et al.*, 2005). A retrospective study done on 3,278 cattle treated in the Large Animal Clinic, University of Nairobi, Kenya during the period 1983 to 1988 indicated that 16.74% of them had non-fracture lameness out of which 65% was caused by foot conditions. From these foot conditions higher percentage had septic arthritis (37.34%) and foot abscess (21.85%). Among those with septic arthritis, 55.12% involved distal interphalangeal (pedal) joints (Mbithi *et al.*, 1991).

Some of the commonest foot conditions that cause lameness in cattle are sole abscesses, vertical and horizontal hoof wall cracks (Hull, 1993), interdigital dermatitis, digital dermatitis, interdigital phlegmon (interdigital necrobacillosis) (Weaver, 1993), and interdigital fibroma (Welker, 1993). Unlike subclinical laminitis (Nocek, 1997; Belge and Bakir, 2005) and chronic laminitis (Nocek, 1997), these foot conditions particularly the infective ones cause severe lameness that makes detection of the affected cattle more obvious (Rhebun and Pearson, 1982). When not treated early, infections of the foot invade deeper tissues particularly the synovial structures, tendons, ligaments and bones (Farrow, 1985; van Metre *et al.*, 2006). These deeper invasions can properly be evaluated for treatment and drawing of prognosis only by radiography (Farrow, 1985). When such infections occur, poor prognosis ensues and the affected animal is likely to be culled.

The retrospective study done by Mbithi *et al.* (1991) covered only a six year period and included all lameness cases of cattle (males and females of all ages) seen in the ambulatory clinic and those admitted in the Large Animal Hospital of the University of Nairobi, Kenya. Further to this, many researchers have shown that most detrimental economic effect of lameness in cattle involves the dairy cow (Melendez *et al.*, 2003; Garbarinio *et al.*, 2004; Hernandez *et al.*, 2005; Sogstad *et al.*, 2006). Moreover, it has been reported that about 90% of lameness in cattle is caused by conditions affecting the claws (Clarkson *et al.*, 1996; Weaver, 2000). Information on how the extent and pattern specifically of foot lameness in dairy cows in Kenya has been was not available. The retrospective study carried out earlier did not include treatment outcomes of the lame cases (Mbithi *et al.*, 1991) A retrospective study of confirmed and followed-up cases of foot conditions involving dairy cows that had calved at least once covering a 26 year period (1981 to 2006) was considered necessary to define the incidence and pattern of foot lameness in dairy cows in Kenya.

The Large Animal Hospital of the Faculty of Veterinary Medicine, University of Nairobi, Kenya is located on the North-Western part of Nairobi city. Through a large animal ambulatory clinic, it serves clients in Nairobi suburbs (Fig.3.2) and part of Kiambu, Kajiado, and Thika districts from where cases that need close follow-up and admission are referred. The hospital is within the Department of Clinical Studies which has an archive of clinical and laboratory records.

4.2 Materials and methods

4.2.1 Data collection

Record cards of all dairy cows admitted to the Large Animal Hospital of the Faculty of Veterinary Medicine, University of Nairobi, Kenya from the year 1981 to 2006 were retrieved from the record archives through case lists in the annual catalogues. The record cards of cases of dairy cows admitted with a history of lameness were separated. From these, those with confirmed diagnoses of foot conditions were identified and separated from those treated for other causes of lameness. All the record cards of cows with foot conditions were further read and scrutinized for details such as breed, age, clinical history, final diagnosis of the foot, the affected limb (fore or hind), the affected claw (medial or lateral), treatment administered, and outcome of the case (Appendix 5). Those that had foot conditions were 625 cases of adult cows.

The data recorded for final computation and analysis from these cases included confirmed diagnosis of the foot condition, number of cows affected by each confirmed foot condition, specific limb (fore or hind) affected in each cow, specific claw (medial or lateral / inner or outer) affected on each limb, treatment administered for each cow and the outcome of each cow after treatment. The data was recorded into data collection sheets (Appendix 5).

4.2.2 Data management and analysis

Data management and analysis was carried out as described in sections 3.5 and 3.6 of chapter 3. The prevalence rate of each foot condition was calculated from the number of cows indicated in the record as positively confirmed to have had the condition, divided by the total number of cows (625) indicated in the records to have had foot lameness multiplied by 100, and it was expressed in percentage. Therefore the prevalence rate of each foot condition was expressed out of 625 cases. Prevalence of foot conditions according to the affected foot was calculated as the number of cows indicated in the records as positive for fore foot or hind foot involvement with any one foot condition divided by the total number of cows indicated in the records as positive for the specified foot condition multiplied by 100, and it was expressed in percentage for each condition. For example, the prevalence rate of fore foot involvement in foot rot was calculated as:

$$\frac{\text{Number of cows positive for fore foot infection with foot rot}}{\text{Total number of cows positive (fore + hind foot) for foot rot}} \times 100$$

The prevalence rate of the treatment outcome for each foot condition was calculated as the number of cows indicated in the records as healed or not healed of a specified foot condition divided by the total number of cows indicated in the records as affected by the specified foot condition multiplied by 100, and was expressed in percentage for every foot condition. For example the prevalence rate of cows healed of foot rot was calculated as:

$$\frac{\text{Number of cows positively healed of foot rot}}{\text{Total number of cows positive for foot rot}} \times 100$$

4.3 Results

4.3.1 Prevalence of the foot conditions

Interdigital necrobacillosis (foot rot) had the highest prevalence (35.71%) followed by interdigital fibroma (11.9%) and sole abscess (11.11%). Those with moderate prevalence rates were trauma (7.94%), claw overgrowth (7.14%), sole necrosis (5.56%), septic fetlock arthritis (5.56%) and septic pedal arthritis (4.76%). Laminitis and related claw lesions (double soles and heel erosion) each had very low (0.79%) prevalence rate (Table 4.1). History in the record cards indicated that 63% of the cases were presented at least 3 weeks after appearance of first clinical signs and had not received any treatment. The hind limb was affected in 75% of the cases, the forelimb in 16% and both limbs simultaneously in 2% of the cases, but in 7% of the cases, the records did not indicate the affected limbs. Among the foot lesions affecting the forelimbs, 57% were on medial claws and 43% on lateral claws, while among those affecting the hind limbs, 83% were on lateral claws and 17% on medial claws. Apart from interdigital fibroma which exclusively involved hind limbs, the rest of the foot conditions affected either the fore or the hind limbs, but with higher prevalence in the hind limbs (Table 4.2). A total of 5.76% of the cows had more than one foot condition.

4.3.2 Treatment outcomes of the various foot conditions

The records showed that 90.48% of all the cows were healed after treatment, and the remaining 9.52% were either slaughtered (5.56%) or died (3.96%). A closer analysis of the outcomes of each foot condition that had more than 5% prevalence indicated that most of these conditions had a healing rate of more than 80% (Table 4.3). A prevalence rate of less than 5% was considered too low for conclusion on outcome of treatment of such a condition due to the low number of cows involved. However, all the cows affected by the conditions that had prevalence of less than 5% (sole ulcer, cellulitis, hoof cracks, periarticular abscesses, foreign bodies, sprain, laminitis, double soles, heel erosion, and septic pastern arthritis) coincidentally were healed of these conditions.

Table 4.1: Prevalence rates of foot conditions from the retrospective study carried out on 625 cases of dairy cows presented for treatment of foot lameness in the Large Animal Hospital of the Faculty of Veterinary Medicine, University of Nairobi, Kenya from 1981 to 2006

Foot conditions	Number of cows per foot condition (n = 625)	Prevalence (%)
Interdigital necrobacillosis (foot rot)	223	35.71
Interdigital fibroma	74	11.9
Sole abscess	69	11.11
Trauma	50	7.94
Claw overgrowth	45	7.14
Septic fetlock arthritis	35	5.56
Sole necrosis	35	5.56
Septic pedal arthritis	30	4.76
Sole ulcer	15	2.38
Cellulitis	15	2.38
Hoof cracks	15	2.38
Periarticular abscesses	15	2.38
Foreign bodies	10	1.59
Sprain	10	1.59
Laminitis	5	0.79
Double soles	5	0.79
Heel abscess	5	0.79
Septic pastern arthritis	5	0.79

Table 4.2: Prevalence rates of foot conditions according to the affected foot in a retrospective study carried out on 625 cases of dairy cows admitted for treatment foot conditions in the Large Animal Hospital of the Faculty of Veterinary Medicine, University of Nairobi, Kenya from 1981 to 2006.

Foot conditions	**Prevalence rates (%) of foot conditions on the fore foot**	**Prevalence rates (%) of foot conditions on the hind foot**
Interdigital fibroma	0	14.3
Interdigital necrobacillosis (Foot rot)	26.7	30.6
Sole abscess	21.4	78.6
Septic pedal arthritis	16.7	66.7
Septic fetlock arthritis	14.3	71.4

Table 4.3: The percentages of cows that were healed and those not healed after treatment of some foot conditions from the retrospective study carried out on 625 cases of dairy cows admitted in the Large Animal Hospital of the Faculty of Veterinary Medicine, university of Nairobi, Kenya from 1981 to 2006.

Foot conditions	Percentage of cows healed (n = 625)	Percentage of cows Not healed (n = 625)
Interdigital fibroma	93.3	6.7
Interdigital necrobacillosis (Foot rot)	86.7	13.3
Sole abscess	92.9	7.1
Septic pedal arthritis	83.3	16.7
Trauma	100	0
Claw overgrowth	77.8	22.2
Sole necrosis	85.7	14.3
Septic fetlock arthritis	85.7	14.3

NB: Protocol followed in management of the foot conditions:

1. General foot cleaning
2. Claw trimming
3. Topical treatment: 10% copper sulphate once per day for 1 week.
   2.5% to 5% formalin every 2nd day for 1½ weeks
4. Systemic treatment: Potentiated sulphonamides or 10%oxytetracycline intravenously or intramuscular once per day for 3-5 days.
   Penincillin-streptomycin intramuscular once per day for 3-5 days.
   Systemic treatment was mainly for invasive infections.
5. Combination of topical and systemic was done for severe cases.
6. Opening and draining (lancing) of abscessed lesions.
7. Surgical removal of growths and wound repair for trauma.
8. Claw amputation for cases not responsive to conservative medical therapy.

4.4 Discussion

The high prevalence rates of interdigital necrobacillosis and sole abscess may be attributed to unhygienic conditions that provide favourable environment for growth of pathogenic bacteria that easily affect the feet of cattle (Berry, 2006). Wet conditions and accumulation of slurry compromise the integrity of external structures of the claw, thus promoting entry and establishment of bacterial foot infections (Somers *et al.*, 2005).

Since cattle with foot infections present severe clinical lameness (Rhebun and Pearson, 1982) and might easily be identified by farmers (Mülling *et al.*, 2006), more of such cases would be presented for treatment and these facts may also have contributed to high prevalence rates of infectious conditions of the foot. The spread of interdigital necrobacillosis and sole abscess infection to deeper tissues may also account for the moderate prevalence of septic arthritis of pedal, pastern and fetlock joints (Farrow, 1985).

High prevalence rate of interdigital fibroma may have been due to high number of cows referred for treatment because as the lesion enlarges, it becomes traumatized ensuing to severe lameness (Rhebun and Pearson, 1982), which makes it easy for most farmers to identify the affected cows. These cases invariably affected the hind feet, but Rhebun and Pearson (1982) reported that it can affect both fore and hind feet. However, it has also been reported that in dairy cows, the lesion tends to affect mainly the rear feet and in beef cattle the fore feet (Welker, 1993). Conversely, laminitis and associated claw lesions are more insidious with less obvious clinical symptoms (Nocek, 1997; Belge and Bakir, 2005), and this makes it difficult for farmers to notice the affected cows (Welker, 1993) and hence not many of them are referred for treatment. This probably explains the low prevalence seen for these conditions.

Higher prevalence of foot conditions on the hind feet than the fore feet (Fig. 4.2), and higher involvement of the lateral claws in the hind limbs and medial claws in the forelimbs was as reported by others (Russell *et al.*, 1982; Tranter *et al.*, 1993). This is probably related to weight distribution in cattle where the hind feet bear more weight (Ossent *et al.*, 1987; Van der Tol *et al.*, 2003). Therefore when risk factors are present, the integrity of the hind claws is most compromised, thus allowing entry of infective agents more frequently into these claws.

Most cows with these feet conditions responded positively to treatment and consequently recovered. The smaller percentage that failed to recover consisted of those presented late for treatment after the conditions had advanced to chronic stages or had become irreversibly destructive to the claws. All cases of foot trauma were presented early for treatment due to accompanying bleeding that alarmed the farmers, and hence healing of all such cases occurred. It is most likely that cases of claw overgrowth and sole necrosis that failed to recover were the undiagnosed chronic laminitis which could be associated with such clinical manifestations (Nocek, 1997). Alternatively, they could have been cases of claw deformities with inherited traits such as corkscrew and beak claws that cannot be managed successfully (Rhebun and Pearson, 1982). The high proportion of non-recovery seen in septic arthritis is probably due to the destructive nature of joint sepsis (Farrow, 1985). It may also account for the cases of foot rot that did not heal, which could have resulted to dissemination of infection to the pedal and fetlock joints (Rhebun and Pearson, 1982).

Comparison of the results of the current retrospective study and the one carried out earlier (Mbithi *et al.*, 1991) indicates high prevalence of infection of the foot (interdigital necrobacillosis and sole abscess) in the this study, but high incidence of septic arthritis (coffin- 55.12%; fetlock- 31.22%; pastern- 3.41 %) in the previous study (Mbithi *et al.*, 1991). However, the two studies were conducted differently as regards the case records used. The current study was done using admission case records of adult (calved at least once) cows with only foot conditions and covered a 26 year period, while in the previous study, Mbithi *et al.* (1991) used both ambulatory clinic and admission hospital case records of lameness affecting all parts of the limb of all ages and sexes of cattle and covered a 6 year period. The risk factors in the two study periods may be varied and this might also contribute to the differences in the results of the two studies. Therefore, the two studies are therefore not rationally comparable.

From the case records studied, the cows that were referred for admission into the Animal Hospital were those that were severely lame and 63% of them in the chronic stage. These cases did not cover the cows that had mild lameness or subclinical lesions. Further to this, in view of the insidious nature of laminitis, it is most likely that farmers would not have identified and referred cows with laminitis. The results therefore cannot be a good representation of the true picture of the extent of foot lameness and particularly laminitis in the area from which the cows were referred. Nevertheless, they provided the background information that formed the basis for designing of a prospective study to determine the prevalence of digital conditions particularly laminitis and associated claw lesions in Nairobi and the environs from where the retrospective cases were referred.

CHAPTER 5

5.0 A PROSPECTIVE CLINICAL STUDY OF LAMINITIS, OTHER CLAW LESIONS AND ASSOCIATED RISK FACTORS

5.1 Introduction

Healthy locomotor apparatus are crucial necessities for normal cow behaviour, social activity and productivity. Under normal conditions, the bovine claw capsule undergoes a continuous turnover process where growth and wear occur at approximately equal rates. However, poor horn quality and overgrown claws will predispose the cow to development of claw disease conditions (Vermunt and Greenough, 1995).

Overloading of the claw is incriminated as the main cause of claw lesions, and on a flat ground, the lateral claws of the hind limbs bear most of the weight (Ossent *et al.*, 1987). When there is discomfort in a particular limb, a cow removes weight from it and redistributes this weight primarily to the contra-lateral limb. With an understanding of how cattle redistribute their weight in response to pain in one or more limbs, lameness can be detected through assessment of this redistribution (Neveux *et al.*, 2006).

Claw lesions contribute significantly to lameness in cattle. They contribute upto 90% of the lameness cases in cattle (Weaver, 2000). Among the common claw lesions are the infective lesions such as interdigital necrobacillosis and sole abscesses (Weaver, 1993), laminitic lesions such as heel erosion, sole bruising, white line separation, double soles and sole ulcers (Nocek, 1997). Laminitis is most important among them because of its enhancing role in the occurrence of other condition (Belge and Bakir, 2005).

Laminitis is a systemic disease with a primary manifestation in the claw due to the claw's unique morphology. Pododermal microvascularization has been implicated as playing a key role in the physiological function and in the pathogenesis of diseases of the bovine claw (Hirschberg and Plendl, 2005). There are three critical structures in the claw; the dermal vascular system, the differentiating epidermal cells, and the connective tissue system in the suspensory and support apparatus (Bergsten and Mülling, 2004). The dermal vascular system of the claw is unique in its three-dimensional arrangement, complexity, and density, which is the reason for its high susceptibility to structural damage and disturbances of microvasculature (Hirschberg, 2001). Structural peculiarities in the vascular system and arteriovenous anastomoses in particular, have been described as having a central role in development of laminitis (Vermunt and Leach, 1992).

Subclinical laminitis is considered to be a major predisposing factor in development of other claw lesions such as sole ulcers, white line disease, heel erosion and double soles (Nocek, 1997; Smilie *et al.*, 1999; Belge and Bakir, 2005). It is a syndrome that makes young cows vulnerable to lameness in subsequent lactations (Smilie *et al.*, 1999). Depending on persistence of low-grade insults subclinical laminitis can be a prolonged, slow and insidious process (Nocek, 1997). It insidiously destroys the claw without any clinical symptoms of abnormal gait or posture, and by the time it becomes clinically evident through one or several of the claw lesions including chronic laminitis, irreversible damage to the claw may already have set in. However, early diagnosis is possible by trimming the claw to visualize the presenting haemorrhages as red or yellow discolourations, or just as unusually softened horn of the sole (Nocek, 1997; Belge and Bakir, 2005). Early diagnosis then helps in making steps to institute remedial therapeutic and preventive measures to arrest any further encroachment of the process on the claws.

Aetiology and pathogenesis of laminitis has not conclusively been established, but studies have shown that it is predisposed by a multiplicity of interactive animal, nutritional, managemental, and environmental factors (Ebeid, 1993; Nocek, 1997; Cook *et al.*, 2004). Furthermore, the interrelationships between laminitis and other claw lesions, and also among the claw lesions are not well understood. Studies done elsewhere show that claw horn lesions account for 60 to 90% of cattle lameness (Bergsten, 1994; Weaver, 2000; Manske *et al.*, 2002b), and that these lesions are sequelae to laminitis (Nocek, 1997; Belge and Bakir, 2005).

In Kenya, 80% of the dairy herd is raised in the small-scale production units and is mainly concentrated in the urban and the peri-urban areas (Wanyoike and Wahome, 2004). The dairy farming trend from pasture to zero-grazing system is bound to continue, given the inevitable reduction in per capita land-holdings that has invariably diminished the available grazing land. To our knowledge, only one study on cattle lameness in smallholder farming systems in Kenya has been undertaken (Gitau, 1994). This study focused on general lameness without emphasis on laminitis and associated claw lesions. Furthermore, diagnosis of claw lesions in that study was based only on macroscopic lesions before trimming.

This study was therefore designed to determine the prevalence of laminitis and associated lesions before and after trimming, their relationship with each other and with cow- and farm-level risk factors in pasture and zero-grazing systems.

5.2 Materials and methods

5.2.1 Study area

The main reason for high concentration of zero-grazed small-scale dairy farming units in Nairobi and the peri-urban areas of Kikuyu, Wangige (Kiambu district), Ngong, Ongata Rongai (Kajiado district), and Ruiru, Juja and Thika (Thika district) is the readily available market for milk which stems from the high population density in these areas. A detailed description of the study area is given in chapter 3, section 3.2.

5.2.2 Farm selection

A purposive selection of 32 farms was done which included 13, 12, 6 and 1 from Nairobi, Kiambu, Kajiado and Thika districts, respectively. They constituted 29 small-scale and 3 large-scale farms that practiced both zero-grazing and pasture-grazing. Further details on farm selection procedure are described in section 3.4.1 of chapter 3.

5.2.3 Animal selection

A total of 300 cows were selected for the study using simple systematic sampling, which is described in details in section 3.4.2 of chapter 3.

5.2.4 Clinical examination and recording of claw disorders

The cows were restrained in a crush and their claws washed and prepared for examination. Claw measurements were taken as shown and described in figure 3.3 (section 3.4.3). Each hind limb was raised off the ground and the claws examined for lesions particularly on the weight-bearing surface. Each sole was trimmed by removal of 1-2 mm of the horn of the sole using standard sharp Quittor and drawing hoof knives in order to expose any underlying lesions particularly sole haemorrhages. Claws with excessive horn growth were initially trimmed with standard sharp hoof shears before the use of Quittor and drawing hoof knives. The claws with exposed lesions were photographed using a digital camera (Sony DSC-S80, 4.1Mega Pixels). Diagnosis of laminitis was based on findings before and after trimming of the horn of the sole and conclusions made as follows:

i) Presence of sole haemorrhages alone, or together with at least one lesion (such as white line separation, sole bruising, heel erosion, and double soles), or presence of more than one of these lesions without haemorrhages was diagnosed as subclinical laminitis, ii) Presence of sole haemorrhages together with claw deformities (such as claw overgrowth, concave, flat or widened claws, and deep horizontal ridges) was diagnosed as chronic laminitis, iii) when only one claw lesion (such as white line separation, sole bruising, heel erosion, or double soles) or only one claw deformity (such as overgrown, concave, flat or widened claws) was present without haemorrhages, it was considered that the involved claw was affected by that manifesting disorder and did not have any form of laminitis. Diagnosis of laminitis or any claw lesion affecting the weight-bearing surface was recorded with respect to 6 conventional zones shown in chapter 3, figure 3.5 and haemorrhages were recorded according to 5 conventional scores shown in chapter 3, table 3.2. When haemorrhage involved only one zone of the weight-bearing surface of the claw, it was categorized as slight (score 1), and if it involved two zones it was categorized as moderate (score 2), but involvement of more than two zones was categorized as severe (score 3). Other examination details are described in section 3.4.3 of chapter 3.

5.2.5 Data collection on cow-and farm-level factors

Data on cow-level factors were collected by the investigator administering questionnaires as the interviewer to farmers, farm managers or stockmen as respondent interviewees before examination of each cow. These included breed, body condition, parity, milk yield per day, and lactation stage. Information on farm-level factors was collected during visitation to each of the 32 farms. This was done by observation, measurements and others by self-to-self administered questionnaires. The information on housing, feeding and environment included presence or absence of cubicles and the type of cubicle bedding, presence or absence of curb (kerb) between the cubicle and walk alley, lunging space and bob zone, floor type, floor slope, stall design, adequacy of feeding space, concentrate feeding, maturity and freshness of fodder, mineral supplementation and frequency of manure removal.

5.2.6 Controls

Claws without lesions were compared with those that had lesions since this was an observational study.

5.2.7 Data management and analysis

The data were stored in Microsoft Office Excel 2003 (Microsoft Corporation, 2003). It was validated and verified to be correct as per the entries from the record sheets. The data were imported into SAS © 2002-2003 (SAS Institute Inc., Cary, NC, USA) and into GENSTAT for Windows Discovery Edition 2 (VSN International). Descriptive statistics and tests of association were computed for animal, farm and environment factors. Prevalence of the claw lesions was computed as: Proportion of the number of positive observations of each lesion type to the number of cows (retrospective and prospective study), or claws (abattoir study) examined. Prevalence rate of each claw disorder was calculated independent of other claw disorders. Chi-square (χ^2) statistic was used to determine unconditional associations between risk factors and laminitis at the level of $p < 0.05$. Multiple logistic regressions were done using SAS by forward selection and backward elimination of eligible predictor risk factors in order to model for occurrence of laminitis against the potential risk factors. This was done while controlling the effects of confounding and interactions of the risk factors and only retained in the model factors that were found to significantly influence the disease (claw lesion) outcome, but the rest were eliminated. Other details of data management and analysis are presented in sections 3.5 and 3.6 of chapter 3.

5.3 Results

5.3.1 Description of the claw disorders

5.3.1.1 Subclinical laminitis

Cows with subclinical laminitis had normal gait but manifested haemorrhages and yellow-waxy discolourations after trimming of a thin layer of the horn of the sole. These haemorrhages were seen in one or at most two zones of the sole (Figure 5.1). Among the cows with subclinical laminitis, 32.4% manifested only sole haemorrhages while 67.6% had haemorrhages together with one or two other claw lesions such as sole bruising, heel erosion, white line separation or double soles.

5.3.1.2 Chronic laminitis

Claws with chronic laminitis had more severe and widespread haemorrhages and yellowish waxy discolourations that involved more than two zones of the sole (Figure 5.2). In addition to haemorrhages, 84 8% of the cows with chronic laminitis also had more than two other claw lesions such as double soles, sole bruising, heel erosion and white line separation. The cows that manifested double soles, 58% had chronic laminitis and 42% had subclinical laminitis. All cases of chronic laminitis, almost invariably had one or more forms of claw deformities such as overgrown, elongated, widened, flattened or concaved claws and prominent horizontal ridges of the dorsal wall (Figure 5.3). Chronic laminitis was always found to be bilateral involving lateral and medial claws of both hind limbs and invariably led to lameness.

5.3.1.3 Sole bruising

The less severe sole bruising involved only zone 5, but the more severe one occurred in zones 1, 4 and 5 of the sole together (Figures 5.4 and 5.5). Less severe sole bruising was superficial, but the more severe types were invasive leaving only a very thin layer of the horn intact. In 33.3% of the cows with sole bruising, heel erosion was concurrent. Bruised sole appeared black and necrotic, and when trimmed, the bruised parts were clearly distinct from the non-bruised parts (Figure 5.6). Sole bruising was always bilateral and involved either both lateral, or both medial claws, but occasionally it occurred in all the four claws of hind limbs. In any herd that this lesion was found, it affected all the cows.

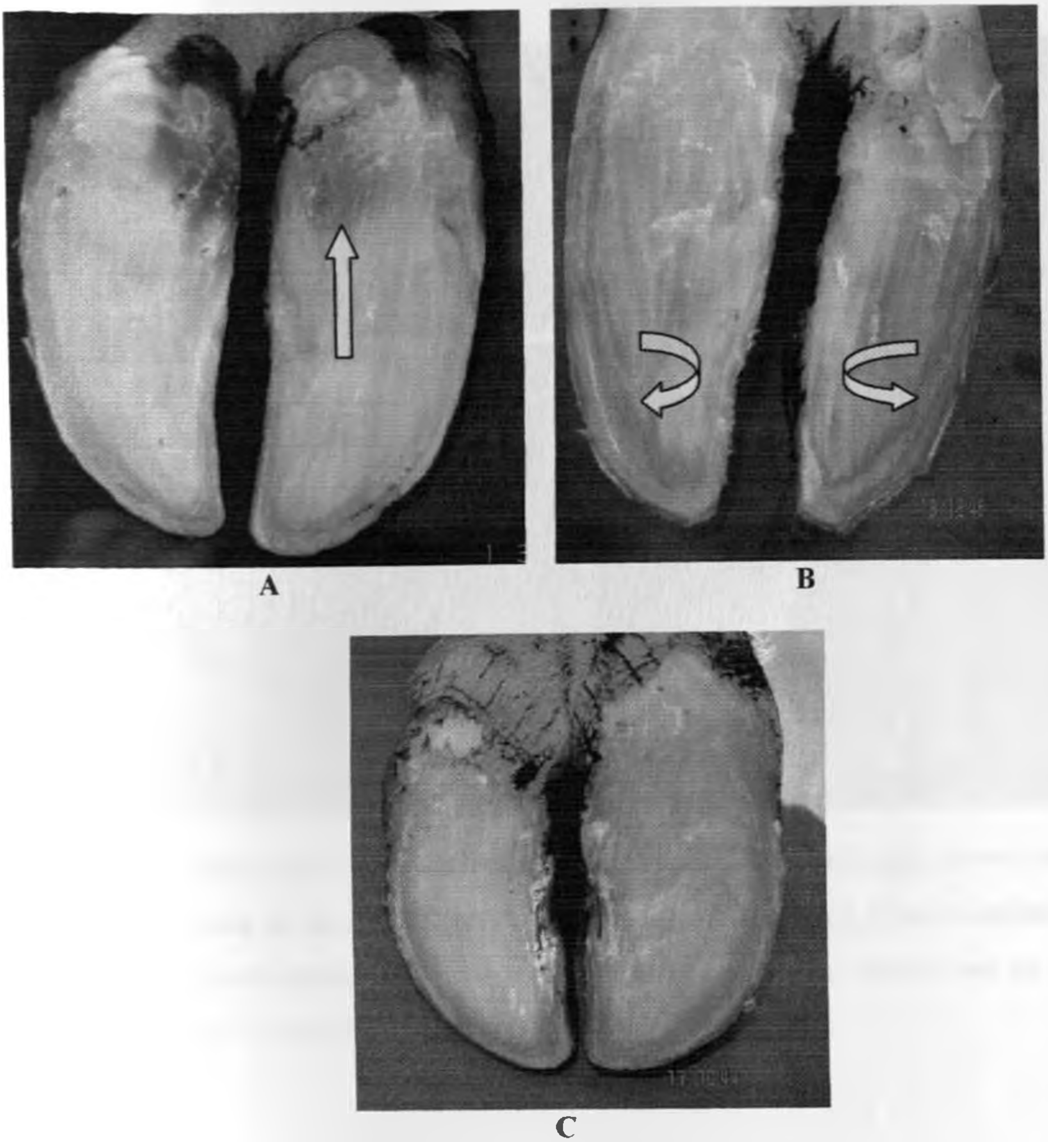


Figure 5.1: **A**-Sole haemorrhages (straight arrow) and **B**-yellow discolourations (curved arrows) seen in subclinical laminitis in dairy cows examined during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs. **C**-Shows the sole of a normal claw, (December 2005-June 2006).

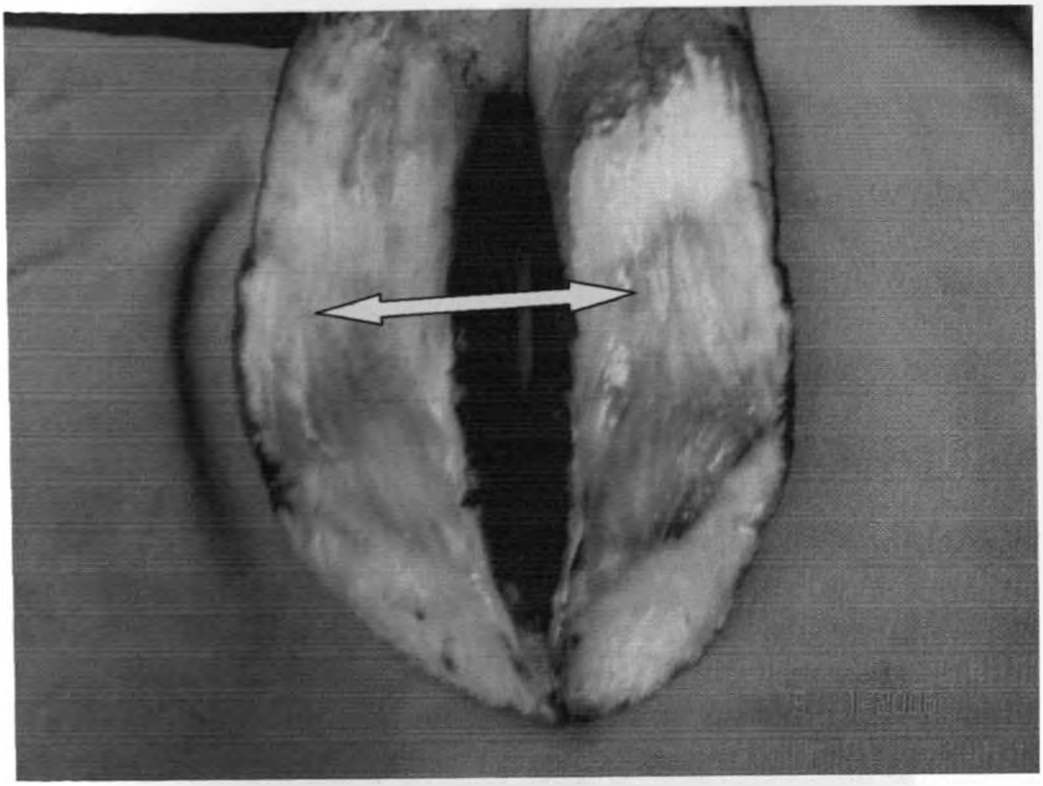
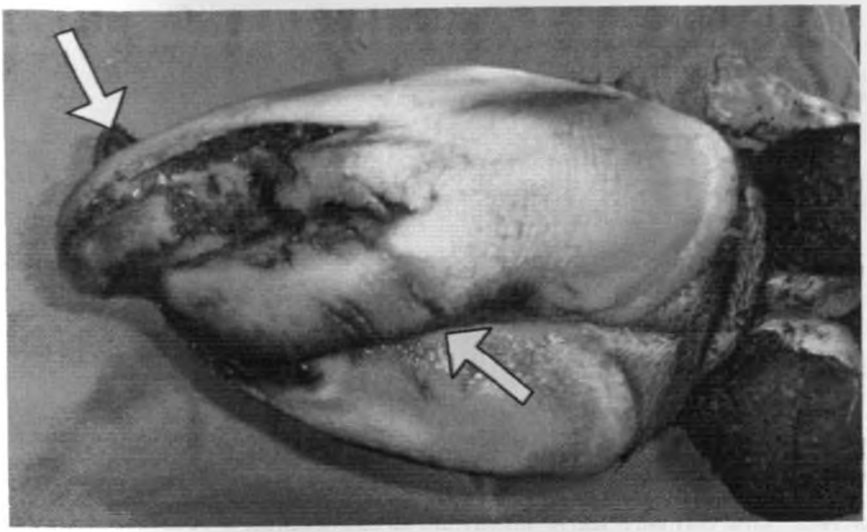
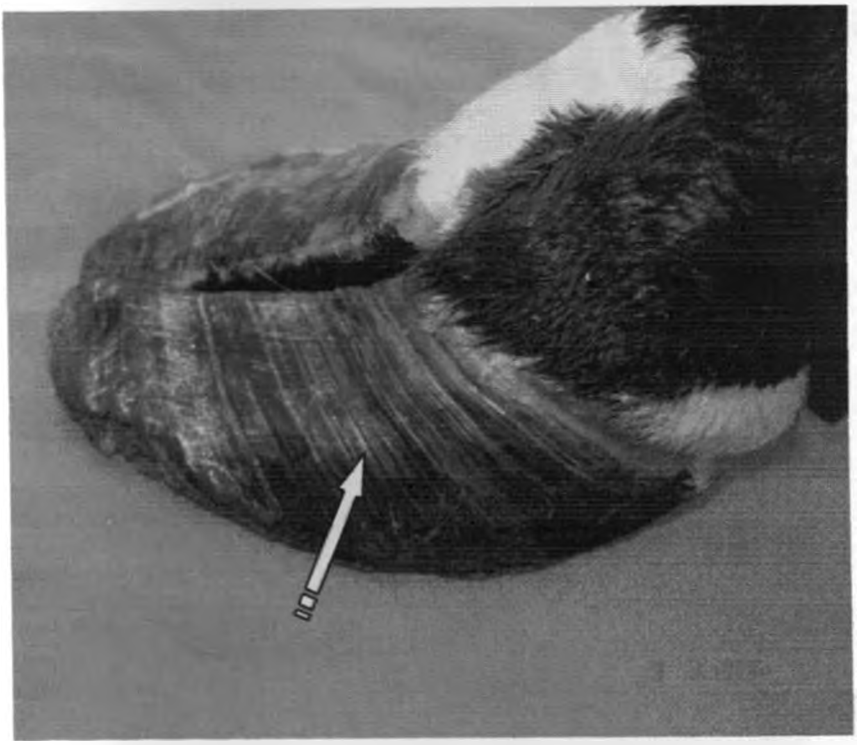


Figure 5.2: More severe and widespread sole haemorrhages (left-right arrow) involving most of the zones of the sole as seen in chronic laminitis in dairy cows examined during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).



A



B

Figure 5.3: Shows some claw deformities associated with chronic laminitis in dairy cows examined in a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006). **A**-Convex sole with overlapped axial walls and toes (block arrows). **B**-Elongated, flattened claws with prominent horizontal ridges (striped block arrow).

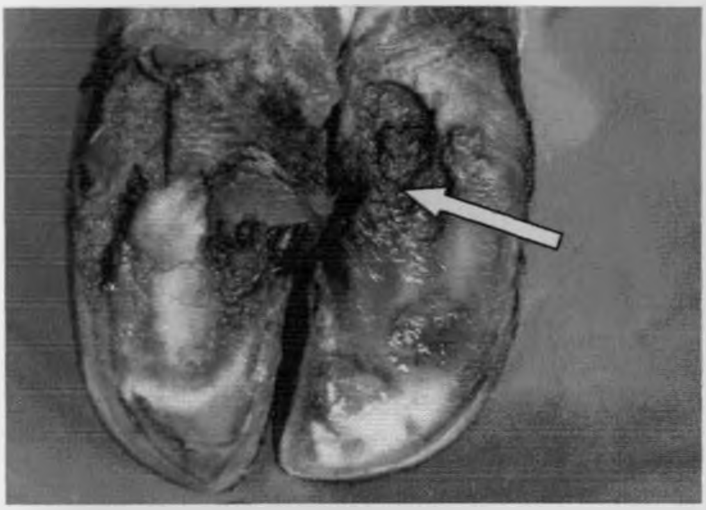


Figure 5.4: Superficial sole bruising involving zone 5 of the sole (arrow) as seen in 135 out of 300 dairy cows examined during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

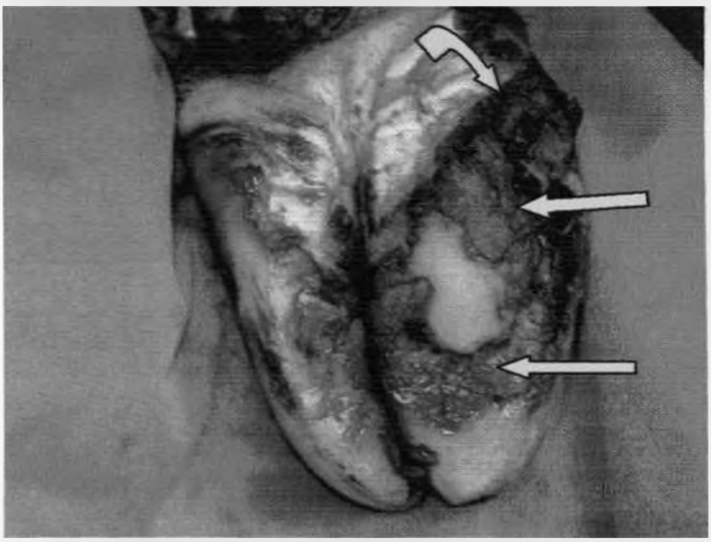


Figure 5.5: Right claw with invasive sole bruising affecting zones 4, and 5 (straight arrows) and concurrent heel erosion (curved arrow) as seen in dairy cows examined during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

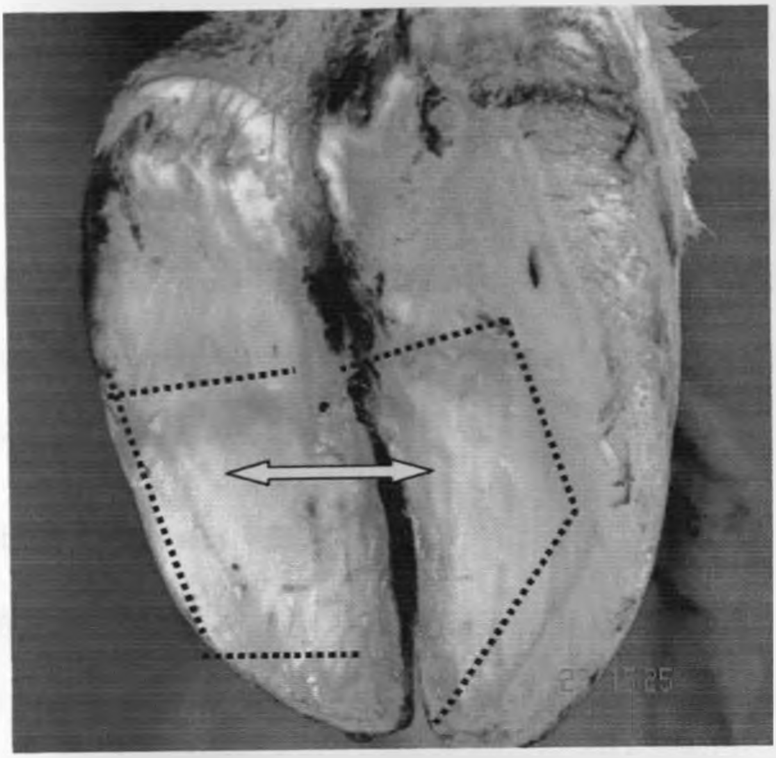


Figure 5.6: Areas of sole bruising appearing distinct after trimming (left-right arrow, bounded by square dotted lines) as seen in a study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).

5.3.1.4 Heel erosion

Heel erosion was invariably found in zone 6 of the sole, but when severe, it extended to zones 3 and 4 (Figure 5.7). It always presented bilaterally involving either both medial, or both lateral claws of the two hind limbs. Other times it affected all the four claws simultaneously. Like sole bruising, it appeared as dark necrotic areas of the heel, was superficial or deep and affected all the cows in any involved herd.

5.3.1.5 Double (underrun) sole

Double soles frequently involved zones 4 and 5, but occasionally extended to the abaxial white zone. In some cases, double soles were evident after thorough washing of the sole and dung was seen underneath the superficial sole. However, the lesion was more discernable after trimming the horn of the sole when a separate underlying thin horn was exposed (Figure 5.8). A superficial traumatized horn of the sole was encountered and could erroneously be diagnosed as double soles (Figure 5.9).

5.3.1.6 White line separation

White line separation involved mainly zone 2 and very occasionally the axial part of zone 4 and 5, and sometimes zone 3. It became more evident after trimming the superficial horn of the sole. There was clear separation between the horn of the sole and the horn of the wall of the claw with dung stuck in the separated gap or infective exudates oozing out (Figure 5.10). White line separation was invariably unilateral involving only one claw.

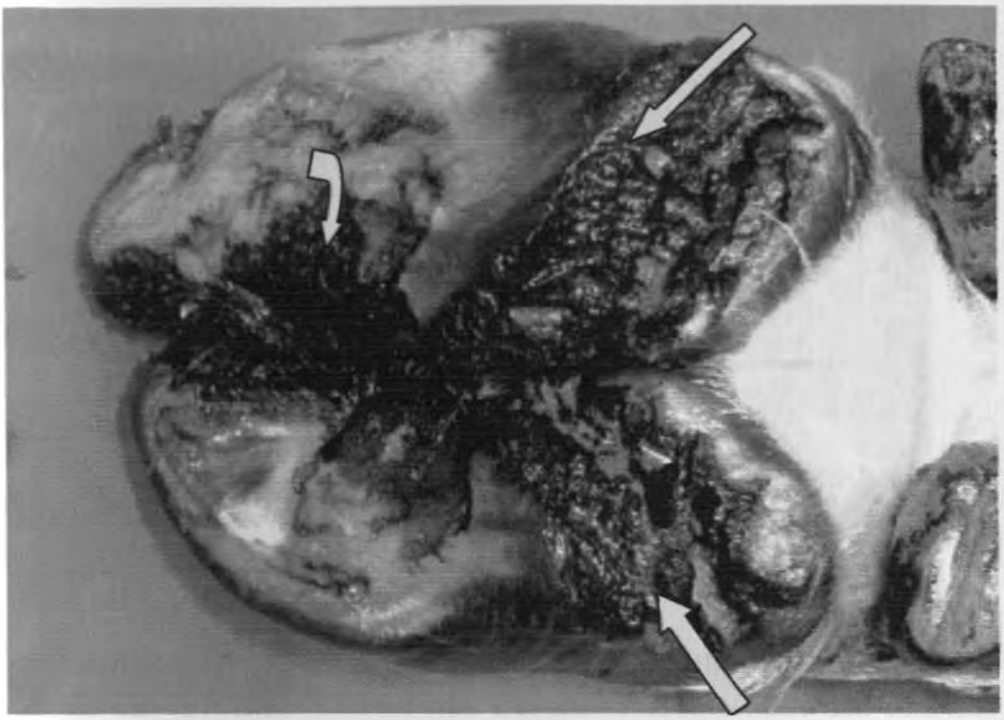
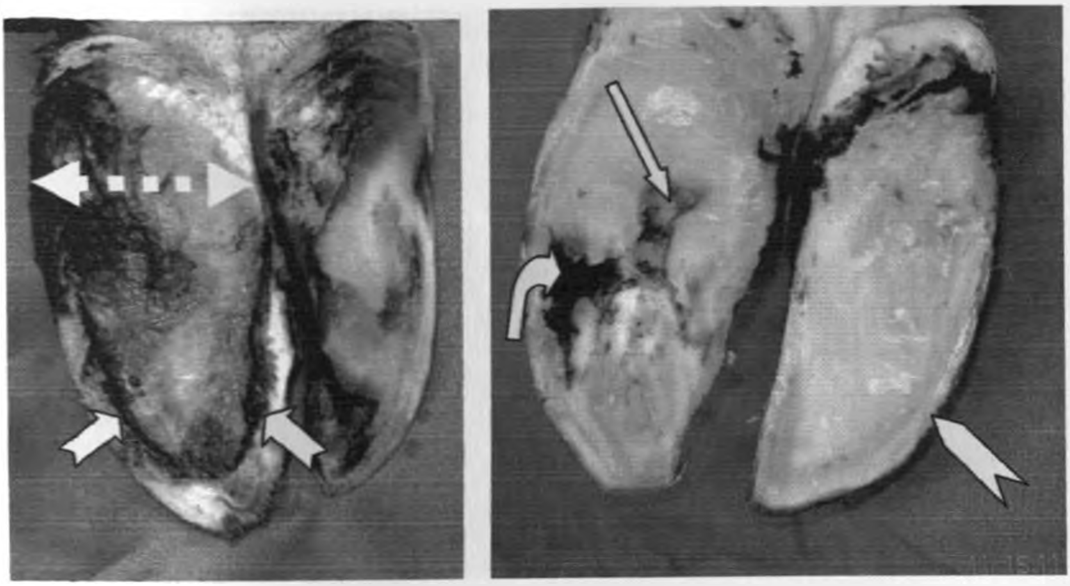
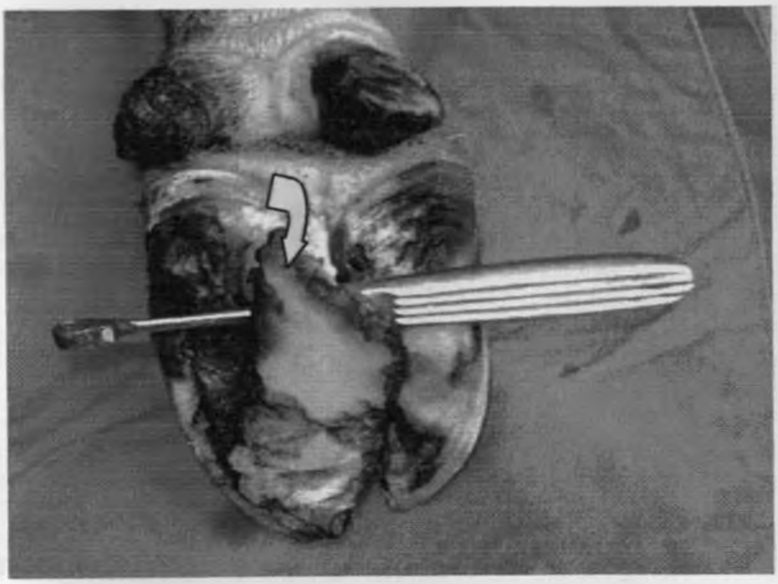


Figure 5.7: Severe heel erosion involving zone 6 of the weight-bearing surfaces of both claws (straight arrows) and concurrent mild sole bruising (curved arrow) as seen in 82 out of 300 dairy cows examined during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).



A B

Figure 5.8: Doubles soles: **A**-before trimming, note the margins of superficial sole (notched arrows) and the wider involved claw (dotted right-left arrow); and **B**-exposed dung stuck between the soles (curved arrow), underlying sole (straight arrow) and the normal right claw (chevron) seen after trimming. These were seen in 51 out of 300 dairy cows whose claws were examined for characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).



A

B

Figure 5.9: **A**-Plantar surface and **B**-Side view of the claw showing traumatized sole that can erroneously be diagnosed as double soles. Note the physically separated severed horn-segment (curved arrows) fitting a quittor knife in the separation. This was seen in 2 out of 300 dairy cows examined during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

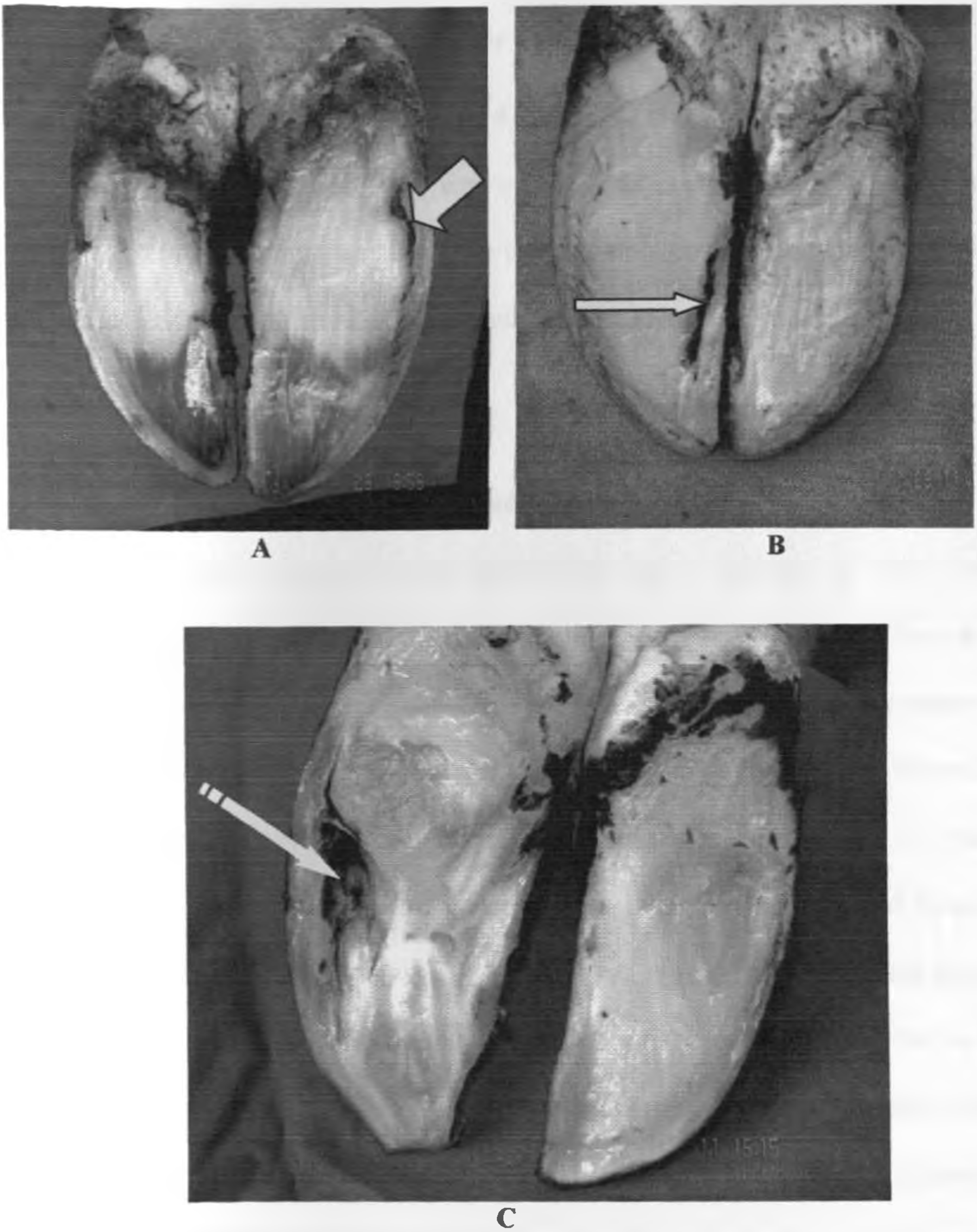


Figure 5.10: Showing white line separation in the claws of 54 out of 300 dairy cows examined during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006). **A**-Abaxial white line separation (thick short arrow), **B**-Axial white line separation (thin long arrow) and **C**-deeper abaxial separation (striped arrow) from which infected exudates was drained after trimming the horn.

5.3.1.7 Sole ulcer (exposed corium, pododermatitis circumscripta)

All the cases of sole ulcers affected zone 4 of the sole and were unilateral involving only one medial claw (Figure 5.11). Any cow with sole ulcer scored 4 or 5 (lame or severely lame) on the locomotion score. Sole ulcer became more obvious on trimming the horn of the sole which exposed characteristic granulation tissue in the ulcerating site.

5.3.1.8 Claw deformity disorders

In this study, 43.7% of the cows examined had one or more forms of claw deformities. There were several forms of claw deformities and a number of them occurred simultaneously in the same cow. Cows with claw overgrowth had entire toe, sole and walls overgrown ranging from slight to extreme overgrowth with subsequent claw deformity and consequently abnormal gait (Figure 5.12). The deformities observed were: up-turned or crooked toe (Figure 5.13), irregularly widened claw (Figure 5.14), concaved claw (Figure 5.15), elongated flattened claw (Figure 5.16), vertical claw wall turned sole-ward to become treading part (Figure 5.17), crossed toes (Figure 5.18), and prominent deep horizontal ridges on the dorsal wall of the claw (Figure 5.3). Claws that had these characteristics in most cases also had chronic laminitis and on trim.ing, they exhibited extensive underlying haemorrhages and yellow discolourations of the sole (Figure 5.19). Some claws however manifested haemarrhagic reddening or yellowish discolourations when washed even before trimming (Figure 5.20).

Splaying of the claws was found independent of other deformities but occasionally concurrent with claw overgrowth (Figure 5.21). Corkscrew claw was not common but when encountered it was bilateral and involved the medial claws of the hind limbs (Figure 5.22). Medio-dorsal spiraling of axial wall of the medial claws turning the claw to tread on the lateral aspect of the abaxial wall was observed in 3 cows and has not been reported previously.

5.3.1.9 Non-laminitis lesions encountered in the study

Non-laminitic claw lesions encountered in the study had a prevalence of 6.1%, out of which 4.7% were due to infective causes (Table 5.1). Sole abscess was encountered in only one cow that had the severest form of lameness. The cow was markedly relieved of pain and improved in gait after the abscess was drained. The abscess affected the lateral claw of one hind limb (Figure 5.23).

Bilateral horizontal hoof-wall fissures were found in an old cow that manifested moderate lameness (Figure 5.24). Seven of the fourteen cows with claw infections had bilateral digital dermatitis (hairy warts) and were found in two farms that practiced similar intensive concentrate feeding and management system. The lesion was located on the caudo-dorsal aspect of the interdigitum (Figure 5.25) and did not cause any lameness. Two cows had claws with growths one of which was bilateral ulcerated interdigital fibroma (Figure 5.26) and the other had extraordinary bilateral excessively enlarged loose skin-fold extending from cranial to caudal aspects of the interdigital spaces (Figure 5.27). One cow had firm painless subcutaneous growths on the foot proximal to the horny claws which did not affect the gait. Some of the cows manifested "cow-hocked" posture with adducted hocks, standing with feet "base wide", resulting in abnormal gait and high locomotion scores. Excessively whitish, softened, and crumbled horn of the sole was observed after trimming the claws in some cows (Figure 5.28).

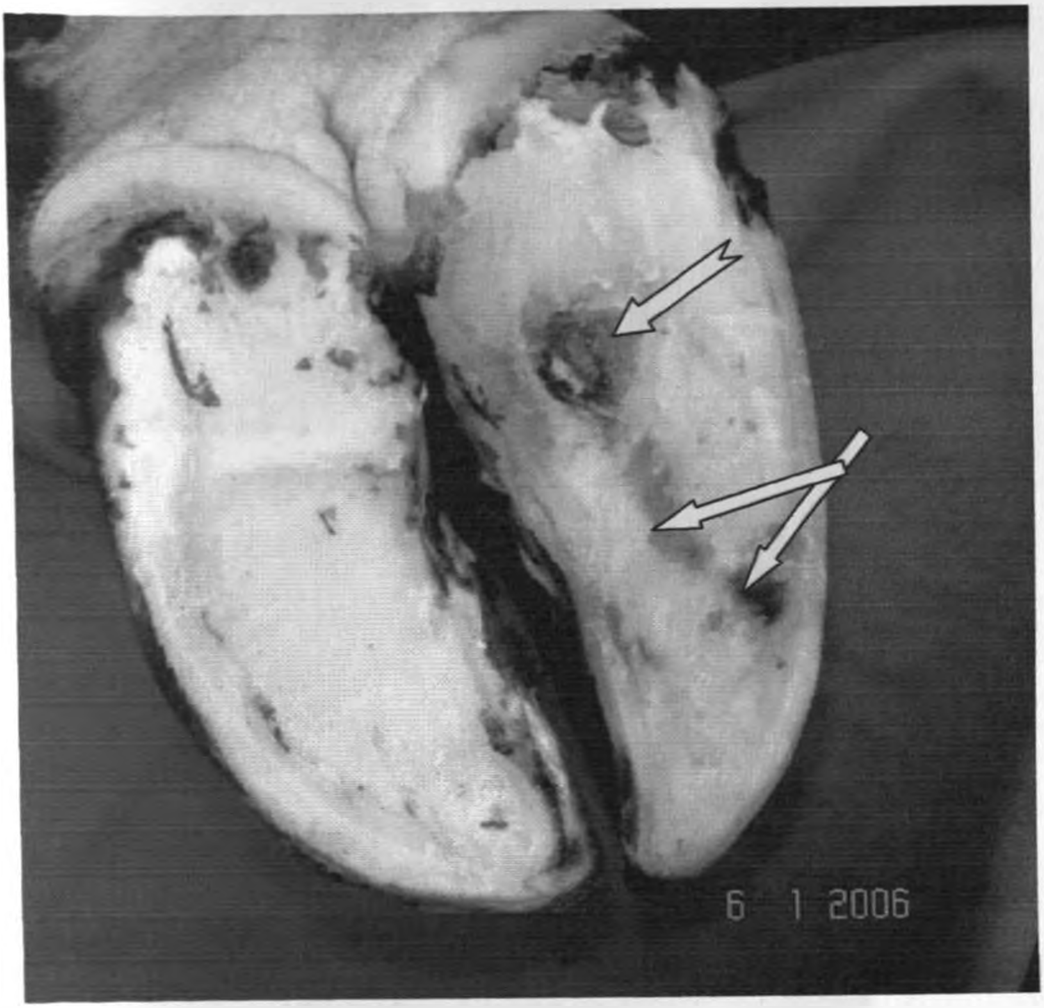
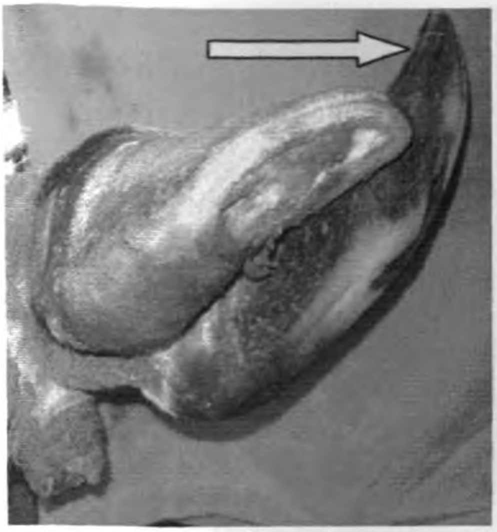
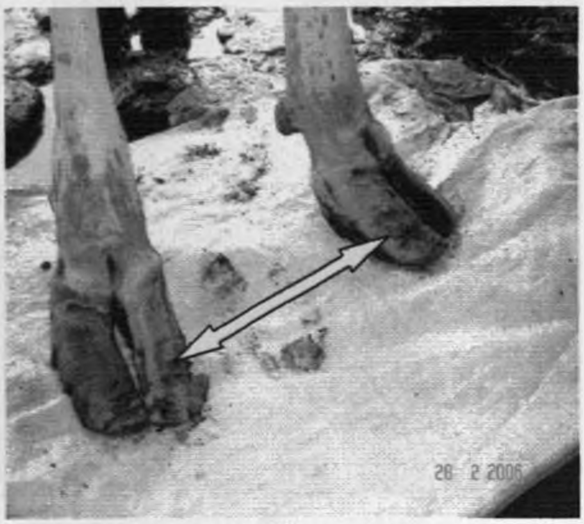


Figure 5.11: Sole ulcer showing granulation tissue (notched arrow) close to the axial part of zone 4 of the weight-bearing surface of the right claw. Sole haemorrhages are present in zone 5 (overlapping arrows). These were seen in 8 of the 300 dairy cows examined during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).



A



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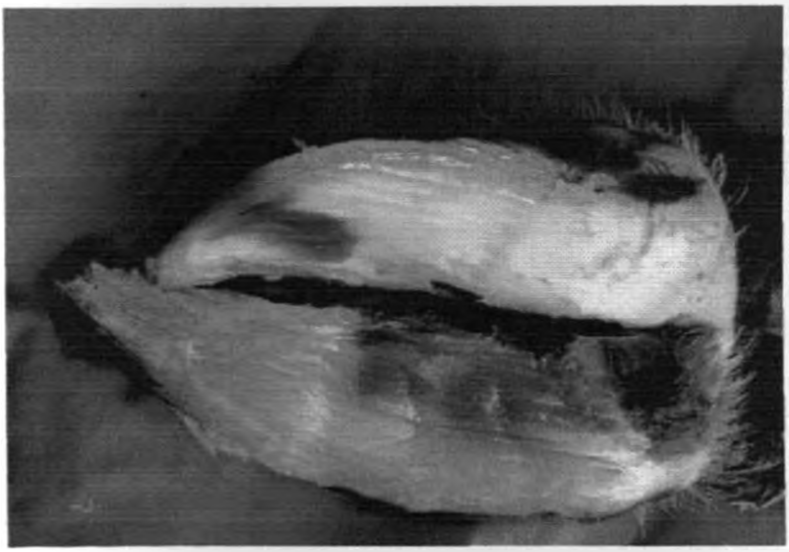
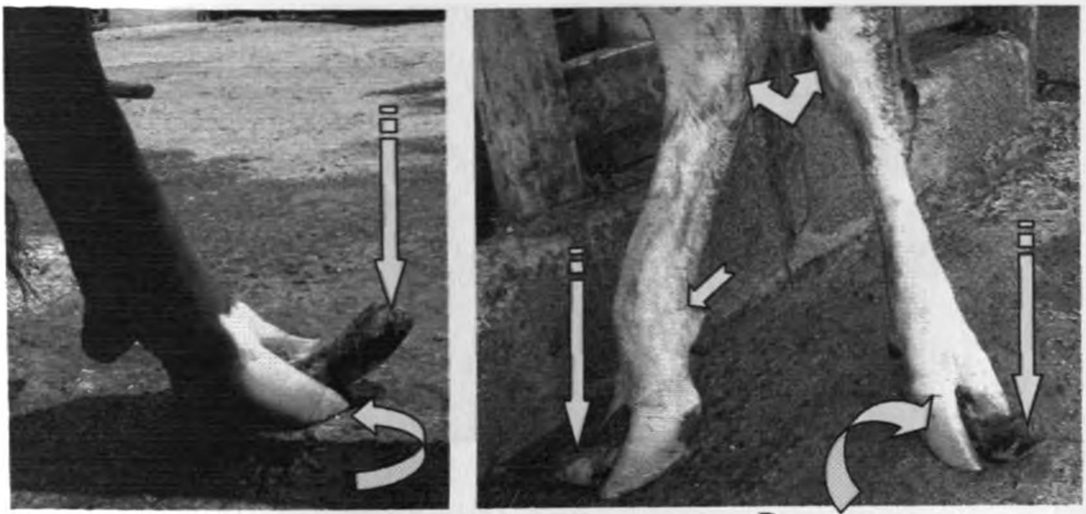


C

Figure 5.12: Regular claw overgrowth in dairy cows seen during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006). **A**-Elongation of the toe (unidirectional arrow) without prominent horizontal ridges. **B**-Elongation without flattening of the claw (left-right arrow).
C-Absence of sole haemorrhages on trimming.



A B

Figure 5.13: A-Crooked and upward elongation of lateral claws with thickened toe (striped arrows) in 2 out of 300 dairy cows examined during the study of characteristics of laminitis and other claws in Nairobi and its environs (December 2005-June 2006). The medial claws were normal size and shape (curved arrows). In **B**-the standing posture was abnormal with flexed fetlock (notched arrow) and adducted hock joints (angled arrows)

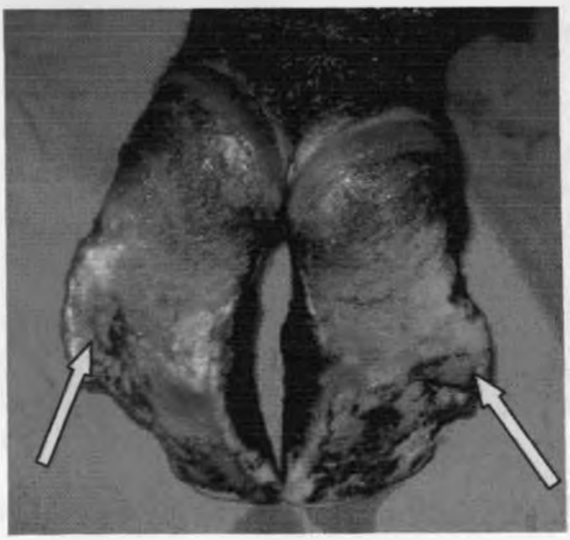
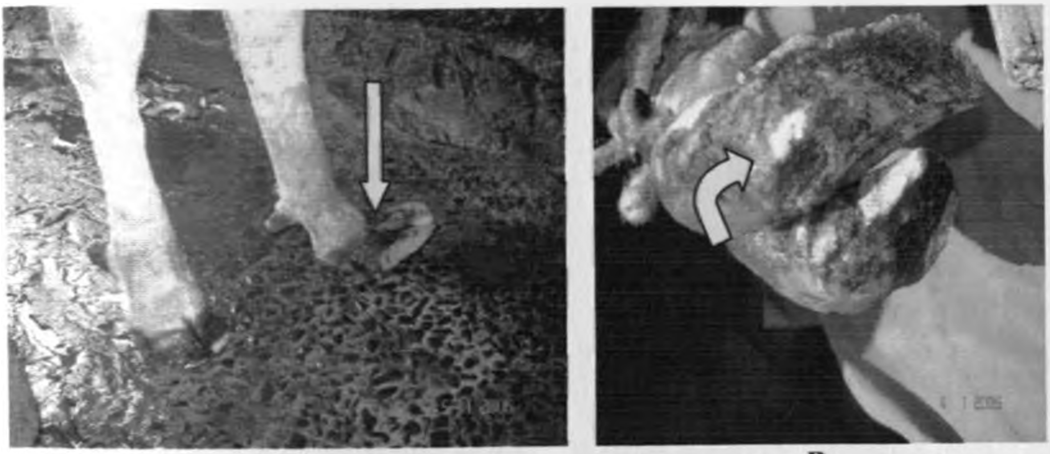
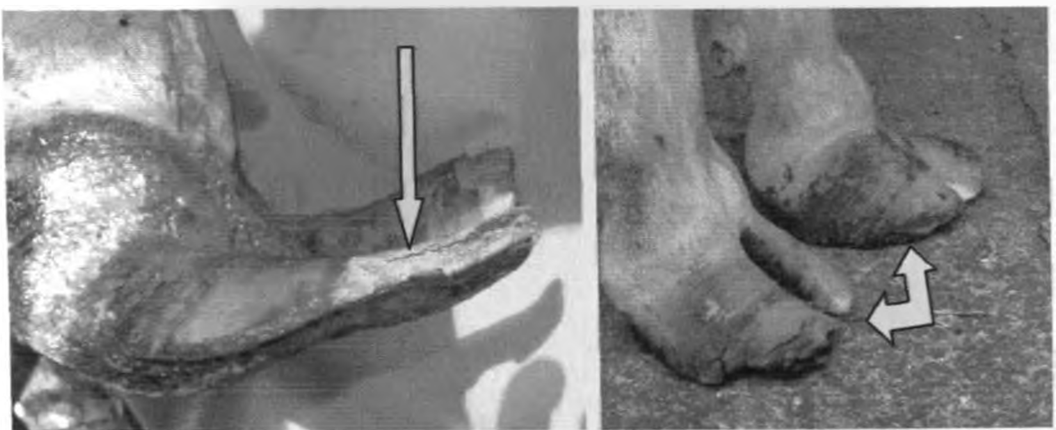


Figure 5.14: Irregularly widened claws with uneven margins (arrows). These were encountered in dairy cows during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).



A B

Figure 5.15: Concave claws as a result of chronic laminitis in 15 out of 300 dairy cows examined during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006). Note: **A**-concave shape of the dorsal wall (straight arrow) and **B**-the extreme convex shape of the weight-bearing surface (curved arrow) of the claw whose opposite side is concave.



A B

Figure 5.16: Elongated flattened claws **A**-(straight arrow) and **B**-(angled arrows) as a result of chronic laminitis that was seen in dairy cows examined during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

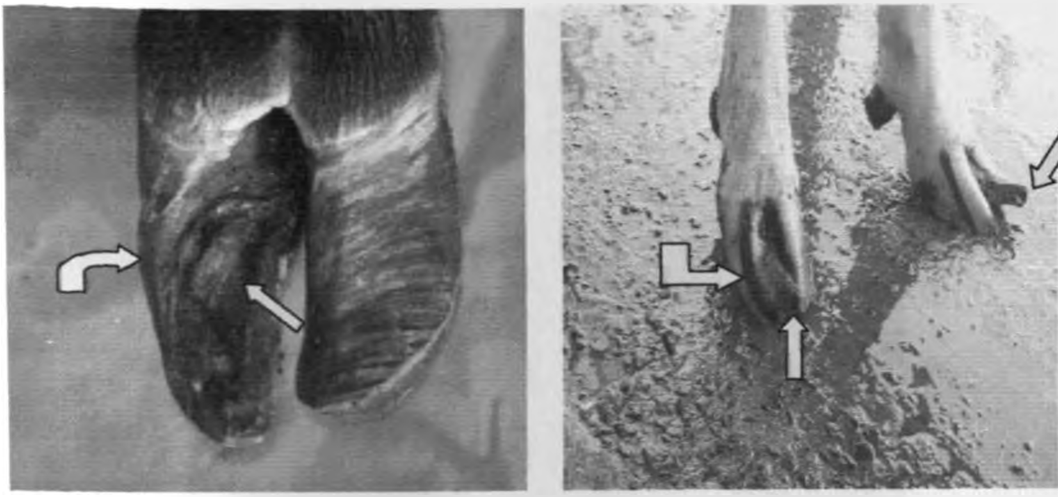


Figure 5.17: Turning of axial wall upwards (straight arrows) and the vertical wall downward to form part of the tread surface (curved arrows) of **A**-medial and **B**-lateral claws in 2 out of 300 dairy cows examined during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

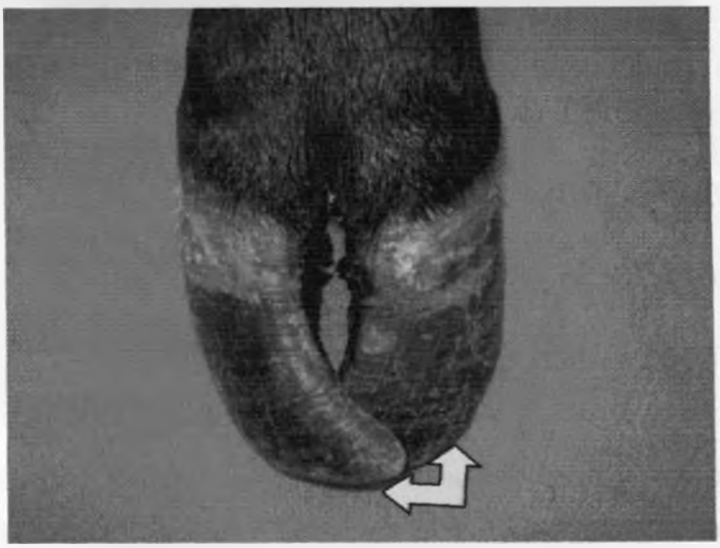
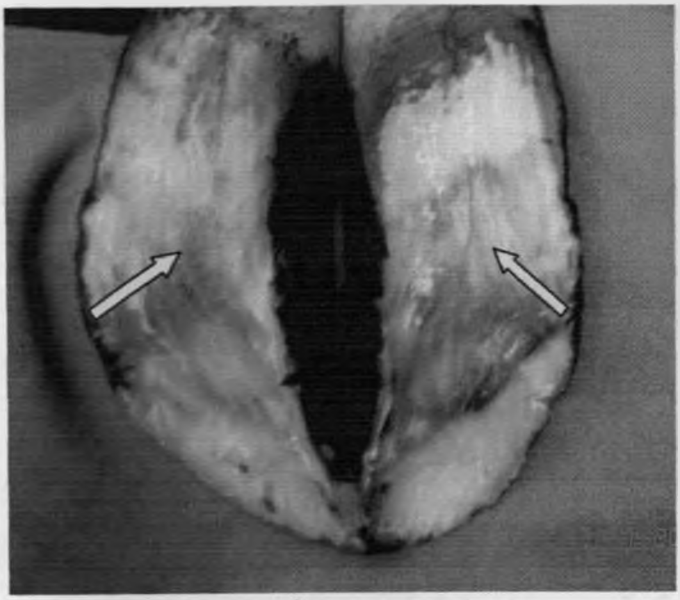
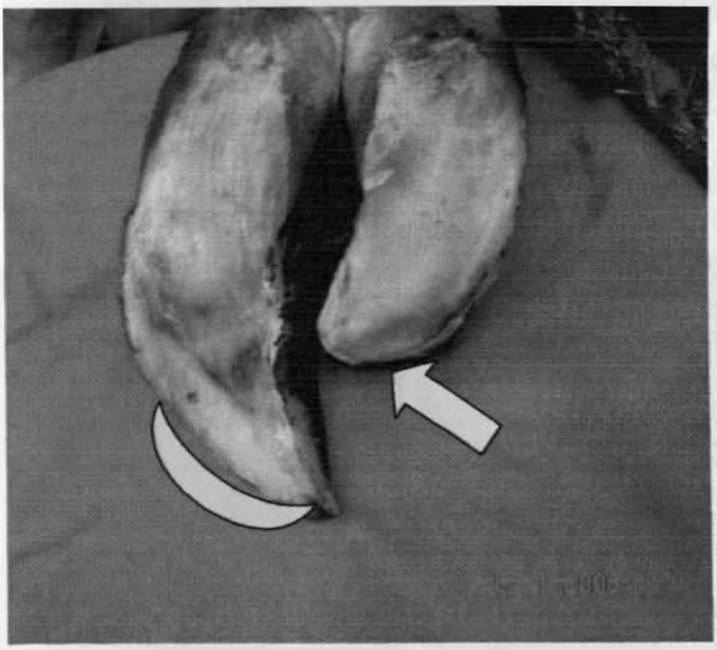


Figure 5.18: Cross toes ("scissor feet") with overlapping toes (angled arrows) as seen in dairy cows examined during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs under (December 2005-June 2006).



A



B

Figure 5.19: Sole haemorrhages evident after trimming of the horn (thin arrows) and occurring concurrently with claw overgrowth (crescent) as a sign of chronic laminitis that were seen in 63 out of 300 dairy cows examined during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006). **A**-Only the sole has been trimmed. **B**-the lengthened part of the right claw has been trimmed off (thick arrow).

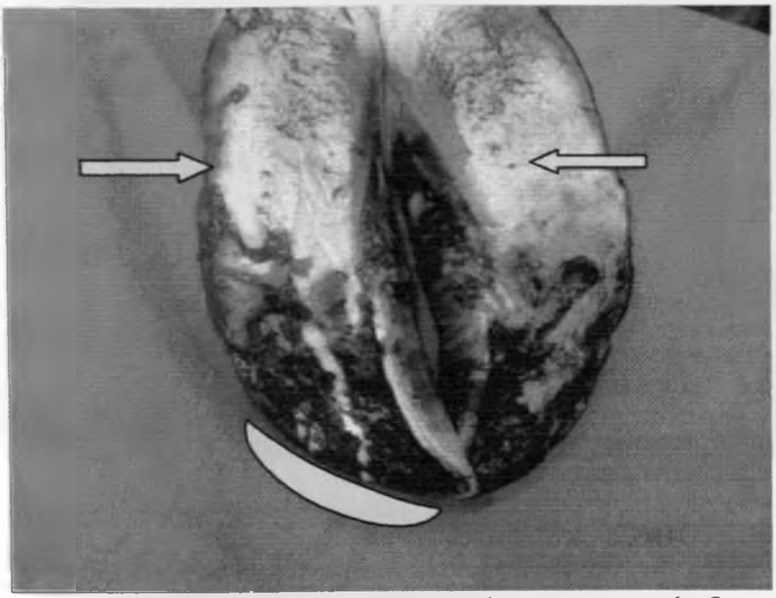


Figure 5.20: Severe sole haemorrhages (arrows) that were seen before claw trimming and occurring concurrently with claw overgrowth (crescent) in cases of chronic laminitis encountered in dairy cows during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 200 5-June 2006).

Figure 5.21: Splayed claws showing extreme separation of the toes (left-right arrows) seen in 26 out of 300 dairy cows examined during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

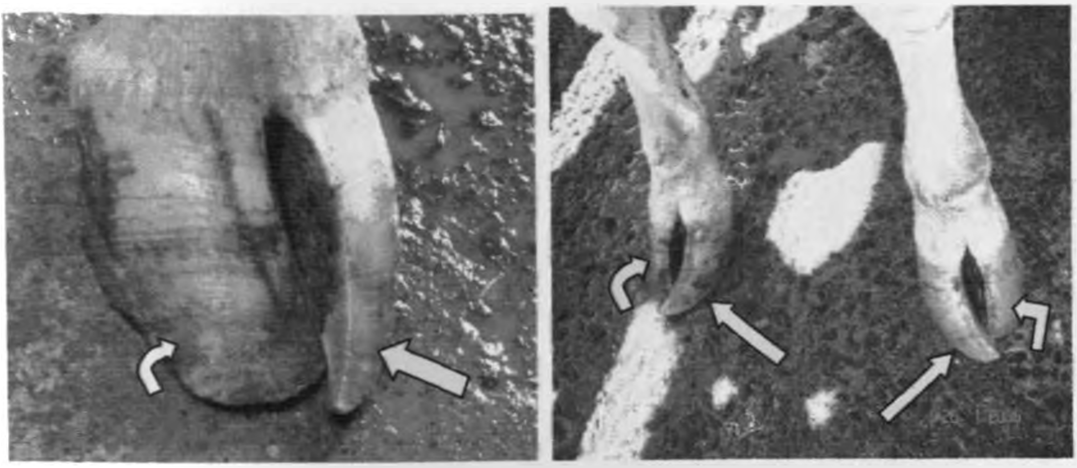
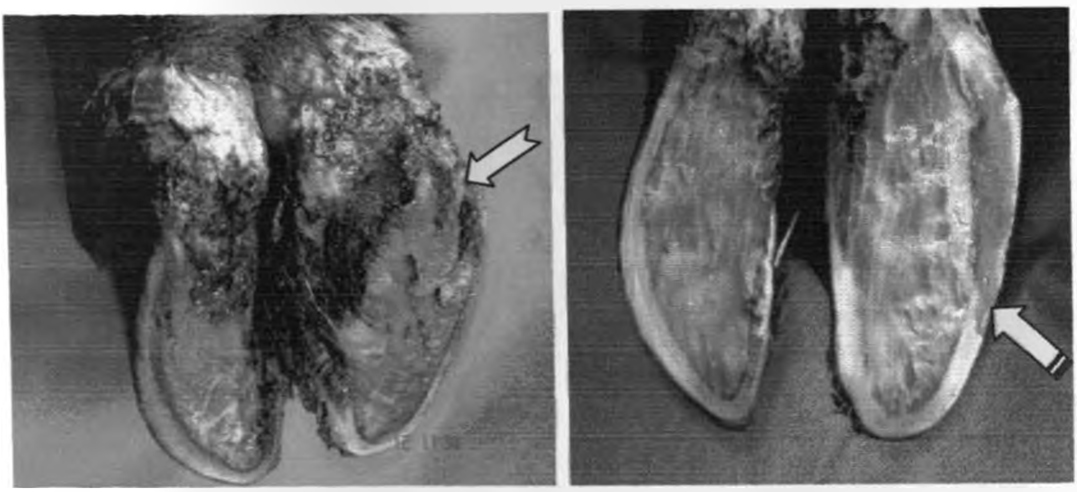


Figure 5.22: Bilateral corkscrew claws affecting medial claws of 14 out of 300 dairy cows examined during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006). Note the spiraling claws (straight arrow) and the normal claws (curved arrow).



A B

Figure 5.23: Sole abscess seen in 1 out of 300 dairy cows examined during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006). Note: **A**-the swollen right claw before lancing (notched arrow) and **B**-purulent exudates drained by lancing (striped arrow).

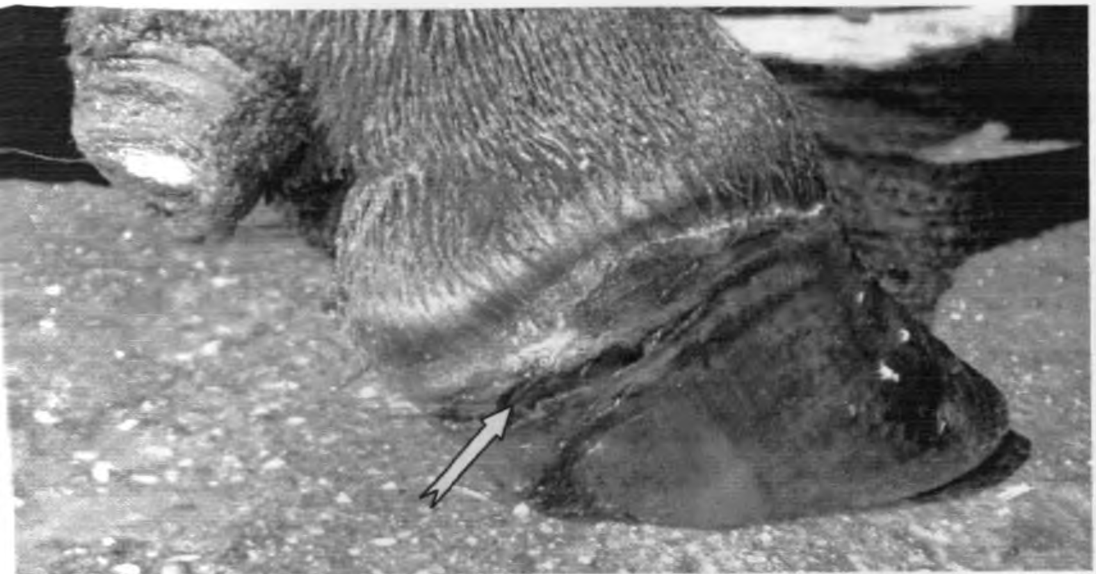


Figure 5.24 Infected horizontal hoof wall fissure that was occurred bilaterally on the lateral claws of hind limbs (notched arrow) in 1 out of 300 dairy cows examined during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

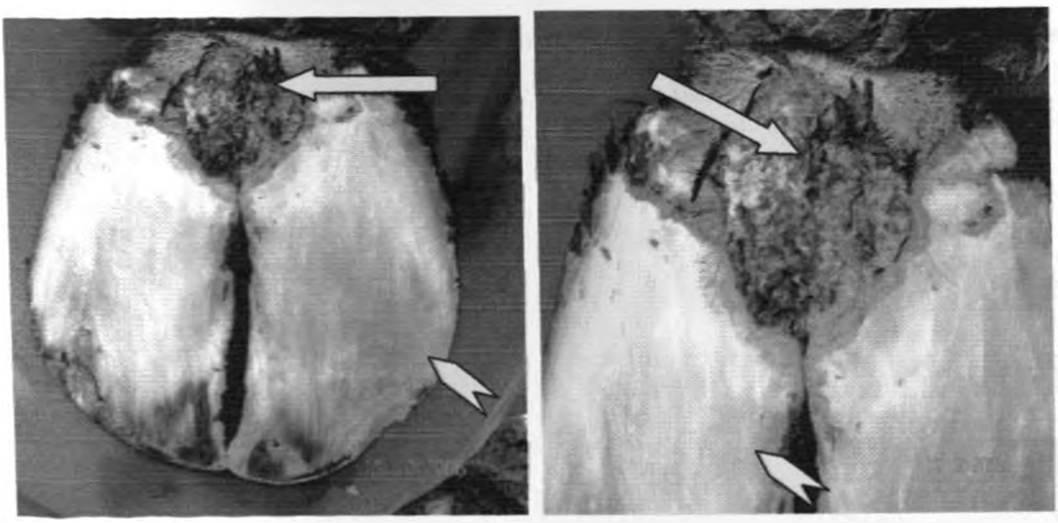


Figure 5.25 Digital dermatitis ("hairy warts," digital papillomatosis) (straight block arrows) lesions seen in 7 out of 300 dairy cows examined during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006). Some had concurrent laminitis evidenced by sole haemorrhages (notched arrows)

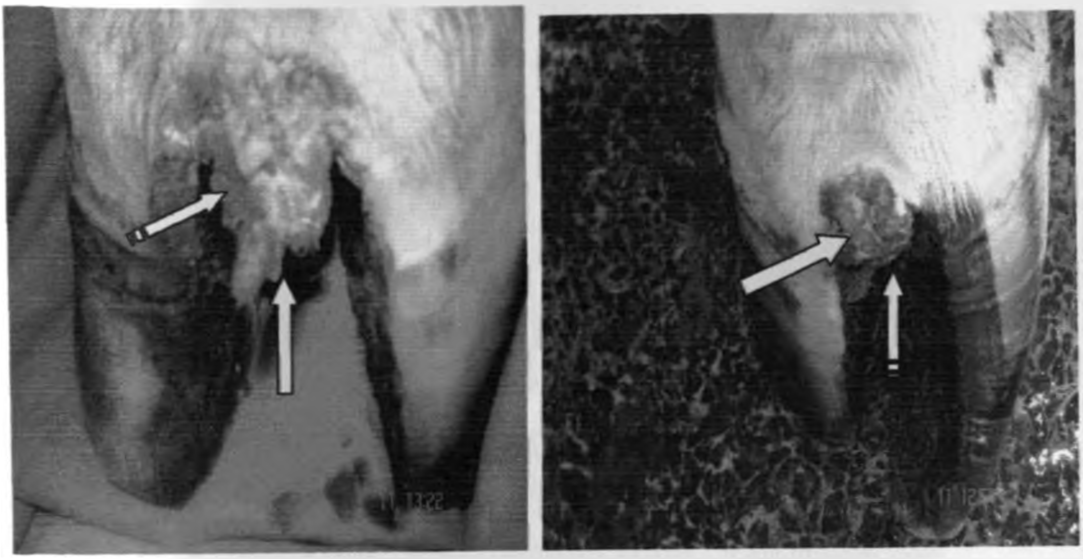


Figure 5.26: Ulcerated and infected interdigital fibromas (straight arrows) that were seen bilaterally in 1 out of 300 dairy cows examined during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006). These fibromas had superficial black necrotic areas (thin striped arrows).

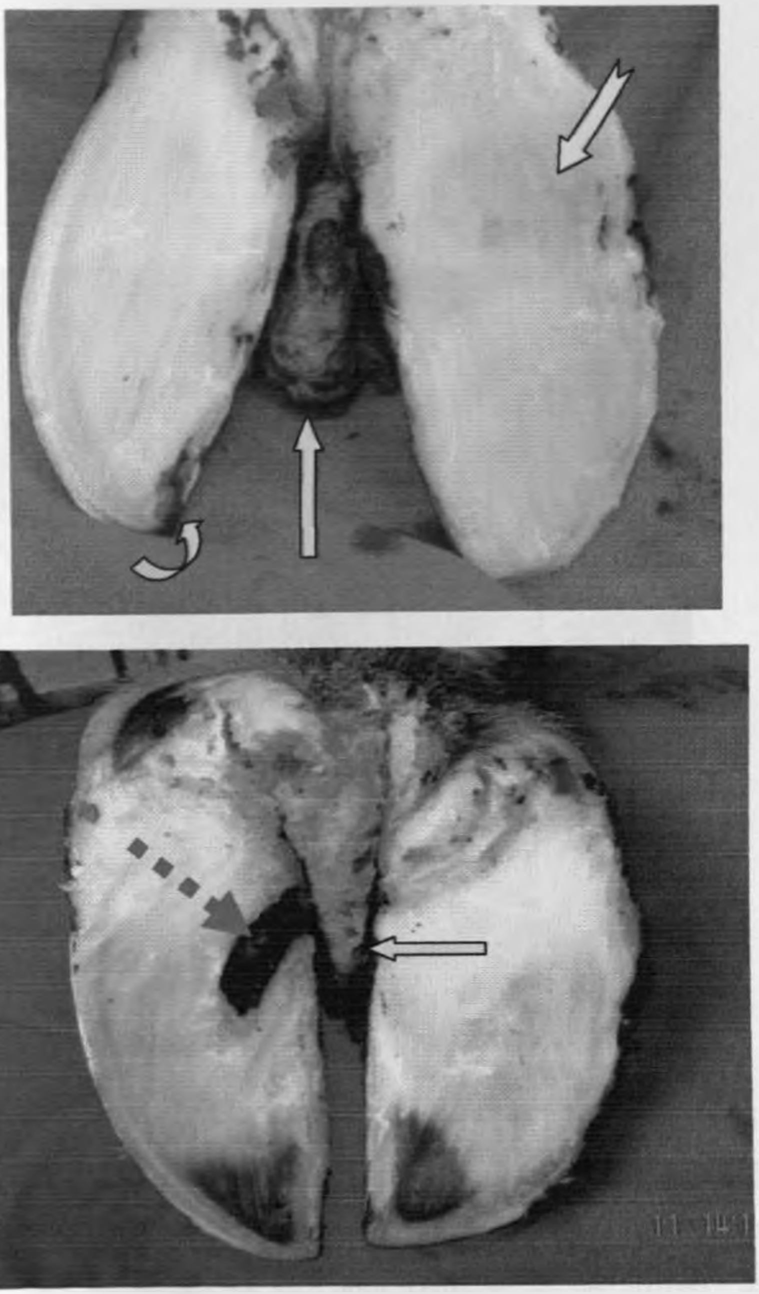


Figure 5.27: Bilateral loose hyperplastic and thickened skin folds that extended from cranial to caudal aspects within the interdigital spaces of the claws (arrows) of hind limbs in 1 out of 300 dairy cows examined during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006). One of the claws had haemorrhages indicating concurrent subclinical laminitis (notched arrow). Another had a sole ulcer (dotted arrow). Curved arrow shows an area of accidental injury during trimming.

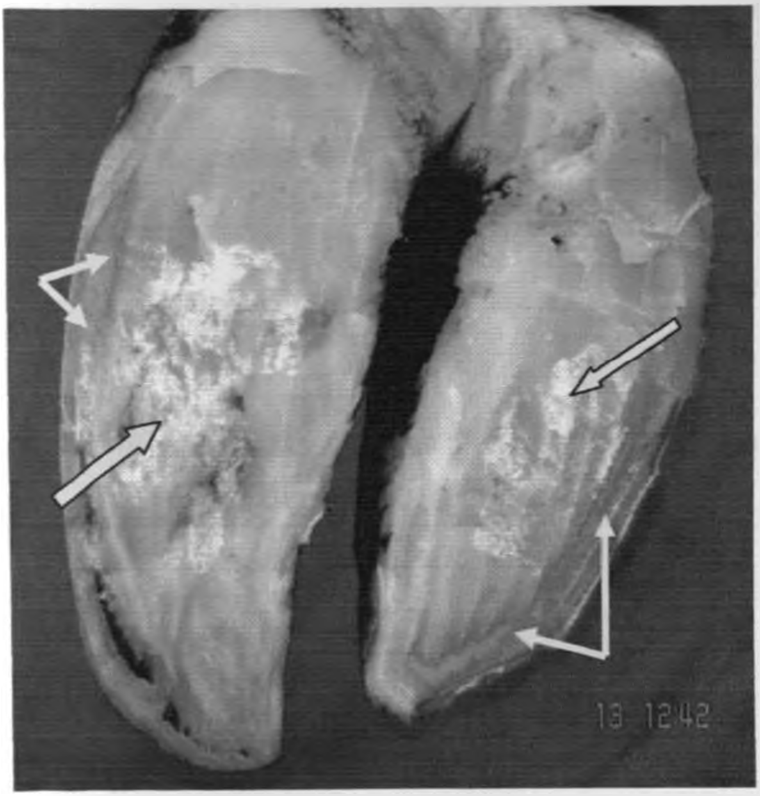


Figure 5.28: White appearance of softened and crumbling horn of the sole seen in some cases of chronic laminitis in dairy cows during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006). Notice the whiteness and looseness of the horn (straight block arrows) and the yellow discolouration of abaxial white line as evidence of laminitis (V-arrows)

5.4 Prevalence rates of various claw disorders

Among the 300 cows examined, 88% (264) had at least a claw lesion. Sixty nine percent (182) of the cows with claw lesions had subclinical lesions and were not lame (Figure 5.29). The prevalence rate of subclinical laminitis was 49.3% (148) and was higher than 21% (63) for chronic laminitis. Among the laminitis associated claw lesions, sole bruising (erosion) had the highest prevalence rate of 45% (135) followed by heel erosion at 27% (82). Sole ulcers had very low prevalence rate of 2.7% (8). The prevalence rates of the rest of the claw lesions are presented in table 5.1.

Among the cows that had subclinical laminitis, 70.3% (104) were zero-grazed and 29.7% (44) were pasture-grazed, but the difference was not statistically significant ($p > 0.05$). The number of cows that had chronic laminitis in the zero-grazed farms was 56 (88.9%) and in the pasture-grazed farms 7 (11.1%). This difference was statistically significant ($\chi^2 = 11.0$, $p < 0.001$) (Figure 5.30)

Among the cows with claw deformities, claw overgrowth had the highest prevalence rate of 30.3% (91) followed by those with prominent deep horizontal ridges (grooves) of the dorsal wall of the claw which had a prevalence rate of 17.8% (53) and flattened claws with 12% (36). Corkscrew claws had the lowest prevalence at 4.7% (14) (Table 5.1). The proportion of lesions in the lateral claws (82.7%) was significantly higher ($\chi^2 = 86.5$, $p < 0.001$) than in the medial claws (46.3%).

Out of the 300 cows examined, 52% (156) manifested sole haemorrhages, and 82% of those with laminitis (subclinical and chronic), had sole haemorrhages. Cows with slight to moderate haemorrhages (scores 1 and 2) were 44.7% (134), while 0.7% (2) had severe haemorrhages (score 3) and exposed corium (score 4) as shown in table 5.2. Zone 4 of the sole was the most commonly haemorrhagic being involved in 34.7% of the cases, but the rarest haemorrhagic zones were 1 and 5 which were involved in 8.7% and 0.7% of the cases respectively (Figure 5.31). However in 52% of the cows, sole hemorrhages occurred concurrently in more than one zone.

Table 5.1: Prevalence rates of claw disorders diagnosed after examining 300 dairy cows during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

Claw disorders	Number of cows (n = 300)	Prevalence (%)
Laminitis		
Subclinical laminitis	148	49.3
Chronic laminitis	63	21.0
Laminitis-related lesions		
Sole bruising (erosion)	135	45.0
Heel erosion	82	27.3
White line separation	54	18 .0
Double (underrun) sole	51	17.0
Sole ulcer	8	2 .7
Sole foreign bodies	1	0.3
Claw deformities		
Sole overgrowth	91	30.3
Horizontal ridges	53	17.8
Flattened claws	36	12.0
Splayed claws	26	8.7
Concaved claws	15	5.0
Corkscrewed claws	14	4.7
Non-laminitic lesions		
Infections	14	4.7
Traumatic	2	0.7
Growths	2	0.7

Key: n = total No. of cows, $(\frac{y}{n}) \times 100$ = % prevalence, y = cows with each lesion

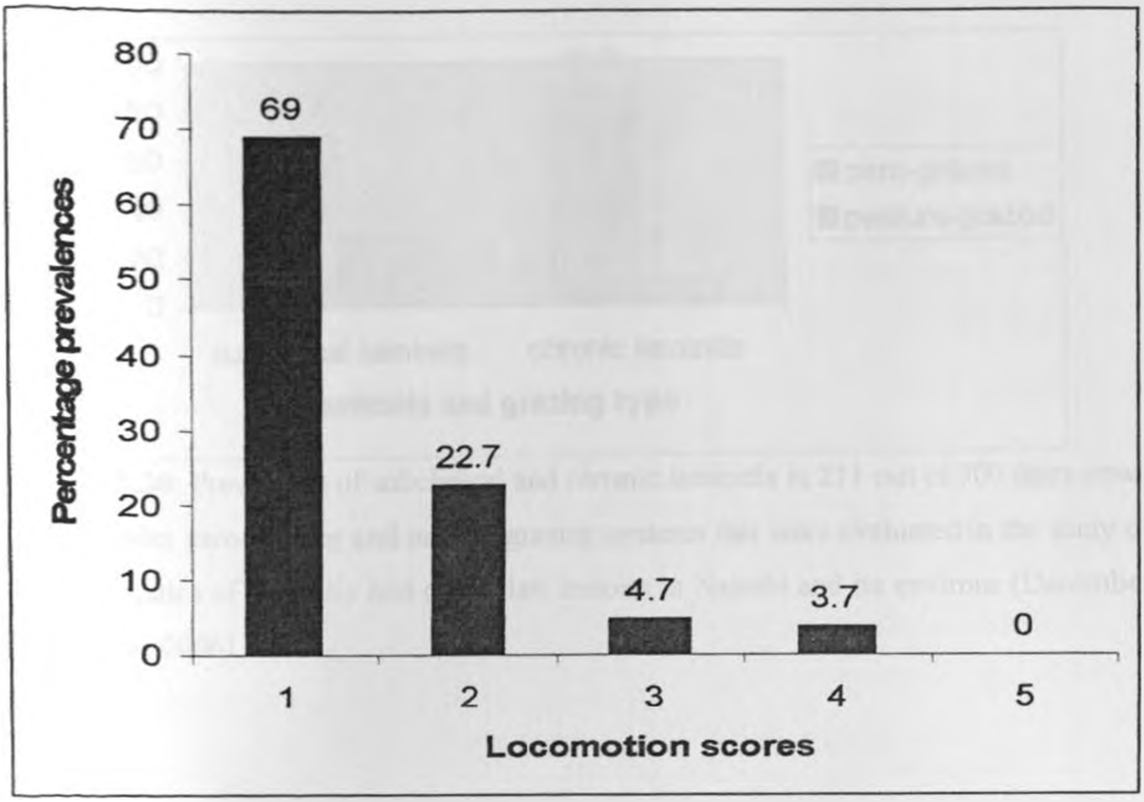


Figure 5.29: Prevalence of lame cows based on categories of locomotion scores after examining 300 dairy cows during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

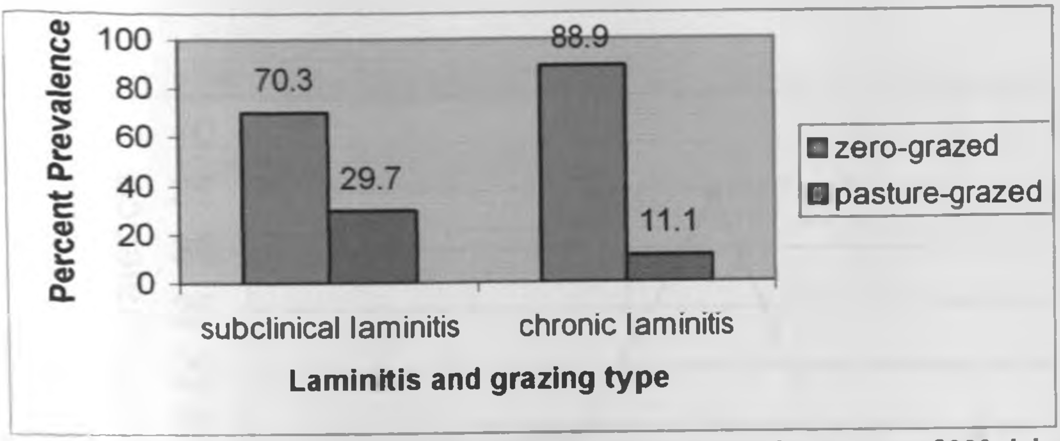


Figure 5.30: Prevalence of subclinical and chronic laminitis in 211 out of 300 dairy cows raised under zero-grazing and pasture-grazing systems that were evaluated in the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

Table 5.2: Prevalence of cows with sole haemorrhages classified according to haemorrhage scores in the 300 dairy cows examined during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

Haemorrhage scores	Number of cows	Prevalence (%)
0	144	48
1	75	25
2	59	19.7
3	20	6.7
4	2	0.7

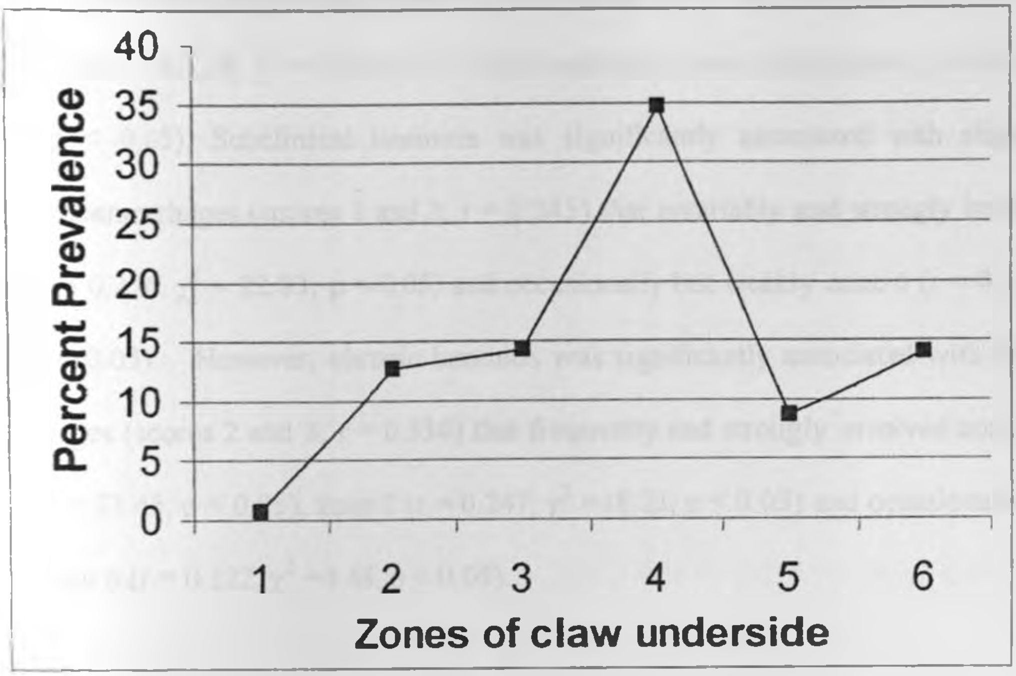


Figure 5.31: Prevalence of sole haemorrhages in subclinical and chronic laminitis according to the zones affected in 156 out of 300 dairy cows examined during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

5.5 Association between laminitis and haemorrhages.

There was significant association between haemorrhage score and subclinical laminitis ($r = 0.546$, O.R. = 21.24, $\chi^2 = 89.45$, $p < 0.05$) and also chronic laminitis ($r = 0.41$, $\chi^2 = 50.16$, $p < 0.05$). Subclinical laminitis was significantly associated with slight to moderate haemorrhages (scores 1 and 2, $r = 0.245$) that invariably and strongly involved zone 4 ($r = 0.276$, $\chi^2 = 22.83$, $p < 0.05$) and occasionally but weakly zone 6 ($r = 0.14$, $\chi^2 = 5.87$, $p < 0.05$). However, chronic laminitis was significantly associated with severe haemorrhages (scores 2 and 3, $r = 0.334$) that frequently and strongly involved zone 3 ($r = 0.28$, $\chi^2 = 23.45$, $p < 0.05$), zone 2 ($r = 0.247$, $\chi^2 = 18.23$, $p < 0.05$) and occasionally but weakly zone 6 ($r = 0.122$, $\chi^2 = 4.48$, $p < 0.05$).

5.6 Association between locomotion and claw disorders

A strong positive association was demonstrated between moderate to severe lameness (locomotion scores 3 to 5) and chronic laminitis ($r = 0.583$, O.R. = 3.7), claw overgrowth ($r = 0.45$), concave claws ($r = 0.33$), and flat claws ($r = 0.307$). However, the most significant association was between higher locomotion scores and chronic laminitis ($\chi^2 = 74.05$, $p < 0.05$). Other claw lesions that showed weak positive association with moderate to severe lameness were white line separation ($r = 0.274$) and sole ulcers ($r = 0.202$). Therefore cows with the rest of the claw disorders such as corkscrew and splayed claws, sole bruising, heel erosion, double soles and horizontal ridges on the dorsal wall of the claw had either normal locomotion (score 1) or mild lameness (locomotion score 2).

5.7 Association between laminitis and other claw disorders

Chronic laminitis showed strong positive and significant association with white line separation ($r = 0.355$, $\chi^2 = 37.78$, $p < 0.05$), double soles ($r = 0.377$, $\chi^2 = 42.57$, $p < 0.05$), claw overgrowth ($r = 0.568$, $\chi^2 = 96.69$, $p < 0.05$), horizontal ridges ($r = 0.45$, $\chi^2 = 61.27$, $p < 0.05$), concave claws ($r = 0.445$, $\chi^2 = 59.39$, $p < 0.05$). flat claws ($r = 0.439$, $\chi^2 = 57.87$, $p < 0.05$) and corkscrew claw ($r = 0.39$, $\chi^2 = 45.71$, $p < 0.05$). It was also demonstrated that chronic laminitis was weakly but significantly associated with sole bruising ($r = 0.192$, $\chi^2 = 11.02$, $p < 0.05$) and sole ulcers ($r = 0.118$, $\chi^2 = 4.16$, $p < 0.05$). The rest of the claw disorders did not show any association with chronic laminitis (Table 5.3). Using relative risk (RR) to predict the likelihood of a diagnosis of chronic laminitis based on presence of certain claw deformities, it was found that those cows with sole overgrowth had about 30 times (RR = 29.84) likelihood of simultaneously having chronic laminitis. Cows with concave (RR = 5.89) or flat (RR = 4.70) claws, and those with horizontal ridges (RR = 4.70) were approximately 5 times likely to concurrently have chronic laminitis. Corkscrew and splayed claws had no prediction influence on chronic laminitis.

A significantly weak but negative association was demonstrated between subclinical laminitis and some claw disorders such as claw overgrowth ($r = -0.23$, $\chi^2 = 15.94$, $p < 0.05$), concave claws ($r = -0.226$, $\chi^2 = 15.37$, $p < 0.05$), flat claws ($r = -0.221$, $\chi^2 = 14.62$, $p < 0.05$), corkscrew claws ($r = -0.218$, $\chi^2 = 14.3$, $p < 0.05$) and horizontal ridges ($r = -0.143$, $\chi^2 = 6.09$, $p < 0.05$). The rest of the claw disorders did not show any association with subclinical laminitis (Table 5.4).

Table 5.5: A comparison of means of various dimensions of claws with and without chronic laminitis in 300 dairy cows examined during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

Claw parameter	Means	± SD	Means	± SD	p-value
	without chronic laminitis	without chronic laminitis	With Chronic laminitis	with Chronic laminitis	
Toe angle right lateral	45.7	8.3	35.8	16.9	<0.001
Toe angle right medial	47.4	8.2	40.1	14.8	<0.001
Toe angle left lateral	47.4	8.2	35.8	14.8	<0.001
Toe angle left medial	47.8	7.5	40.1	18.6	<0.001
Digit width right foot	47.2	8	34.4	14.8	<0.001
Digit width left foot	15.5	16.2	40.2	13.1	<0.0036
Claw diagonal right lateral	9.8	0.9	24.1	1.6	<0.001
Claw diagonal right medial	14	1.5	10.3	2.4	<0.001
Claw diagonal left lateral	14.1	1.5	15.7	2.2	<0.001
Claw diagonal left medial	14.2	1.5	15.5	2.3	<0.001

of the farms had cow units with slight to moderate floor slope (< 3% gradient), while 9% were steep (> 3% gradient), and 29% had no slope at all.

5.9.2.2 Cubicles

A total of 59% of the farms were either stocked to capacity (cubicle to cow ratio 1:1), or under-stocked (more cubicles than the number of cows). These two categories of farms had 47% of the cows included in the study. Farms without cubicles were 22% and had 35% of the cows in the study. The rest (16%) of the farms, were over-stocked (more cows than cubicles) and 3% had tie-stalls with individual cow per stall.

The proportion of farms without cubicle bedding was 38% and in these farms, the cows lay on bare concrete. Wood shavings as cubicle bedding were in 25% of the farms, soil bedding in 19% and the rest of the bedding included sawdust, sand, rubber mattresses, loose stones and rice husks all together in 18% of the farms (Figure 5.33).

5.9.2.3 Neck-bar, lunging space and bob zone

Among the farms studied, 43% were without neck-bars, 16% had proper level (0.6m from ground-level) neck-bars, and 41% either had too high (> 0.6m) or too low (< 0.6m) level neck-bars. Lunging space was adequate (≥ 0.4m for forward head movement during the act of standing) in 63% of the farms, while in 22%, it was inadequate (< 0.4m) and in the latter, the cows struggled to stand from lying position. In the rest of the farms (15%), lunging space did not apply since they had no cubicles. In 72% of the farms, bob zone was adequate (0.4-0.6m for up-down movement of the head during the act of standing) and in 16% it was inadequate (< 0.4m) (Figure 5.34), while in 12% the bob zone did not apply since there were no cow houses.

5.9.2.4 Curb (Kerb)

The curb being considered in this study was between the walk alley and the cubicles. In 50% of the farms, cow units did not have curbs and in 19%, curbs were proper height from the ground (10-15 cm) where the cows did not struggle to get in or out of the cubicles. However, 31% of the units had curbs that were too high (> 15 cm) which were difficult for the cows to go over especially when walking backwards out of the cubicles (Figure 5.35).

5.9.2.5 Feeding space

In 88% of the farms, cow units had adequate feeding area (≥ 0.8m/cow) for all the cows to feed simultaneously. In most of them the older and younger stock fed separately. However, cow units in 12% of the farms had inadequate feeding space (< 0.8m/cow) due to overstocking (Figure 5.36).

5.9.2.6 Concentrate feeding

Each of the farms included in this study had put into place a system of feeding the cows with concentrates. In 81% of them, concentrate feeding was regular (at every milking), which was at least 2-3 times a day, and in some there was additional feeding between milking times. In 19% of the farms, concentrate feeding was very occasional, being done mostly during the first week of the month after farmers were paid for milk supplied to the co-operative dairies and to individual consumers during the previous month. It was also done one week before the end of the month when farmers would borrow feed on credit from sellers with promise of settling the bill at the end of the current month. However, the levels of concentrate feeding in these farms were not determined in this study because even within the same farm the levels varied from day to day. Concentrates were either commercially available mixtures from local feed millers, or on-farm-made ration mixtures of carbohydrate, protein, mineral and vitamin raw materials.

5.9.2.7 Fodder type

In 50% of the farms, cows were fed on withered mature fodder, but in 25% of the farms, they were fed on fresh (not withered) mature fodder, while 18.75% of the farms had dry fodder feeding. Only in one farm were cows fed on fresh succulent fodder and in one other farm, total mixed ration (TMR) feeding. The fodder used in these farms was either napier grass or maize stems chopped into small pieces. In 16% of the farms, apart from green fodder, there was additional supplementation with corn or Napier grass silage (Figure 5.37).

5. 9.2.8 Mineral supplement

Cows in 47% of the farms were fed regularly (once/day) with 50-100g mineral supplements, and in 10% of the farms they were fed *ad libitum*, but in 40% of the farms, they were occasionally (at most 1-2 weeks per month) supplemented with $\leq$ 50g of minerals per day. However, only in 3% of the farms were cows not given mineral supplementation at all. The mineral supplements given were the locally available commercial mineral mixtures for dairy production such as "unga high phosphorus" (Unga

Ltd, Kenya), or "super maclick" (Cooper Kenya Ltd). The powdered mineral supplements were fed mixed with concentrates. Additionally in some farms, mineral-lick blocks were provided *ad libitum*.

5.9.2.9 Manure (slurry) removal

In 72% of the farms, manure was removed from the alleyway at least once per day and in 18% it was removed more than once per day, while in 10% of the farms, it remained for more than one day (Figure 5.38).

5.10 Association of cow-and farm-level factors with claw disorders

5.10.1 Association between cow-level factors and laminitis

Chronic laminitis had a significant association with cows in three or more parities ($\chi^2 = 11.57$, $p<0.05$) as well as those between 90 to 180 days in lactation ($\chi^2 = 9.75$, $p < 0.05$). But those between 1-90 days in lactation were significantly associated ($p < 0.05$) with subclinical laminitis. The rest of the cow-level factors (such as breed, body condition and milk yield) did not seem to influence occurrence of subclinical or chronic laminitis.

5.10.2 Association between farm-level factors and subclinical laminitis

The farm-level factors that were shown to have unconditional association with subclinical laminitis were frequent manure removal ($r = 0.215$, $\chi^2 = 13.85$, $p < 0.05$), regular concentrate feeding ($r = 0.135$, $\chi^2 = 5.45$, $p < 0.05$) and lack of mineral supplementation ($r = 0.172$, $\chi^2 = 8.90$, $p < 0.05$) (Table 5.6). However stepwise logistic regression analysis (screening interactions of floor types, presence or absence of cubicles, type of cubicle bedding, manure removal, concentrate feeding, type of fodder and mineral supplementation) revealed that the most significant farm-level contributor to the occurrence of subclinical laminitis was regular concentrate feeding (O.R. = 2.08, $p < 0.05$).

5.10.3 Association between farm-level factors and chronic laminitis

The farm-level factors that were found to have unconditional association with chronic laminitis were overstocking (less cubicles than cows) ($r = 0.36$, $\chi^2 = 38.87$, $p < 0.05$), type of cubicle bedding ($r = 0.312$, $\chi^2 = 29.13$, $p < 0.05$), earthen floor type ($r = 0.203$, $\chi^2 = 12.33$, $p < 0.05$), presence of a curb between alleyway and the cubicles ($r = 0.157$, $\chi^2 = 7.43$, $p < 0.05$), leaving manure in the alleyways ($r = 0.279$, $\chi^2 = 23.33$, $p < 0.05$), regular feeding with concentrates ($r = 0.218$, $\chi^2 = 14.25$, $p < 0.05$), and regular mineral supplementation ($r = 0.321$, $\chi^2 = 30.85$, $p < 0.05$) (Table 5.7). However, stepwise logistic regression analysis (testing interactions of all these unconditionally associated factors) pointed out the farm-level factors that most significantly contributed to the occurrence of chronic laminitis. These factors were: presence of fewer cubicles than the number of cows or overstocking (O.R. = 1.7, $p < 0.05$), earthen floor type (O.R. = 1.5, $p < 0.05$), and presence of a curb between alleyways and the cubicles (O.R. = 1.5, $p < 0.05$).

5.10.4 Association between farm-level factors and other claw disorders

In this study, earthen floor was found to be a significant protector against the occurrence of sole bruising (β-estimate = -1.796, S.E. = 0.835, $p < 0.05$). Regular concentrate feeding seemed to significantly enhance sole bruising (β-estimate = 2.187, S.E. = 0.814, p

< 0.05). Regular mineral supplementation was also protective against occurrence of sole bruising (β-estimate = -4.59, S.E. =1.50, $p < 0.05$).

Removal of manure more than once a day appeared to be significantly protective (β-estimate =-3.58, S.E. =1.01, $p<0.05$) against occurrence of white line separation. Regular concentrate feeding seemed to significantly enhance (β-estimate =3.69, S.E. =1.24, $p<0.05$) occurrence of white line separation, but regular mineral supplementation was found to reduce its frequency (β-estimate =-4.07, S.E. =2.05, $p<0.05$). Good concrete floors (non-slip and non-potholed) seemed to be protective (β-estimate =-1.969, S.E. =0.597, $p<0.05$) against heel erosion. There were no statistically significant associations between all the other claw disorders and the farm-level factors.

Table 5.3: Association between chronic laminitis and other claw disorders in 300 dairy cows examined during a study of characteristics of laminitis and claw lesions in Nairobi and its environs (December 2005-June 2006).

Claw disorders	Chi square (χ^2)	r-value	p-value	Conclusion
Claw overgrowth	96.69	0.568	<0.0001	Associated
Corkscrew claw	45.71	0.39	<0.0001	Associated
Flat claws	57.87	0.439	<0.0001	Associated
Concave claws	59.39	0.445	<0.0001	Associated
Splay claws	0.07	0.015	0.7929	No association
Horizontal ridges	61.27	0.45	<0.0001	Associated
Haemorrhage scores	50.16	0.41	<0.0001	Associated
Haemorrhage zone 1	0.54	-0.042	0.4644	No association
Haemorrhage zone 2	18.23	0.247	<0.0001	Associated
Haemorrhage zone 3	23.45	0.28	<0.0001	Associated
Haemorrhage zone 4	11.05	0.192	0.0009	Associated
Haemorrhage zone 5	5.23	0.132	0.0222	Associated
Haemorrhage zone 6	4.48	0.122	0.0343	Associated
Sole ulcers	4.16	0.118	0.0412	Associated
Sole bruising	11.02	0.192	0.0009	Associated
White line separation	37.78	0.355	<0.0001	Associated
Heel erosion	3.38	0.106	0.07	No association
Double soles	42.57	0.377	<0.0001	Associated
Sole foreign bodies	0.27	-0.03	0.6055	No association

Table 5.4: Association between subclinical laminitis and other claw disorders in 300 dairy cows examined during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

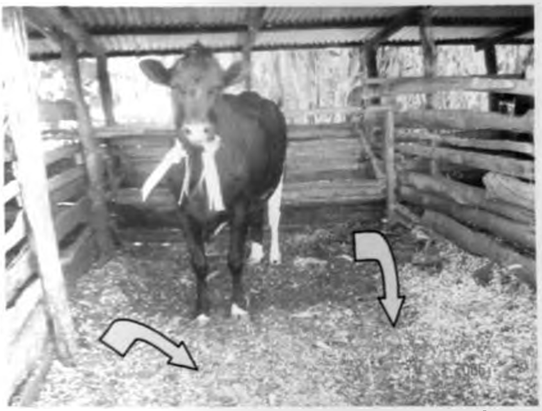
Claw disorders	Chi square	r-value	p-value	Conclusion
Claw overgrowth	15.94	-0.23	<0.0001	Associated
Corkscrew claw	14.3	-0.22	0.0002	Associated
Flat claws	14.62	-0.22	<0.0001	Associated
Concave claws	15.37	-0.23	<0.0001	Associated
Splay claws	1.74	0.08	0.1865	No association
Horizontal ridges	6.09	-0.14	0.0136	Associated
Haemorrhage scores	89.45	0.55	<0.0001	Associated
Haemorrhage zone 1	2.07	0.08	0.1504	No association
Haemorrhage zone 2	0.19	0.03	0.6634	No association
Haemorrhage zone 3	0.07	0.02	0.7954	No association
Haemorrhage zone 4	22.83	0.28	<0.0001	Associated
Haemorrhage zone 5	1.7	0.08	0.1927	No association
Haemorrhage zone 6	5.87	0.14	0.0154	Associated
Sole ulcers	0	0	0.9695	No association
Sole bruising	0.11	0.02	0.7452	No association
White line separation	1.95	-0.08	0.1631	No association
Heel erosion	2.88	0.1	0.0898	No association
Double soles	2.52	-0.09	0.1127	No association
Sole foreign bodies	1.03	0.06	0.3101	No association

Table 5.5: A comparison of means of various dimensions of claws with and without chronic laminitis in 300 dairy cows examined during a study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

Claw parameter	**Means**	**± SD**	**Means**	**± SD**	**p-value**
	without chronic laminitis	without chronic laminitis	With Chronic laminitis	with Chronic laminitis	
Toe angle right lateral	45.7	8.3	35.8	16.9	<0.001
Toe angle right medial	47.4	8.2	40.1	14.8	<0.001
Toe angle left lateral	47.4	8 2	35 8	14 8	<0.001
Toe angle left medial	47.8	7.5	40.1	18.6	<0.001
Digit width right foot	47.2	8	34.4	14.8	<0.001
Digit width left foot	15.5	16.2	40.2	13.1	<0.0036
Claw diagonal right lateral	9.8	0.9	24.1	1.6	<0.001
Claw diagonal right medial	14	1.5	10.3	2.4	<0.001
Claw diagonal left lateral	14.1	1.5	15.7	2.2	<0.001
Claw diagonal left medial	14.2	1.5	15.5	2.3	<0.001

1 – Concrete floor

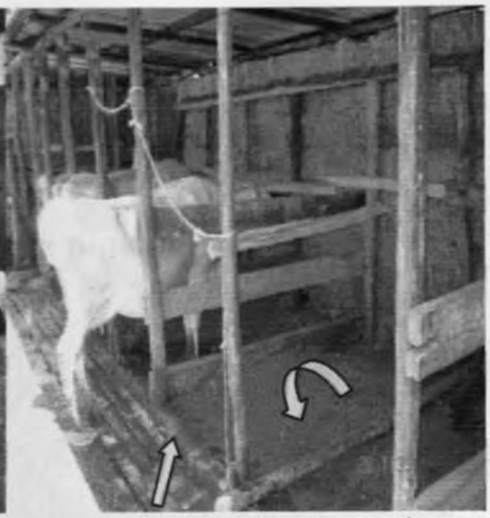
2 – Earthen floor



3 – Individual tie-stall with soil and wooden shavings

4 – An earthen open yard

Figure 5.32: Examples of floor types in some of the farms from which 300 dairy cows were sampled during the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006). **1**-Concrete floor with scattered manure (V-arrows), **2**-Earthen floor in the alley and feeding area (straight arrow), **3**-Tie-stall with soil and wooden shavings (curved arrows), **4**-Earthen open yard (quad arrow)

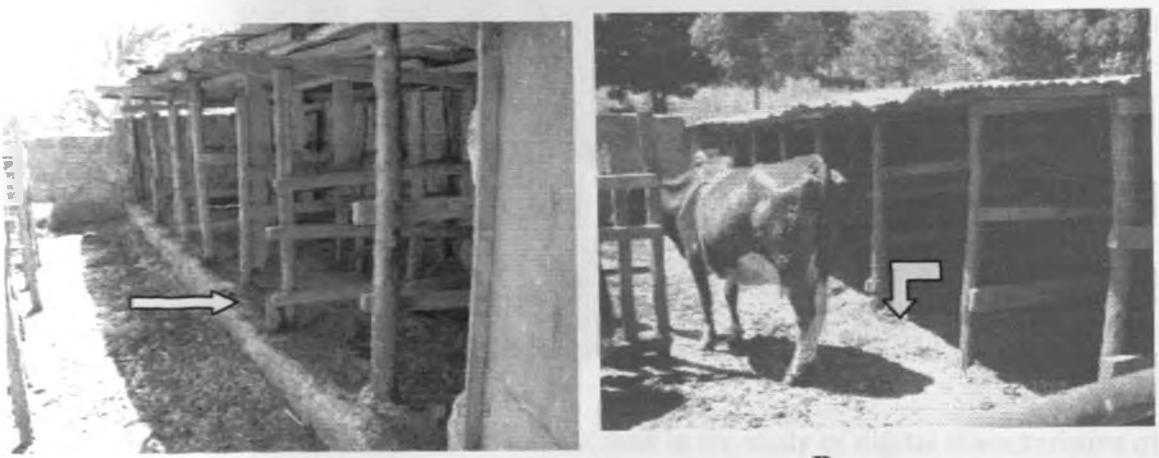



1 – Cubicles with sand bedding. **2** – Cubicles with soil bedding


3 – Cubicles with wood shavings **4** – Cubicle with rubber mat

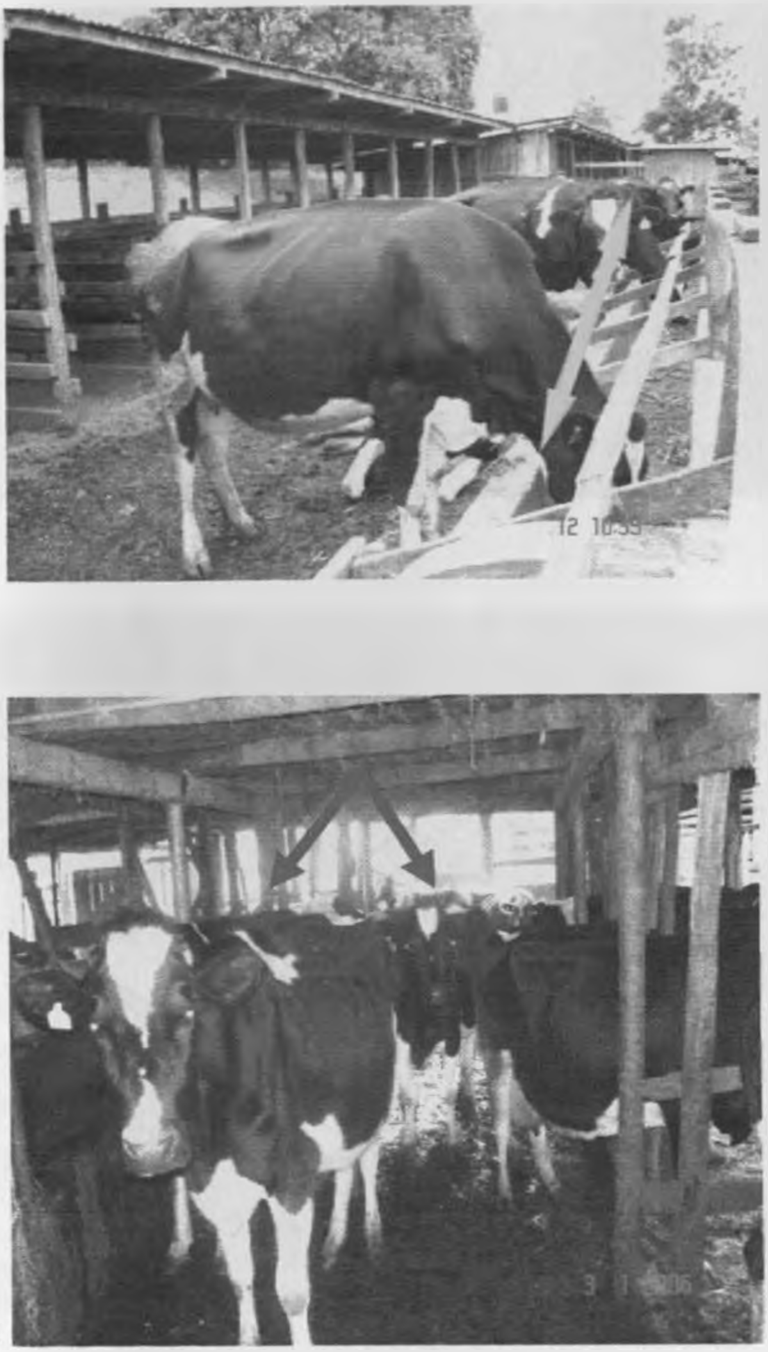
Figure 5.33: Cubicles showing different bedding types (curved arrows) in some of the farms used in the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006). Note the position of the curbs (kerbs) (straight arrows).

Figure 5.34: Low neck bar (notched arrow), inadequate lunging space (double sided up-down arrow) and inadequate bob zone (quad arrow) seen in some of the farms used in the study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). Note a cow struggling to stand under the neck bar.



A **B**

Figure 5.35: Cubicles: **A**-with a high curb (straight arrow) and **B**-without any curb (curved arrow) in some of the farms included in the study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).



A

B

Figure 5.36: An example of some cow units seen in the study of digital characteristics of laminitis and related claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). **A**-adequate feeding space (two sided arrow), **B**-overcrowding (V-arrows) and inadequate feeding space.

A

B

Figure 5.37: **A**-growing young succulent fodder (long thin arrow) and **B**-mature withered fodder is being transported to a farm in a pick-up truck (long block arrow). These were used to feed cows in some of the farms included in the study of characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

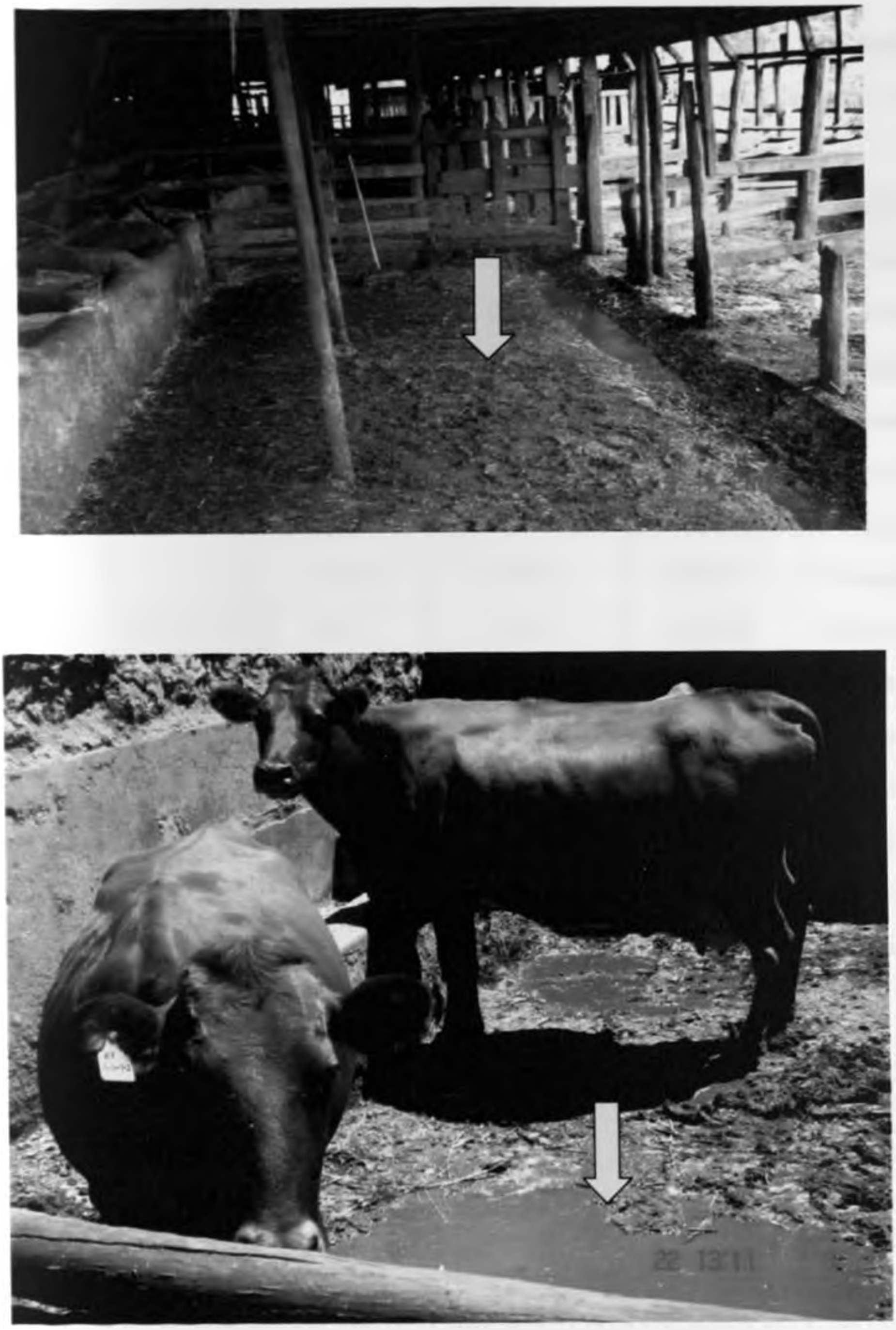


Figure 5.38: Two dairy cow units in which manure (arrows) was not removed daily. Some of the zero-grazed units included in the study of characteristics of laminitis and other claw lesions in Nairobi and its environs were left in this state for long. This resulted in accumulation of the slurry in the walk alleys (arrows).

Table 5.6: Association of subclinical laminitis with farm-level factors in a study carried out in 300 dairy cows from 32 farms to evaluate characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

Farm variables	Chi square	r-value	p-value	Conclusion
Floor types	5.52	0.1356	0.02381	No association
Cubicles	6.2	0.1438	0.1844	No association
Cubicle bedding	7.2	0.1549	0.5155	No association
Neck rail	0.44	0.0382	0.9322	No association
Lunging space	0.24	0.0283	0.8871	No association
Bob zone	0.35	0.0342	0.8393	No association
Curb	0.13	0.021	0.9361	No association
Floor slope	4.8	0.126	0.1872	No association
Stocking percentage	1.74	0.076	0.42	No association
Feeding space	0.08	-0.016	0.7784	No association
Manure removal	13.85	0.2149	0.001	Associated
Concentrate feeding	5.45	0.1348	0.0196	Associated
Fodder type	3.26	0.104	0.5151	No association
Mineral supplementation	8.9	0.1722	0.0307	Associated

Table 5.7: Association of chronic laminitis with farm-level factors in a study carried out in 300 dairy cows from 32 farms to evaluate characteristics of laminitis and other claw lesions in Nairobi and its environs (December 2005-June 2006).

Farm variables	Chi square	r-value	p-value	Conclusion
Floor types	12.33	0.203	0.0151	Associated
Cubicles	38.87	0.36	< 0.0001	Associated
Cubicle bedding	29.13	0.312	0.0003	Associated
Neck rail	4.84	0.127	0.1837	No association
Lunging space	5.05	0.13	0.0802	No association
Bob zone	2.79	0.096	0.2482	No association
curb	7.43	0.157	0.0244	Associated
Floor slope	7.32	0.156	0.0625	No association
Stocking percentage	6.69	0.149	0.035	Associated
Feeding space	0.81	0.052	0.3687	No association
Manure removal	23.33	0.279	< 0.0001	Associated
Concentrate feeding	14.25	-0.218	0.0002	Associated
Fodder type	7.732	0.1605	0.1019	No association
Mineral supplementation	30.85	0.321	< 0.0001	Associated

5.11 Discussion

The high prevalence (88%) of claw lesions in cows in this study closely agrees with the findings of Manske *et al.* (2002b). This also agrees with reports by other researchers that claw lesions are by far the most common causes of lameness in cattle (Clarkson *et al.*, 1996, Weaver, 2000). Considering that many of the farms included in the current study were zero-grazing smallholder systems, the high prevalence of claw lesions could be attributed to the long hours cows stood on concrete floor confinement without being released to pasture or open yards at all (Mülling *et al.*, 2006). Confinement provides suitable underfoot environment in which multiple interactive factors (such as concrete floors, stocking rate, presence of slurry, concentrate feeding, parity, and stage of lactation) favour development of claw lesions (Clarkson *et al.*, 1996; Cook *et al.*, 2004).

A high percentage (69%) of the cows that had claw lesions did not show any clinical signs of lameness and scored normal on locomotion score. The lesions in such cases could have been in the subclinical phase or they may have been of the type that cannot independently cause lameness. Such lesions follow an insidious course that eventually contribute to the development of severer future lameness episodes as long as the predisposing factors persist (Nocek, 1997; Smilie *et al.*, 1999; Belge and Bakir, 2005). Moreover, the insidious effects of such lesions have far reaching significance in that by the time clinical lameness becomes evident, they already will have caused remarkable functional damage to the claws, subsequently leading to reduced productivity and long-term poor foot health in the affected cows (Hernandez *et al.*, 2005). One of the main insidious syndromes is subclinical laminitis which has been incriminated as major underlying predisposing cause for development of chronic laminitis and associated claw lesions such as sole bruising, heel erosion, white line separation and double soles (Nocek, 1997; Belge and Bakir, 2005).

The high prevalence rate of sole haemorrhages (52%) seen in the current study almost proportionally compares with the 49.3% prevalence rate of subclinical laminitis seen among the examined cows. This observation supports reports of other researchers who have previously employed presence of sole lesions and haemorrhages to determine diagnosis of laminitis in cattle (Greenough and Vermunt, 1991; Bergsten, 1994; Bell, 2004; Belge and Bakir, 2005). However, sole haemorrhages in the current study had higher prevalence rate than the 30% reported by Manske *et al.* (2002b), but lower than 62% reported by Belge and Bakir (2005) and Smilie *et al.* (1999) probably due to differences in environmental or cow-level factors between these studies.

In this study, all the cows with sole haemorrhages had either subclinical or chronic laminitis. This linkage is likely to be attributed to the fact that the initial phase of the pathogenesis of laminitis involves changes in pododermal microvasculature, which results in transvascular seepage of serum and subsequently manifest as haemorrhages in the sole (Nocek, 1997; Hirschberg and Plendl, 2005). Furthermore, it has previously been reported that the initial stage preceding the development of claw lesions, is the occurrence of haemorrhages in the sole, heel and wall of the claw due to bleeding from capillary pegs of the corium into the tubules of the horn (Greenough, 1987; Vermunt and Greenough, 1996). Haemorrhage is manifested as red or yellow discolouration of the horn of the sole (Ebeid, 1993). This is probably the main sign that can be used to diagnose subclinical phase of claw lesions particularly laminitis.

The varying distribution of haemorrhages among zones of the weight-bearing surface of the claw has been reported previously (Vermunt and Greenough, 1996). However, higher frequency of haemorrhages observed in zone 4 (sole-bulb junction) and the moderate frequency in zones 2, 3 and 6 could be attributed to the fact that these zones naturally have the weakest and softest horn, which becomes even softer and weaker during laminitis (Ebeid, 1993). Furthermore, during laminitis weight is redistributed in such a way that these zones bear most of it and hence the underlying corium is subjected to greater degree of pressure-insult than zones 1 and 5 that are more distal and were therefore found to be hardly haemorrhagic. In addition, chronic laminitis is accompanied by claw deformities that cause weight redistribution to the more proximal parts of the claws (zones 2, 3, 4 and 6) to be excessive, leading to severer blood vessel breakdown and hence higher degree of haemorrhages than in subclinical laminitis, which is not accompanied by claw deformities (Greenough and Vermunt, 1991; Nocek, 1997). This probably might explain the reason for the frequent association of haemorrhages in zones 2, 3 and 6 with chronic laminitis. On the other hand, the high association of haemorrhages in zone 4 with subclinical laminitis could possibly be attributed to the fact that disturbance in the pododermal microvasculature, results to an initial escape of blood components into the tubules of the horn of the sole and the bulb. Parts of these regions of the claw constitute sector 4, which then becomes the main zone that shows haemorrhages in the early (subclinical) phase of laminitis (Greenough and Vermunt, 1991).

The prevalence of chronic laminitis (21%) was found to be markedly less than half that of subclinical laminitis (49.3%). This might probably be due to low initial insult or lack of its persistence long enough for subclinical laminitis to advance to the chronic phase. Occurrence of chronic laminitis is reported to depend on frequency and intensity of each acute episode and ultimately, the degree of damage each preceding episode has caused as a result of the initial metabolic insult. Spontaneous recovery of some of the subclinical and acute laminitis episodes might also have contributed to the lower prevalence rate of chronic than subclinical laminitis (Nocek, 1997).

The results of this study indicated that in chronic laminitis, affected claws had invariably more than one associated claw lesion and deformity. In view of laminitis being incriminated as a predisposing cause of lesions such as sole ulcers, white line separation, heel erosion and double soles (Nocek, 1997, Smilie *et al.*, 1999; Belge and Bakir, 2005), one or more such lesions will inevitably manifest in cows with laminitis. Presence of more than one claw lesion causes the cows with chronic laminitis to to manifest in signs of lameness. Additionally in chronic laminitis, disruption of the growth of keratinized horn alters the shape of claws making them to subsequently become more elongated, flattened and broadened (Nocek, 1997). The dorsal angle of the claw also becomes markedly reduced, while the dorsal wall may become concave (Weaver, 1993).

Subclinical and chronic laminitis always occurred as bilateral conditions. This might be attributed to the fact that laminitis occurs as a systemic disease whose primary manifestation appears in the claws as a result of their unique morphology in which pododermal microvasculature plays a central role in its pathogenesis (Hirschberg and Plendl, 2005).

Some of the laminitis associated claw lesions had prevalence rates that were lower than those reported by others and this could be attributed to the differences in the predisposing factors such as the plane of concentrate feeding in each study (Blowey *et al.*, 2004; Okwee-Acai and Acon, 2005). In a study done on high level grain-fed dairy cattle in Kampala Uganda, prevalence rates of heel erosion, double soles, sole ulcer, white line separation, and foreign body penetration were 79%, 29.6%, 14.4%, 5% and 2.4% respectively (Okwee-Acai and Acon, 2005) and these were higher than those found in the current study. Studies by Gitau (1994) on dairy cows in Kikuyu division, Kiambu district, Kenya, reported incidence rates of heel erosion and double soles as 4.4% and 1.2% respectively and these were lower than 27.3% and 17.0% respectively found in the current study. However, sole bruising which was the main laminitis associated claw lesion in the current study as well as white line separation and foreign body penetration have not been reported in the previous Kenyan study. Roughness of the concrete floors in the current study farms may account for the high prevalence rate of sole bruising and also involvement of all cows in any affected single herd. The invariable involvement of sole bruising in either both lateral, or both medial claws for any affected cow might probably be attributed to weight distribution. In this regard, lateral claws bear more weight than medial claws of the hind limbs in any individual cow thus precipitating symmetrical occurrence of the lesion. Bruising is compounded on concrete floors in which case it becomes severer (Shearer, 2006). Heel erosion also occurred in a similar pattern to sole bruising except that cases of concurrent involvement of medial and lateral claws were seen. The extensiveness (from zone 4 to 3) and invasiveness seen in the severe cases of heel erosion might be attributed to softness of the zones involved in comparison with other zones of the weight-bearing surface of the claw (Shearer, 2006).

In all cases, double soles, were concurrent with chronic laminitis. This agrees with previous report (Nocek, 1997). This could be employed as a distinguishing feature between double soles due to chronic laminitis, and double soles caused by trauma in which case signs of laminitis would be absent.

White line separation was consistently seen in zone 2 especially on the lateral claw of the hind limbs. It becomes more evident when the superficial horn of the sole is trimmed. This has been reported previously and is attributed to the fact that white line is the weakest point of impact which is likely to succumb and fissure under pressure insults (Baggott and Russell, 1981).

Sole ulcer affected the axial part of zone 4 and 5 and had very low prevalence rate, but when present, the cow was severely lame due to exposed corium. Such description has also been reported (Baggott and Russell, 1981). It was probably less common than other claw lesions because it occurs in very advanced cases of chronic laminitis. In such cases the pedal bone drops distally to compress the corium towards the horn of the sole. The horn then gives way at the axial part of zone 4 and 5 thus exposing the corium (Baggott and Russell, 1981; Hull, 1993; Nocek, 1997).

In the current study, regular claw overgrowth occurred at a higher prevalence than other claw deformities. This was probably because in most farms regular claw trimming was not practiced (Personal information from the farms). Some claws were not only overgrown but were also grossly misshapen or extremely crooked with irregular widening, concavity, turning of vertical claw wall toward the sole to become part of the tread surface. Others had prominent deep horizontal ridges on the dorsal wall. Regular claw overgrowth occurs mostly when cattle are raised on soft surfaces where little hoof-wear takes place, and this results in the claw becoming misshapen (Rhebun and Pearson, 1982). When claws are extremely misshapen and grossly crooked, it is most likely the effect of chronic laminitis rather than regular overgrowth. This is confirmed by presence of severe sole haemorrhages after claw trimming (Singh *et al.*, 1993a; Nocek, 1997).

Claws with regular overgrowth were trimmed and restored back to or near normal anatomical shape. However, those misshapen as a result of chronic laminitis could not be restored to normal shape by trimming. This is partly due to extreme hypertrophy that manifests itself as an overproduction of the horn underneath the claw (Toussaint-Raven, 1985). As was reported previously, trimming in such cases is only palliative owing to difficulties of returning the claws to normal shape (Rhebun and Pearson, 1982). Although Toussaint-Raven (1989) suggested that heel horn erosion causes local irritation to the corium that subsequently contributes to excess sole-horn production, Bradley *et al.* (1989) reported that it was not present in all animals with overgrown soles.

Corkscrew claw had a low prevalence rate possibly because it is an inherited problem (McCormack, 1978; Rhebun and Pearson, 1982). However in the current study, it was observed to occur bilaterally affecting the medial claws. This differed with a previous report indicating that it affects the lateral claws of the rear feet (McCormack, 1978). Nevertheless, gross description of the lesion observed fits that of corkscrew claw, and hereby document its involvement in the medial claws as well. One deformity that was seen on 3 cows in this study which could be either inherited or acquired is a bilateral medio-dorsal spiraling of axial wall of the medial claws with the claw treading on the lateral aspect of the abaxial wall. It has not been documented previously. Splaying of the claws appeared to occur independent of other deformities and from previous reports, it is likely to be an inherited condition (Greenough *et al.*, 1972).

Low prevalence rate of infections of the claw observed in this study might be attributed to an improved hygiene in cattle house and general environment in the farm animal units. In most of these farms, removal of the slurry (manure) was regular, and the cow house walk alleys were washed regularly. These practices improve hygiene tremendously thus making it difficult for pathogenic bacteria to propagate under such environment.

Presence of digital dermatitis (2.3%) which is also known as digital papillomatosis or "hairy warts" in cows in two farms with similar forms of management system suggested a managemental factor in its aetiological predisposition. The two farms were the most intensively managed zero-grazed units in this study and had the highest plane of concentrate feeding and an open yard where the cows rested after feeding. It has been reported that the aetiology of digital dermatitis is unknown; however, *Bacteroides nodosus* has been isolated from the surface of the lesion though its significance is not verified (Weaver, 1993). The condition can develop into sporadic or epidemic form, and easily spreads through the herd. It is predisposed by confinement on concrete floors, overcrowding, and slurriness (Weaver, 1993). These predisposing factors were present in the two farms in which the disease was seen. Furthermore, the open yards on both farms were not made of concrete and therefore are not washed thus enhancing unhygienic environment that would promote development and spreading of this contagious lesion. The reason digital dermatitis has not previously been reported in Kenya might be due to lack of many intensively managed farms and probably because the condition does not cause lameness and unless cattle feet are closely examined, it would pass unnoticed. Other lesions seen during the study, such as interdigital fibroma, loosely enlarged and extensive interdigital skin-fold, non-specific painless subcutaneous growths and horizontal hoof wall fissures were of negligibly low prevalence for any statistical significance. However, the extensively enlarged loose interdigital skin-fold that covered the whole interdigital space from cranial to caudal aspects though affecting only one cow was a notable observation and is not previously reported. Nevertheless it has a likelihood of being predisposed by constant interdigital skin irritation and could be related to the occurrence of interdigital fibroma.

The incidental "cow-hocked" condition in which the cows adopted hock adduction posture with hocks knocking each other during locomotion caused severe abnormal gait. This gait resulted from abnormal limb conformation rather than pain and the affected cows had notably poor body condition. Such cows are highly predisposed to development of claw lesions (Vermunt, 1990). This conformation related condition is most probably an inherited trait and the affected cows cannot be assisted. but the best remedy is to cull and avoid breeding them.

The excessively soft and whitish crumbling horn seen on the sole and along the white line of some cows after claw trimming, has not been reported previously. It is probably an effect of chronic laminitis emanating from production of low integrity softer horn with impaired keratinization (Higuchi and Nagahata, 2001). This same effect can also explain the strong association found between white line separation, heel erosion, double soles and chronic laminitis in which the horn on the heel, sole and along the white line easily succumbs to separation and injury. This means that the three lesions (white line separation, heel erosion and double soles) would easily occur as a result of chronic laminitis.

Results of this study indicate that chronic laminitis in cows can tentatively be predicted by presence of some claw deformities. Among the claw deformities with high relative risk and likelihood of concurrently occurring with chronic laminitis are: claw overgrowth, concave claws and prominent deep horizontal ridges of the dorsal wall of the claw. This predictive association between claw deformities and chronic laminitis is supported by findings of others (Greenough, 1987; Ebeid, 1993; Weaver, 1993).

The strong positive association found between higher locomotion scores (scores 3 and 4) and chronic laminitis can be attributed to misshaping of the claw by the laminitis associated deformities (Greenough, 1987; Nocek, 1997) and to the severity of laminitis-associated claw horn lesions (such as white line separation, double soles, heel erosion and sole ulcers) (Weaver, 1979; Baggott and Russell, 1981; Mülling, 2002). It could also be related to a change in the configuration of the pedal bone within the horn capsule (Shearer and van Amstel, 2000). These effects in the claw will then cause more severe lameness, which is reflected by higher locomotion scores. White line separation and sole ulceration were also found to be associated with higher locomotion scores. The reason for this association is likely to be due to more pain caused by entry of traumatic debris and infection underneath the separated white line horn, and the physical exposure of the corium in sole ulceration. When such claws tread on the ground, the result is more severe lameness (Baggott and Russell, 1981; Hull, 1993), hence higher locomotion scores.

Higher percentage of lesions that occurred on the outer than the inner claws of the hind limbs tallied with reports of others (Tranter *et al.*, 1993; Vermunt and Greenough, 1996). This is thought to be caused by the functional differences in structure, size and shape between the inner and outer claws of the hind feet (Russell *et al.*, 1982), which lead to overloading of the outer claws thus making them more susceptible to lesion occurrence (Ossent *et al.*, 1987; Paulus and Nuss, 2002).

Significantly lower toe angle, higher digit width and higher claw diagonal obtained in the measurements of claws with chronic laminitis compared to those without chronic laminitis, was a reflection of measurable overgrowth of the claws during laminitis. The toe angle became smaller as a result of elongation and flattening of the claw particularly the toe, while digit width and claw diagonal increased due to broadening of the claw in the process of chronic laminitis. Such changes have previously been documented (Greenough, 1987; Weaver, 1993).

In this study, it was found that cows with three or more parities were at a higher risk of developing chronic laminitis. This is in agreement with suggestions of Andersson and Lundstrom (1981) and Russell *et al.* (1982) that acute laminitis is more common in heifers but chronic laminitis in older cows. This also compares closely with observations of Sogstad *et al.* (2005b) who found most lameness to be generally associated with third or higher parities in Norwegian Red dairy cattle, but reported that sole haemorrhages were more prone in the first parity. This partly concurs with the reports of others who found that primiparous cows were more prone to sole lesions and higher scores of sole hemorrhages than multiparous cows (Bergsten, 1994; Bergsten and Herlin, 1996). It has been demonstrated that cows suffering claw conditions causing lameness during the first lactation are more susceptible to future episodes of lameness in subsequent lactations. This means that the events of first parturition are important determinants of future lameness episodes (Hirst *et al.*, 2002).

In the current study, cows between 90 to 180 days in lactation had a higher risk of developing chronic laminitis. This closely tallies with a previous study that found the incidence of lameness in cattle to be highest in the first 120 days of lactation and lowest the last three months (Rowlands *et al.*, 1985). The current study further revealed that lactation stage of 1-90 days was a significant risk factor for occurrence of subclinical laminitis, which according to Vermunt (2004) is the period that coincides with high level of energy intake. Further to this, it is also the period when cows come under intense stress of heavy milk production and thus exacerbate to subclinical laminitis (Rowlands *et al.*, 1985). This may also help to explain the reason why in our study, milk yield above 15kg per day seemed associated with subclinical laminitis. It also tallies with the suggestions of Vermunt (2004) on the hypothesis of high plane energy intake, which in this case might have been caused by high level concentrate feeding for cows producing above 15kg of milk per day. It then seems that the total claw lesion scores are higher during the peri-parturient period and become increasingly higher in each subsequent lactation (Offer *et al*, 2000). The nutritional phenomenon of subacute ruminal acidosis (SARA) and production of vasoactive substances that insidiously trigger initiation of subclinical laminitis, subsequently predisposing the cow to other claw lesions including chronic laminitis, explains the association of regular concentrate feeding with the occurrence of these claw lesions (Nocek, 1997; Cook *et al.*, 2004; Vermunt, 2004).

The finding that regular mineral supplementation is a possible protector against occurrence of subclinical laminitis and white line separation, agrees with the report by Tomlinson *et al.* (2004) which stated that feeding trace-minerals tends to lower claw lesion scores. It improves the quality and integrity of the horn produced with overall promotion of claw health (Bergsten *et al.*, 2003; Tomlinson *et al.*, 2004), and the result is that the horn does not easily succumb to white line separation or other forms of horn injuries. Amory *et al.* (2006) further reported that failure to supplement lactating cows with vitamins and minerals was a lameness risk factor and caused higher locomotion scores.

Failure to regularly remove manure from the walk alley around the feeding area increased the slurry and was statistically found to be associated with the occurrence of subclinical and chronic laminitis. This is attributed to a prolonged and persistent wet environment under the cow's claws that inevitably increases the water content of the claws thus proportionately reducing their hardness. Subsequently, the horn of the sole is excessively softened to the extent that the corium is reached easily by pressure insults and therefore becomes more susceptible to severe lesions such as laminitis (Borderas *et al.*, 2004).

Results of the current study indicated that housing cows on earthen (soil) floors was an important risk factor for occurrence of chronic laminitis. Soft (yielding) surfaces tend to promote overgrowth of the claws due to lack of constant hoof-wear (Rhebun and Pearson, 1982). On such surfaces, claw angle becomes smaller in comparison to being steeper angles on concrete surfaces (Somers *et al.*, 2003). Moreover, overgrowth and change in claw angle causes redistribution of weight-bearing that subsequently overloads specific zones of the claw particularly during locomotion (Van der Tol *et al.*, 2003). Consequently, this predisposes the affected claws to development of laminitis and other claw lesions (Sagues, 2002; Neveux *et al.*, 2006). However, earthen floors were found to be protective against occurrence of sole bruising. This can probably be explained by the nature of the floor being soft, yielding and non-abrasive and closely agrees with previous report that cows raised on yielding straw-yard surfaces were found to have the very low prevalence of claw disorders (Somers *et al.*, 2003).

Fewer cubicles than the cows (overstocking) were a predisposing risk factor of chronic laminitis. This is primarily due to long hours of standing caused by inadequate lying space, which then causes much pressure injury on the corium and becomes an exacerbating factor in the development of claw lesions (Leonard *et al.*, 1994). Further to this, presence of a curb (kerb) between the cubicles and walk alley increases stress on the claws particularly as the cow climbs into the cubicle. The stress is even greater on the hind feet as the cow disembarks backwards from the cubicle (Leonard *et al.*, 1994; Philipot *et al.*, 1994). As a result of this, cows may prefer to stand on the alley compared to occupying the cubicles. When it happens, the "cow-comfort" is compromised and the corium stressed and all this emanates from presence of a high curb. Thus it can be concluded that high curbs enhance development of laminitis, and the current study showed that the higher the curb the greater the enhancement.

Chronic laminitis is the only claw disorder that showed a significant difference between cows in zero-grazed and in pasture-grazed farms with higher prevalence in zero-grazed cows. The hard concrete surface that was more common in the zero-grazed farms, coupled probably with regular concentrate feeding could have contributed to the difference in the prevalence rates of chronic laminitis between zero-grazed and pasture-grazed farms (Bergsten, 1994; Vokey *et al.*, 2001; Somers *et al.*, 2003).

CHAPTER 6

6.0 EVALUATION OF GROSS PATHOLOGY AND RADIOGRAPHIC CHANGES OF CLAWS COLLECTED FROM ABATTOIRS

6.1 Introduction

Subclinical laminitis is associated with changes in the texture and colour of the hoof that include: softness of the hoof, as well as distinct yellow tinge and red discolouration, due to haemorrhages of the sole and walls of the claws (Greenough, 1987). In chronic laminitis, the claw becomes much taller, flattened or concaved, sometimes widened and more boxy than normal. It might mistakenly be regarded as mere hoof deformity, described as "slipper foot" because it appears like the Persian slipper. Its coronary band becomes hard, rough and dull in appearance compared to the usual shiny periople, and the dorsal wall acquires distinct deep irregular ridges (Nilsson, 1963; Maclean, 1966; Greenough, 1987). Other macroscopic lesions of the claw that are associated with laminitis are: sole ulcers, white line separation, heel erosion, and double soles (Nocek, 1997; Smilie *et al.*, 1999; Belge and Bakir, 2005).

The gross pathology of laminitic claws discernible from vertical transverse and sagittal sections includes an increase in the amount of fat in the os pedis that makes it more purple than normal with prominent blood vessels and slight deviation of the pedal bone from its normal position in relation to the hoof capsule (Nilsson, 1963; Maclean 1966). In addition, the pedal bone is severely atrophied especially in the lateral claws, and acquires a pink colouration that is more pronounced at the posterior edge (Maclean, 1966).

White line separation is simply seen as a fissure between the wall of the claw and the horn of the sole. It affects both the axial and abaxial white line but with high incidence of the abaxial side (Baggott and Russell, 1981). Heel erosion is grossly seen as areas of black rotten horn that has been eroded and sometimes looking sore. However, sole bruising is seen as areas of the sole with excessive wear of the horn (Greenough, 2005). Double sole phenomenon implies presence of a superficial outer horn of the sole and a deeper underlying horn of the sole on the same claw. It is seen mainly after claw trimming but can be discernible occasionally before trimming (Greenough, 2005). Sole ulcer is normally seen after claw trimming as an area of exposes corium discernible by protruding granulation tissue (Hull, 1993).

Radiographic changes in the claws associated with laminitis include: downward rotation of the pedal bone (Bargai *et al.*, 1989; Greenough *et al.*, 1990), well delineated vascular channels, and exostoses seen at the pyramidal process (Maclean, 1970), reduced overall radiodensity of the pedal bone (Maclean, 1970), atrophy, deformation and missing apex of the pedal bone in cases of chronic laminitis (Greenough *et al.*, 1990). However, in chronic laminitis, deviation of the pedal bone is not as consistently found in cattle as in the horse (Weaver, 1988).

The arteriographic features of laminitic claws are more pronounced in the lateral than the medial claws. They include: dilatation, constriction, tortuous and irregular course of blood vessels, poor vascularization in the specific ulcer site, widening of the medial branches of the claw artery and widening of the well-delineated vascular channels of the claw artery and the primary branches in the pedal bone (Boosman *et al.*, 1989b).

Previous studies of claw lesions using abattoir samples (Parizi and Shakeri, 2002) have not focused on laminitic claws or claws with laminitis associated lesions. Furthermore, the radiographic appearances of laminitis related claw lesions such as white line separation, sole erosion, heel erosion, double soles and sole ulcers as well as claw deformities have not been compared.

To evaluate further the pathology of claw lesions that were found to be common in the smallholder herds, it became necessary to study the gross and radiographic changes of lesions in the claws obtained from abattoirs that slaughtered cows from the same production systems as for the prospective study.

6.2 Materials and methods

6.2.1 Selection of abattoirs and claws

Kiserian abattoir and Wangige Market slaughter-slab were purposively selected because previous pilot survey, by the author, had revealed regular slaughter of dairy cows, obtained from the same production systems as for the prospective clinical study. The slaughtered cows were mainly those that had been culled due to various production related reasons including old age. The claws were selected from dairy cows that had calved at least once and slaughtered between January 2006 and May 2006. Further details are included in chapter 3 subsection 3.5.1.

6.2.2 Collection of claw samples

A total of 159 dairy cow feet (318 claws) samples were collected, of which 96 were from Wangige Market slaughter-slab and 63 were from Kiserian abattoir. Among these, 109 were hind limb claws and 50 were forelimb claws. More claws were collected from Wangige Market slaughter-slab owing to more dairy cows being slaughtered there than Kiserian abattoir. The difficulties of getting claw samples from dairy cows necessitated inclusion of both forelimb and hind limb claws and did not allow any randomization to be carried out.

6.2.3 Preparation of the claw samples for examination

All the claw samples were separated from the rest of the limb by severing at the fetlock joint. They were prepared and examined on the same day of collection. Each claw was thoroughly washed with soap and water, and visually examined for gross lesions on every surface. All gross lesions were noted and recorded. They were then radiographed in dorso-palmar or palmar-dorsal and dorso-plantar or plantar-dorsal projections. The radiographs were examined and all lesions recorded. The soles of these claws were trimmed and underlying lesions noted and recorded. As the claws lost their water content rapidly, making trimming difficult, they were dipped in water for 2-3 hours before trimming was done. Gross examination and diagnosis of lesions of these claws was carried out similar to the description given in section 3.4.3 of chapter 3. Sagittal section of each claw was made starting from the toe to the first phalanx (Figure 6.1) (drawing adapted from Toussaint-Raven, 1989). Any gross changes in the corium and the pedal bone were recorded.

6.2.4 Data analysis

The prevalence rate of each macroscopic claw disorder was calculated as the number of feet samples with positive observations for the disorder divided by 159 (total number of feet samples) multiplied by 100. The prevalence rate of each radiographic feature was also calculated in a similar way to the prevalence rate of macroscopic lesions. Therefore for each claw disorder, the total number of feet samples (including those positive and those negative for the specific disorder) was 159.

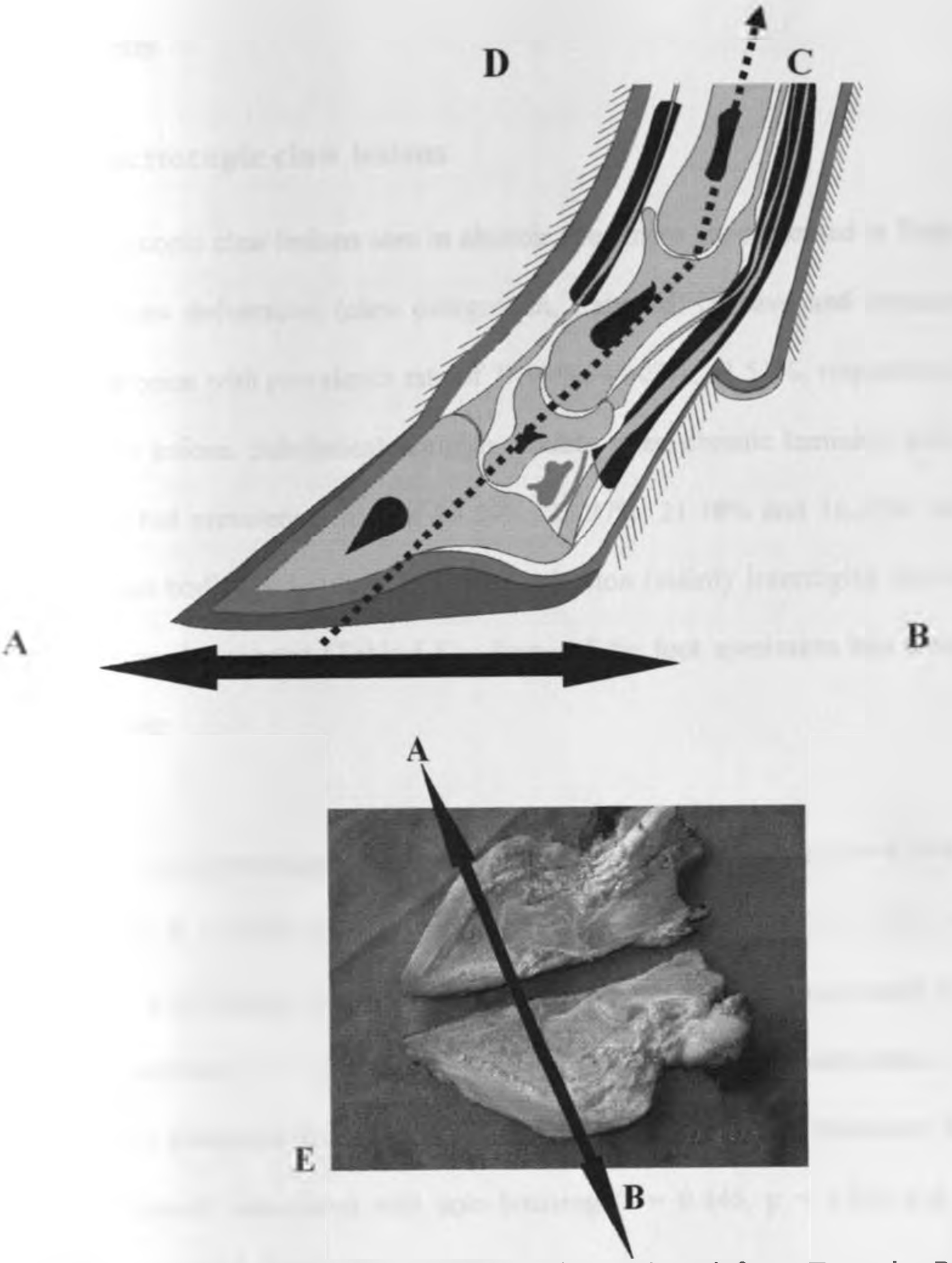


Figure 6.1: **D**-Schematic diagram of the foot (adapted from Toussaint-Raven, 1989) showing line of transection (dotted arrow) and the plane of sagittal sectioning in the direction A to B (Bold left-right arrow) starting from the sole surface to proximal end of the first phalanx at C. **E**-Shows actual sagittal section of one of the normal digits collected from the abattoir during the study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its evirons (December 2005-June 2006).

6.3 Results

6.3.1 Macroscopic claw lesions

The macroscopic claw lesions seen in abattoir specimens are presented in Table 6.1. Sole bruising, claw deformities (claw overgrowth, flattened, concave and corkscrew claws) and heel erosion with prevalence rate of 77.99%, 44.03%, 41.51%, respectively, were the commonest lesions. Subclinical laminitis, double soles, chronic laminitis, and white line separation had prevalence rates of 34.59%, 23.27%, 21.38% and 16.35%, respectively. Sole foreign bodies, sole ulcer, and claw infection (mainly interdigital necrobacillosis) had low prevalence rates (Table 6.1). Some of the foot specimens had more than one claw disorder.

Chronic laminitis was significantly associated with claw deformities ($r = 0.594$, $p < 0.05$), double soles ($r = 0.874$, $p < 0.05$) and white line separation ($r = 0.515$, O.R =15.25, $p < 0.05$). But additionally, white line separation was significantly associated with foreign body penetration ($r = 0.407$, $p < 0.05$). However, claw deformities were also significantly associated with double soles ($r = 0.508$, $p < 0.05$). Furthermore, heel erosion was significantly associated with sole bruising ($r = 0.446$, $p < 0.05$) and subclinical laminitis ($r = 0.455$, O.R = 7.8, $p < 0.05$).

There was severe congestion of the solear corium in claws that had subclinical laminitis as well as those with chronic laminitis. However in chronic laminitis, the congestion was severer. The pedal bone was more dark red in laminitic claws than normal ones (Figure 6.2).

Double soles and the effect of sole erosion were more discernible after sagittal sectioning of the claws. Areas of the sole that had undergone erosion had thinner horn that resulted in the solear corium being very close to the surface of the sole (Figure 6.3).

6.3.2 Description of the radiographic features

6.3.2.1 Dilated and prominent vascular channels

The vascular channels within the pedal bone were more pronounced at the distal ends of the bone (Figure 6.4). In most cases of subclinical and chronic laminitis, the vascular channels were not only prominent but also markedly dilated (Figure 6.5A), but in non-laminitic claws, they were hardly seen (Figure 6.5B).

6.3.2.2 Irregular margins of pedal bones

In chronic laminitis. margins of the pedal bones had superficial serrations. but in subclinical laminitis and in the claw specimens with only laminitis related lesions (such as sole bruising, heel erosion, white line separation and double soles), the serrations were absent (Figure 6.6).

Table 6.1: Prevalence rates of macroscopic disorders of 159 cow feet (318 claws) samples collected from Kiserian abattoir and Wangige Market slaughter-slab in a study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).

Claw lesions	**Number of samples** (n = 159)	**Percent prevalence** ($\frac{x}{159}$ X100)
Sole bruising	124	77.99
Claw deformities	70	44.03
Heel erosion	66	41.51
Subclinical laminitis	55	34.59
Double sole	37	23.27
Chronic laminitis	34	21.38
White line separation	26	16.35
Foreign bodies	5	3.14
Sole ulcer	1	0.63
Claw infection	1	0.63

Note: Some of the feet samples had more than one claw lesion.

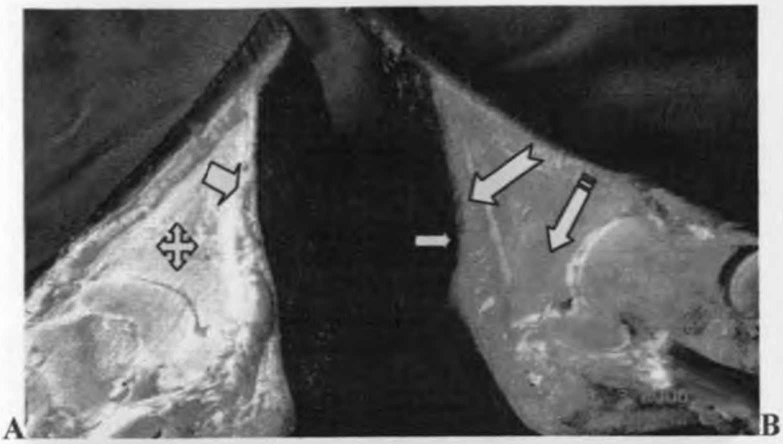
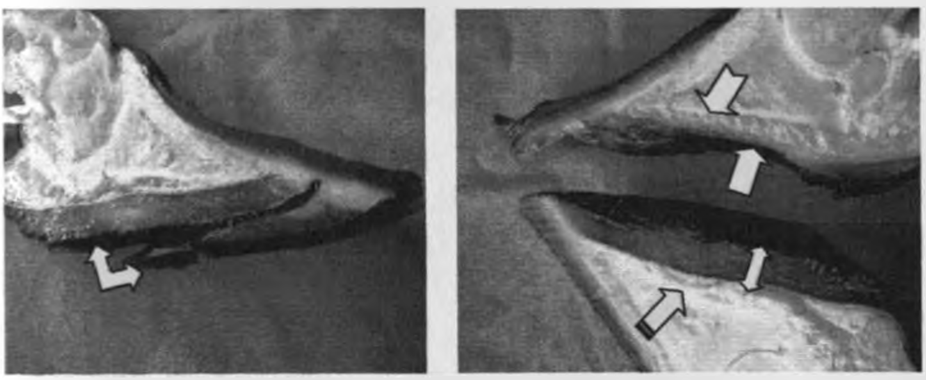


Figure 6.2: A- Normal claw showing pink-coloured solear corium (short block arrow) and normal colour of pedal bone (quad arrow). **B**-Laminitic claw showing eroded horn of the sole (short thin arrow) and congested solear corium (notched arrow) and more reddish pedal bone (striped arrow). These were seen during an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).



A B

Figure 6.3: Sagittal sections through the digit showing: **A**-double soles (angled arrow) with thickened inner sole due to the long standing nature. **B**-severely eroded horn of the sole (straight block arrow) that brings the solear corium close to the surface (notched arrow). Note the thickness of the horn of the sole in the normal claw (up-down arrow) and the normal position of the solear corium (striped arrow). These disorders were seen during an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).

Figure 6.4: Radiograph showing prominent non-dilated vascular channels (notched arrows) in the pedal bones of claws with laminitis as seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). Compare to normal figure 6.5B.

Figure 6.5A: Radiograph showing dilated vascular channels in the pedal bones (notched arrows) of claws with laminitis seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). Compare to normal figure 6.5B.

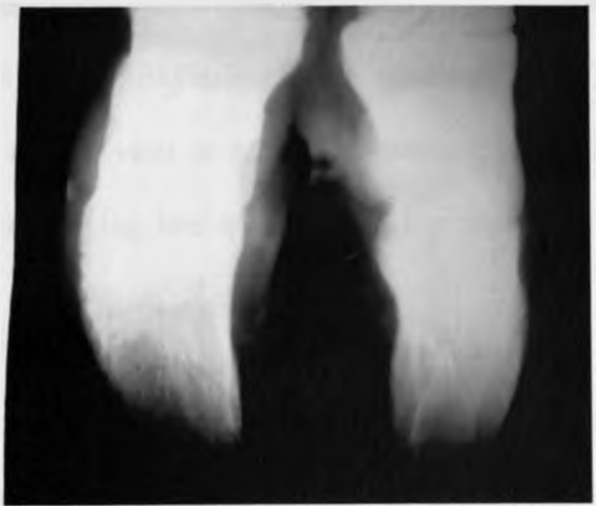


Figure 6.5B: Radiograph of a normal claw as seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2005).

Figure 6.6: Radiograph showing irregular margins of pedal bone (notched arrows) in the claws with laminitis as seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).

6.3.2.3 Exostoses of pedal bone

In chronic laminitis there was obvious osseous growth on the periosteum of the affected pedal bone (Figure 6.7). Similar lesions were observed in a few cases of claw deformities, but none were evident in subclinical laminitis and other laminitis related claw lesions such as sole bruising, heel erosion, white line separation and double soles.

6.3.2.4 Narrowed pedal bone

Narrowed pedal bone occurred in chronic laminitis with extreme claw deformities such as twisted toe, in which the axial wall was turned dorsally and the abaxial wall turned towards the sole to become part of the tread surface. The affected pedal bone appeared smaller, thinner and narrowed towards the apex of the bone (Figure 6.8A). This radiographic feature was not seen in subclinical laminitis or other claw lesions.

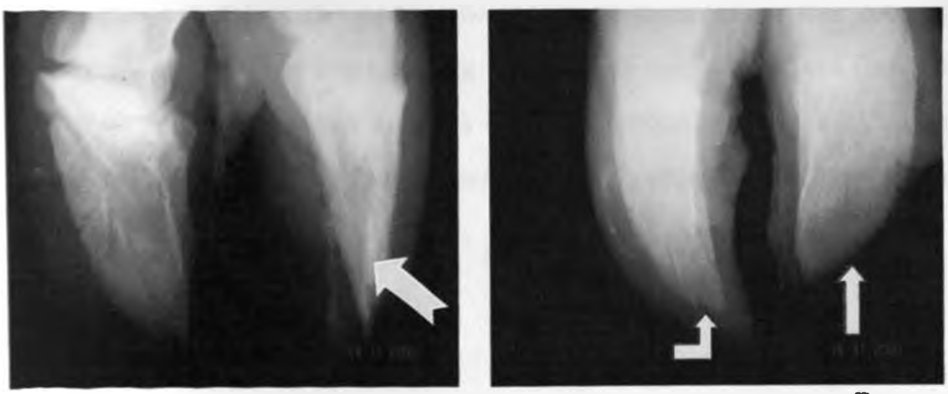
6.3.2.5 Dissolution of the apex of the pedal bone

There was partial or complete dissolution of part of the apex of the affected pedal bone (Figure 6.8B) in claws with chronic laminitis and severe twisting of the toe. It was however not seen in other types of claw lesions.

6.3.2.6 Rotation of pedal bone

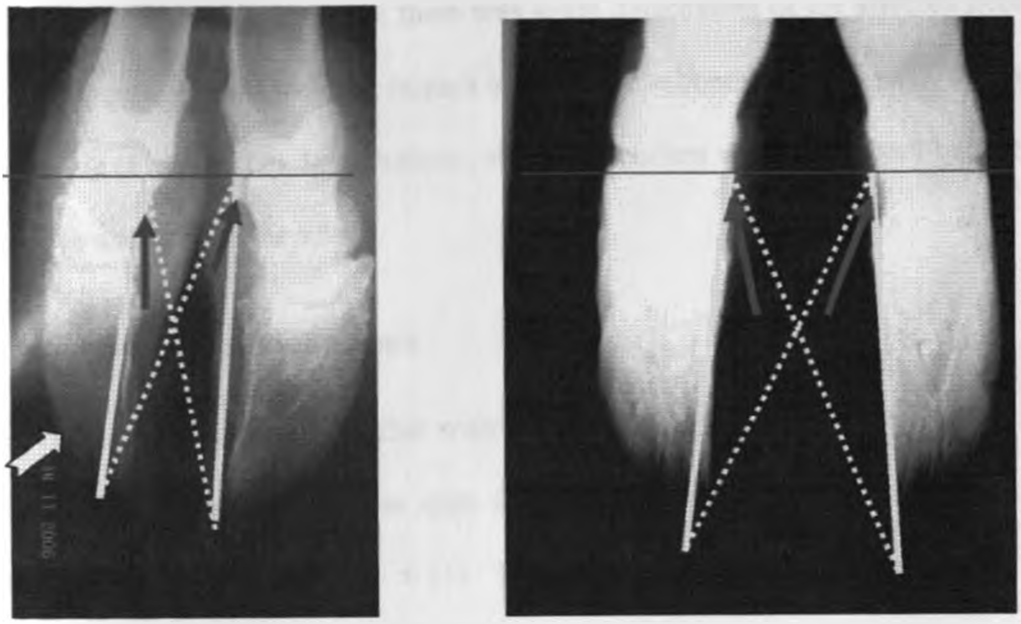
Slight twisting of the affected pedal bone within the horny capsule interfering with congruency of the pedal joint, was seen in claws that had chronic laminitis together with extreme claw deformities (Figure 6.9). This radiographic feature was absent in subclinical laminitis.

Figure 6.7: Radiograph showing exostosis of the pedal bones (notched arrows) of claws with chronic laminitis as seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).



A **B**

Figure 6.8A and B: Radiograph A-showing narrowed pedal bone (notched arrow) and radiograph **B**–showing a missing small part of the sharp apex of the pedal bone (straight arrow) compared to the normal complete contralateral pedal bone (angled arrow). These were seen in deformed claws with chronic laminitis during an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).



A B

Figure 6.9: Radiograph **A**-showing slight rotation of pedal bone in some deformed claws with chronic laminitis seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). Note the straightness of this bone coming in line with middle phalanx (notched arrow). In **A**- the angle pointed by longer arrow is 19° and by shorter arrow is 21°. In comparison with **B**-(contra-lateral) symmetrically placed pedal bones where both angles are equal each at 27° (long arrows).

6.3.2.7 Dropped (or "sinking") pedal bone

In a few claws with chronic laminitis, there was slight detachment of the affected pedal bone from the dorsal wall of the claw in such a way that the bone sunk to a small degree towards the sole (Figure 6.10). In such claws, the solear corium was compressed between the pedal bone and horn of the sole.

6.3.2.8 Rounded pedal bone apex

In claws with chronic laminitis together with severe deformities, particularly involving the toes, the normal sharpness of the apex of the pedal bone was compromised and appeared rounded and blunt (Figure 6.11). This feature of the pedal bone apex was however not observed in subclinical laminitis.

6.3.2.9 Fissures fracture of the pedal bone

Some claws with sole and heel erosion occurring together with severe deformities but without any form of laminitis were observed to have fissures within the respective affected pedal bone (Figure 6.12). However, this fissuring was not severe and thus no bone loss was observed in these cases.

6.3.2.10 Pedal bone outgrowths

Two pairs of claws with concurrent sole erosion and overgrowth but without laminitis were observed to have outgrowths of the distal parts of the affected pedal bones (Figure 6.13).

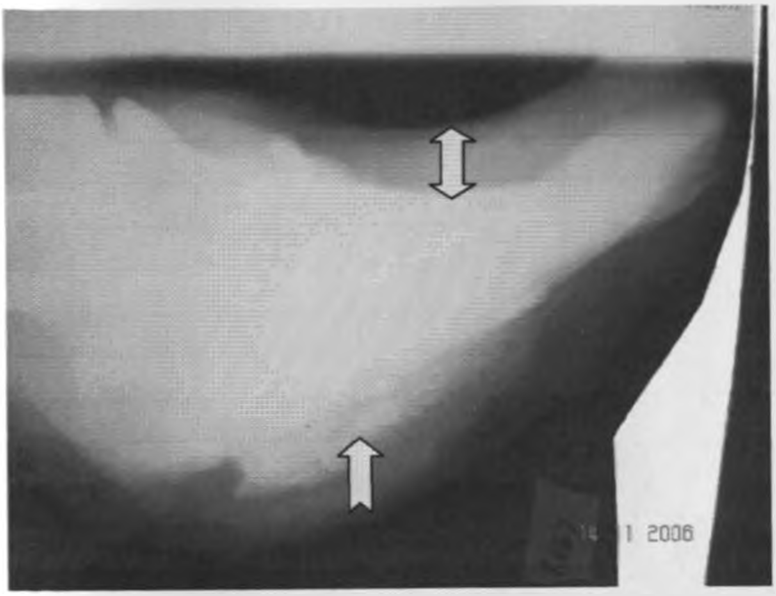


Figure 6.10: Radiograph showing dropped pedal bone. Note the level of the dorsal horn wall (up-down arrow). There is bone growth on ventral side (notched arrow). These were seen in chronic laminitis in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).

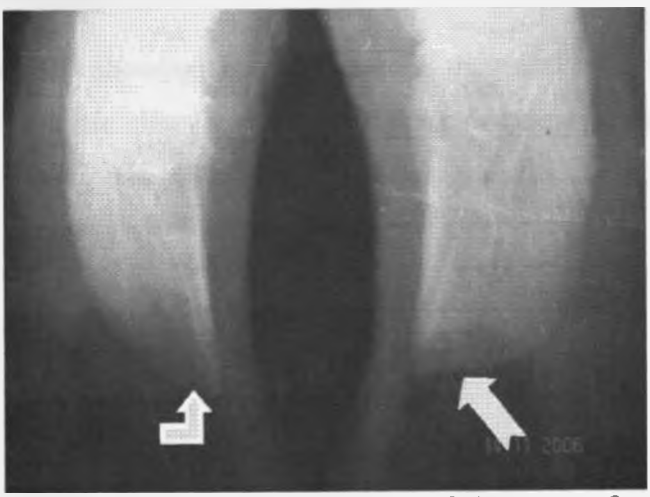


Figure 6.11: Radiograph showing slight rounding of the apex of pedal bone (notched arrow) compared to the contralateral normal bone (angled arrow) as seen in laminitic claws in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).

Figure 6.12: Radiograph showing fissure fracture of the pedal bone close to the margin (arrow) as seen in laminitic claws in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).

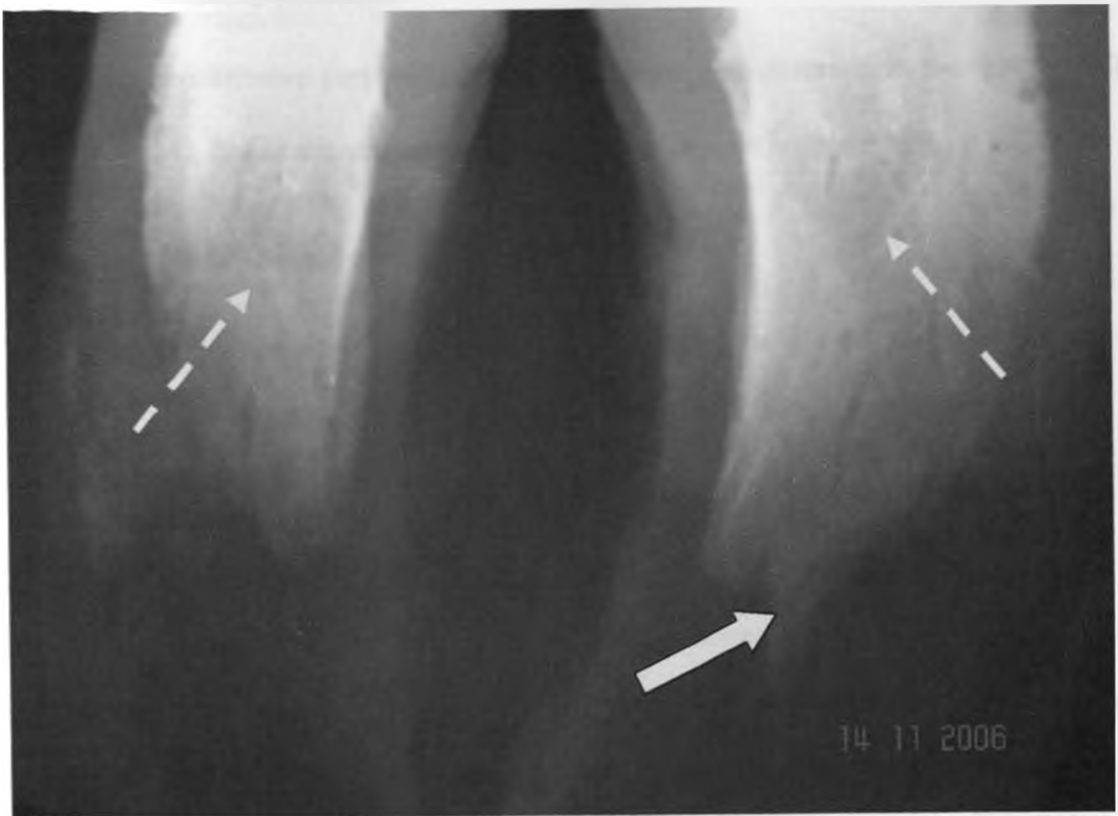


Figure 6.13: Radiograph showing an out-growth of distal part of the pedal bone (arrow) and diffuse radiolucent areas showing osteolysis (broken arrows) in a claw with chronic laminitis seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).

6.3.2.11 Pedal periostitis

A mildly proliferative periostitis of the pedal bone was observed in two pairs of claws (Figure 6.14). It was not associated with any specific claw lesion.

6.3.2.12 Pedal osteolysis

This was seen as reduced radio-density of the pedal bone in one pair of claws, but was not associated with any specific claw lesions (Figure 6.15).

6.3.3 Prevalence of radiographic lesions

The radiographic changes seen in the claws examined affected the pedal bone and associated blood vessels. Among the 159 abattoir foot samples examined, 41 had more than one radiographic lesion. The most prevalent and consistent features were dilated vascular channels (60.76%), prominent but not dilated vascular channels (24.05%), irregular pedal bones margins (13.92%), exostoses of pedal bone (8.23%) and narrowed pedal bone (5.7%). The rest of the radiographic features had prevalence rates of less than 5% (Table 6.2).

Missing apex of the pedal bone was the radiographic change found significantly associated with the narrowing ($r = 0.482$, $p < 0.05$) and rotation ($r = 0.600$, $p < 0.05$) of pedal bones. The rest of the radiographic changes did not show any statistical association with each other. Statistical tests of simple associations revealed that there were no associations between macroscopic claw lesions and the radiographic changes observed.

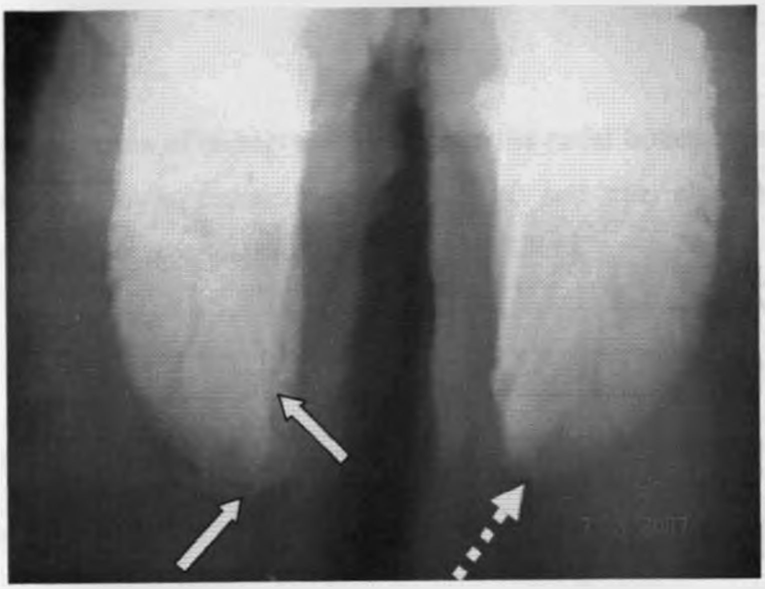


Figure 6.14: Radiograph showing periostitis mainly on the medial and distal aspects of the pedal bone (arrows) of a claw with chronic laminitis as seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). Note the unaffected normal pedal bone (dotted arrow).

Figure 6.15: Radiograph showing radiolucent areas of focal osteolysis on both pedal bones (notched arrows) of claws with chronic laminitis as seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).

Table 6.2: Prevalence rates of radiographic lesions in the pedal bones of laminitic claws as seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).

Radiographic lesion	Number of samples (n = 159)	Percent prevalence $\left(\frac{x}{159} \times 100\right)$
Dilated vascular channels	96	60.76
Prominent vascular channels	38	24.05
Irregular P3 margins	22	13.92
P3 exostosis	13	8.23
Narrowed P3	9	5.7
Rotated P3	6	3.8
Absent P3 apex	4	2.53
Dropped ("sunken") P3	4	2.53
Broken P3	3	1.9
P3 periostitis	2	1.27
P3 out-growth	2	1.27
P3 osteolysis	1	0.63

Key: P3 means pedal bone (3rd phalanx)

6.4 Discussion

The pattern of occurrence of subclinical and chronic laminitis as well as laminitis-related claw lesions in the abattoir study was similar to that of prospective clinical study described in chapter five. The similarity could be as a result of exposure of the cows to similar risk factors, since the abattoir claw samples were obtained from cows raised in the same areas and with similar production systems like the prospective clinical study.

Laminitis is thought to influence the occurrence of other claw lesions such as sole bruising (erosion), heel erosion, white line separation, double soles and some claw deformities (Nocek, 1997; Smilie *et al.*, 1999; Belge and Bakir, 2005). In the current study the prevalence of both subclinical and chronic laminitis was high and this could explain the correspondingly high prevalence of laminitis related claw lesions.

The prevalence of the infectious claw lesions in the abbatoir samples was low. Similar findings were obtained from the prospective clinical study. The low prevalence of the infectious conditions was in contrast to the high prevalence of subclinical and chronic laminitis and that of lesions and deformities associated with laminitis. The high prevalence rate of laminitis as well as laminitis associated lesions could probably be attributed to factors in modern farming systems such as high plane concentrate feeding and long hours of standing and confinement of dairy cows on concrete floor housing that have been reported as predisposing causes of such lesions (Singh *et al.*, 1993b; Nocek, 1997; Vermunt. 2004; Somers *et al.*, 2003 and 2005;).

In this study, there was strong positive association between chronic laminitis and claw deformities, in which case the affected claws could mistakenly be regarded as merely having hoof deformity. Similar observations have previously been made (Greenough, 1987). Laminitis causes abnormal horn production that leads to hoof overgrowth and increased length of the wall or sole that misshapes the claw (Toussaint-Raven, 1985). This occurs particularly when cattle are raised on soft surfaces where little hoof wear takes place (Rhebun and apearson, 1982). The positive association between double soles and chronic laminitis may be attributed to necrosis and walling-off of the haemorrhagic areas in chronic laminitic claws (Nocek, 1997). These areas provide good environment for growth of anaerobic bacteria that produce gas and exudates, which in-turn cause pressure build-up that separates the horn from underlying corium in the areas of least resistance. The corium then produces new horn that is deposited separate from the overlying one and hence the resulting double sole phenomenon. This phenomenon is common in chronic laminitis but the process may be initiated at the subclinical laminitis phase (Nocek, 1997). The high likelihood of white line separation in claws with chronic laminitis might be linked to production of poor quality, extremely softened horn of the sole in chronic laminitis, which also contains channels of necrotic material (Greenough. 1987; Nocek, 1997). Hence any inwardly or outwardly directed pressure insult on the sole will cause the white line to easily separate. The white line separation results when the wall of the claw separarates from the horn of the sole at the sole-wall junction.(Nocek, 1997). The white line naturally has the softest horn on the weight-bearing surface of the claw (Berry, 1999). In laminitic claws, the already soft horn of the white line becomes abnormally softer due to production of inferior horn. This then enhances separation of the white line in laminitis.

In this study, there was a positive association between claw deformities and double soles. This association has not been described previously. However, the strong positive association of both the claw deformities and double soles with chronic laminitis that was also observed in the current study could help explain this finding.

Heel erosion was found to be positively associated with subclinical laminitis. These findings were in agreement with previous studies that indicated an association between the two lesions (Nocek, 1997; Smilie *et al.*, 1999; Belge and Bakir, 2005). It has been suggested that subclinical laminitis may be involved in predisposing the cow to heel erosion (Greenough, 2005). Similarly, subclinical laminitis is thought to influence occurrence of sole bruising, and this may explain the positive association that was also found between heel erosion and sole bruising.

White line separation was significantly associated with foreign body penetration. This could be as the result of production of softer poor horn quality in chronic laminitis. Moreover, chronic laminitis has been shown to occur together with white line separation (Nocek, 1997).

Congestion and redder colouration of the corium that was observed on sagittal sections of the claws could be related to haemorrhages or prominence of blood vessels that occur in cases of laminitis (Nilsson, 1963; Maclean, 1965).

The prevalence of dilated vascular channels within the pedal bones of laminitic claws was high and this observation was in agreement with reports made by Boosman *et al.* (1989b) that dilated vascular channels are consistent findings in subclinical and chronic laminitis. They reported that prominent vascular channels without dilatation are also seen in laminitic claws. Both of these vascular changes were observed to be more pronounced in lateral than medial claws as previously reported (Boosman *et al.*, 1989b).

In cases of chronic laminitis, there was exostosis of the pyramidal process of the pedal bone as reported previously (Maclean, 1970). Its occurrence could be linked to periostitis of the pedal bone following prolonged inflammatory stimuli in chronic laminitis. The outgrowth from the apex of the pedal bone could be exostotic though looking different from characteristic exostosis reaction. The outgrowth could also be due to an osteolysis of some parts of the apex of the pedal bone thus leaving the non-osteolytic parts projecting distally beyond the margins of osteolysed parts. This occurrence has not been reported previously.

In this study there was narrowing of the pedal bones of some crookedly deformed chronic laminitic claws, a feature not previously reported. The closest comparison to this is the atrophy of pedal bone reported to occur in cattle with chronic laminitis (Greenough *et al.*, 1990). However, narrowing of the pedal bone can be the result of osseous tissue necrosis (osteosis). One of the causes of osteosis is related to deprivation of nutrition and oxygen particularly when there is compromise of local blood supply similar to the one that occurs in the claw in chronic laminitis (Jubb *et al.*, 1993). Furthermore, thromboembolic occlusion of individual blood vessels resulting in chronic local anaemia also causes osteosis, whose outcome depends on efficiency of the collateral circulation. In addition, osseous tissues have poor inefficient collateral circulation due to small anastomotic vessels that are incapable of good compensatory dilation. Subsequently, this leads to osseous ischaemia and necrosis with occurrence of osteoclastic resorption of the necrotic bone (Jubb *et al.*, 1993) hence narrowing of the bone. The current study also showed some pedal bones presenting with absence of the apex in severe crookedly deformed chronic laminitic claws as reported previously (Greenough *et al.*, 1990). The explanations for the missing apex of the pedal bone might be similar to that of narrowing of the same bone, which then elaborates the significant positive association found between the two lesions.

The finding of dropped or "sinking" of pedal bone observed in this study has previously been reported (Shearer and van Amstel, 2000). This is associated with weakening of the connective tissue supporting structures as well as destruction of the dermal-epidermal junction that permits laminar separation (Shearer and van Amstel, 2000; Tarlton *et al.*, 2002). As the laminar separates the pedal bone begins to "sink" within the horny capsule

Pedal bone osteolysis could be related to a reduction in overall density of the bone in chronic laminitis especially at the toe Maclean (1970). Periostitis in chronic laminitis might occur in response to chronic irritation of the periosteum due to extensive inflammation of the corium. This could also be the reason for the occurrence of radiographic appearance of irregular margins of the pedal bone. Pedal bones in the lateral claws had more severe radiographic changes than in the medial claws. This agrees with calier reports that the prevalence and severity of lesions on the lateral claws of hind limbs of cattle is greater than the medial claws (Russell *et al.*, 1982; Tranter *et al.*, 1993).

CHAPTER 7

7.0 HISTOPATHOLOGICAL AND TRANSMISSION ELECTRON MICROSCOPIC STUDIES OF THE CORIUM OF ABATTOIR CLAWS WITH SUBCLINICAL AND CHRONIC LAMINITIS

7.1 Introduction

Vascular system in the dermis of the claw is unique in its three-dimensional arrangement, complexity and density. That makes it highly susceptible to structural damage and disturbances; hence the most prominent histopathological changes associated with laminitis affect the dermal vascular system (Hirschberg *et al.*, 2001). These changes include proliferation of tunica intima, hypertrophy of tunica media, and fibrosis of tunica adventitia of arteries and arterioles (Andersson and Berman, 1980). Other vascular changes include thrombosis and arteriosclerosis (Singh *et al.*, 1992; Bergsten and Mulling, 2004).

Arteriovenous anastomoses and shunts are invariable histopathological findings in laminitis (Boosman *et al.*, 1989a; Vermunt and Leach, 1992). In addition, disruption of vascular wall occurs in subclinical and chronic laminitis and enhances occurrence of oedema of the corium (Andersson and Berman, 1980). Other histological changes reported in chronic laminitis in cattle include degenerative changes in the bovine pododerm (Nocek, 1997; Christmann *et al.*, 2002), vacuolization of the stratum basale

(Boosman *et al.*, 1991) and disruption of the dermal-epidermal junction (Nocek, 1997; Shearer and van Amstel, 2000).

Histopathological changes associated with acute laminitis, the most common form encountered in large feedlots systems, have been elucidated (Mülling *et al.*, 2006). However, histopathological and electron microscopic changes in claws of cattle with chronic laminitis have not been comprehensively documented. Furthermore, systematic transmission electron microscopic studies of the corium in cattle laminitis have not been undertaken. Moreover, knowledge of histopathological and electron microscopic changes of the corium of the claw is paramount to the understanding of pathophysiology of laminitis, which is the most devastating clinical disease syndrome of the digital organ of cattle (Monteiro-Riviere *et al.*, 1993). This study was therefore designed to understand further the pathomorphological changes detectable under light and electron microscopy, in the corium of claws with subclinical and chronic laminitis since laminitis was the most prevalent disease in the current prospective clinical and abattoir studies.

7.2 Materials and methods

7.2.1 Histological examination of the corium

7.2.1.1 Specimen collection for histology

Claws were collected from Kiserian abattoir, Kajiado District and Wangige Market slaughter slab in Kiambu District as previously described in Section3.4.1 chapter 3. Ten claws with subclinical laminitis and another 10 claws with chronic laminitis were purposively selected. Sagittal sections of all these 20 selected claws were done starting from the fetlock joint level through proximal, middle and distal phalanges (Figure 3.7 chapter 3) and the horn of the sole removed with a knife to expose the solear corium. The distal parts of the sectioned digits were disarticulated at the level of pedal joints. Sections of about 5 mm thickness of the corium specimens were harvested from the solear and laminar corium in transverse, longitudinal and horizontal planes from each of the claw samples. These together with the remaining parts of the corium attached to the pedal bones were immersed in 10% buffered formalin individually for fixation. The tissues were kept in formalin for 1-3 weeks. After this period, the corium tissues with the attached pedal bones were immersed in 30% formic acid for decalcification of the bones. Tissues that had subclinical laminitis were decalcified separate from those with chronic laminitis. Formic acid was changed once every week. The decalcification process was allowed to continue for 4 weeks before the tissues were processed (Bradbury, 1969).

7.2.1.2 Tissue processing for histological examination

The corium with the attached pedal bone was sectioned into 1-2 mm pieces and dehydrated through ascending concentrations of absolute isopropyl alcohol starting from 80% to100%. The tissues were cleared in xylene, embedded in paraffin wax, blocked on wooden chunks, and fixed on the microtome.

The tissues in paraffin wax blocks were cut into pieces of 5µm thickness. Four sections were made from every block specimen. These tissue sections were then dewaxed in xylene and hydrated through graded alcohol (100 to 50%), cleared in xylene, alcohol and washed in water. They were then stained with haematoxylin and eosin (H&E). After dehydration, the tissues were then mounted on microscope slides and cover slips using

Destrene 80, dibutyl Phthalate and Xylene (DPX) mountant (Luna, 1968). The sections were examined under the light microscope using x10, x40 and x100 objective lenses. The results were recorded and where necessary, photomicrographs were taken using an ordinary camera (Axioscope 50, Carlzeiss).

7.2.1.3 Controls

Corium specimens taken from abattoir claws that did not show any signs of subclinical or chronic laminitis were used as controls. These were collected, fixed, processed and examined as described in section 7.2.1.2.

7.2.2 Electron microscopy of the corium tissue

7.2.2.1 Tissue fixation and processing

Claws were collected and prepared as described in section 7.2.1.1 above. Specimens for electron microscopy were collected from five claws with subclinical laminitis and five others with chronic laminitis. From these, 1 mm thick cuboidal corium specimens were cut. These cuboidal corium specimens were fixed in 2.5% buffered glutaraldehyde and stored in the refrigerator at 4°C until processed. They were washed in phosphate buffer and put in 1% osmium tetroxide for 2 hours at room temperature. They were then washed again in phosphate buffer. The tissue specimens were dehydrated in increasing concentration of analytical ethanol starting from 30 to 100% for 5 minutes each.

They were cleared in 100% propylene oxide and infiltrated through different ratio mixtures of propylene oxide to resin for 30 minutes in each mixture. The propylene oxide and resin mixtures were in ratios of 3:1 and 1:1 respectively. The tissue specimens were placed in pure resin and left overnight in the oven at 37°C. Then they were embedded in resin mixture at 60°C followed by cutting of semi-thin and ultrathin sections using a microtome. Four semi-thin tissue sections of 1-2μm were cut from each specimen, mounted on microscope slides and stained with toluidine blue for light microscopy. A further four ultrathin sections of 0.5 to 0.9μm thickness were cut from each specimen, placed on copper grid mesh and stained with 5% uranyl acetate in lead citrate (Glauert and Phillips, 1965). Tissues in copper grid mesh were examined under transmission electron microscope, cellular changes recorded and micrographs taken and interpreted.

7.2.2.2 Controls

Corium specimens taken from abattoir claws that did not show any signs of subclinical or chronic laminitis were used as controls. These were collected, fixed, processed and examined as described for the laminitic claws in section 7.2.2.1.

7.3 Results

7.3.1 Histopathological features observed in laminitic claws

The main histological lesions consistently observed in this study included arteriovenous (AVs) shunting, dermal-epidermal junction disruption, vascular wall rupture, vascular thrombosis and vascular proliferation. Other histological lesions that were more rarely seen included oedema in the solear dermis and connective tissue, arterial wall thickness, degeneration and necrosis of the connective tissue supporting the pedal bone, epidermal cell damage, spongiosis in the stratum basale and spinosum, haemorrhages in the corium, degeneration of connective tissue of the sole region and enlarged veins (Table 7.1).

Arteriovenous shunts (Figure 7.1) were observed in 40% (n = 10) and 50% (n = 10) of the corium specimens from claws with subclinical and chronic laminitis, respectively. Vascular wall damage (Figure 7.2) and dermal-epidermal junction disruption (Figure 7.3) were each observed in 30% (n = 10) and 50% (n = 10) of the corium specimens from claws with subclinical and chronic laminitis, respectively. However, vascular wall damage was seen more regularly in the arterioles and venules than in the larger vessels. Furthermore, endothelial disruption was more frequently seen than damage of the rest of the blood vessel wall. In addition to these, rupture of the entire thickness of blood vessel wall followed by haemorrhage into the surrounding tissues was seen in 10% and 20% of the corium specimens from claws with subclinical and chronic laminitis, respectively. Most of the aforementioned histological changes were more common and extensive in the corium specimens from claws with chronic than subclinical laminitis.

Vascular thrombosis was encountered in 70% (n = 20) of all the specimens (Figure 7.4), but was present in all the specimens from claws with chronic laminitis and in 40% of those with subclinical laminitis. Vascular proliferation elaborated by numerous capillary network, was a feature seen in 60% of the specimens, 30% each from subclinical laminitis and chronic laminitis (Figure 7.5).

Oedema of solear dermis and connective tissue was observed in 40% of the specimens, half each from subclinical and chronic laminitis (Figure 7.6). Thickening of blood vessel walls mainly large arteries was present in 40% of the specimens, 30% of which had subclinical laminitis. Tunica media appeared more thickened than other layers of the blood vessels, and in some specimens, it was evident that this thickening was due to oedema (Figure 7.7).

All the 40% of the specimens showing degeneration of the connective tissue supporting the pedal bone were from claws with chronic laminitis. Spongiosis was encountered in 30% of the specimens from chronic laminitic claws but none from subclinical laminitic claws (Figure 7.8).

Histological evidence of corium haemorrhages was seen only in 30% and 10 % of the specimens with chronic and subclinical laminitis respectively. Mild solear connective tissue degeneration was seen in 30% of the specimens from chronic laminitic claws (Figure. 7.9). In 20% of all specimens with subclinical and chronic laminitis, veins had enlargements that seemed like dilatations (Figure 7.10).

Table 7.1: Comparison of prevalence of histopathological lesions occurring in the corium specimens of claws with subclinical and chronic laminitis in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006).

Histopathological lesions	**Prevalence (%) in subclinical laminitis** (n = 10)	**Prevalence (%) in chronic laminitis** (n = 10)
Arteriovenous shunts (AVs)	40	50
Vascular wall damage	30	50
Dermal-epidermal junction disruption	30	50
Vascular thrombosis	40	100
Vascular proliferation	30	30
Oedema of corium and connective tissue	20	20
Vascular wall thickness	30	10
Connective tissue degeneration	0	30
Haemorrhages of corium	10	20
Spongiosis	0	30

Note: Some specimens had more than one histopathological lesion.

Figure 7.1: Arteriovenous shunting (AVs) seen in the histological sections of the corium of claws with subclinical and chronic laminitis as seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). Note the branching out of the wall of the artery (bold arrow) and inclusion of veins within the arterial wall boundaries (thin arrows) and the position of capillary-beds (curved arrows). H & E, x400.

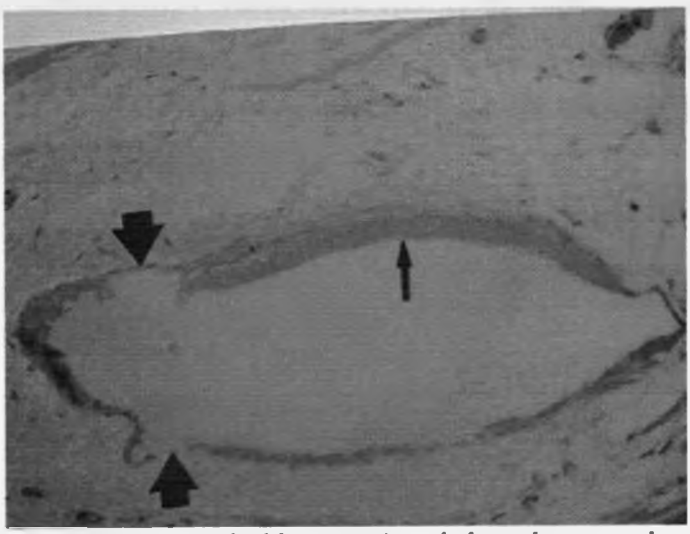


Figure 7.2: Venous wall damage (bold arrows) and thrombus attachment to the wall of the vein (narrow arrow) seen in the corium of claws with subclinical and chronic laminitis in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). H&E, x400.

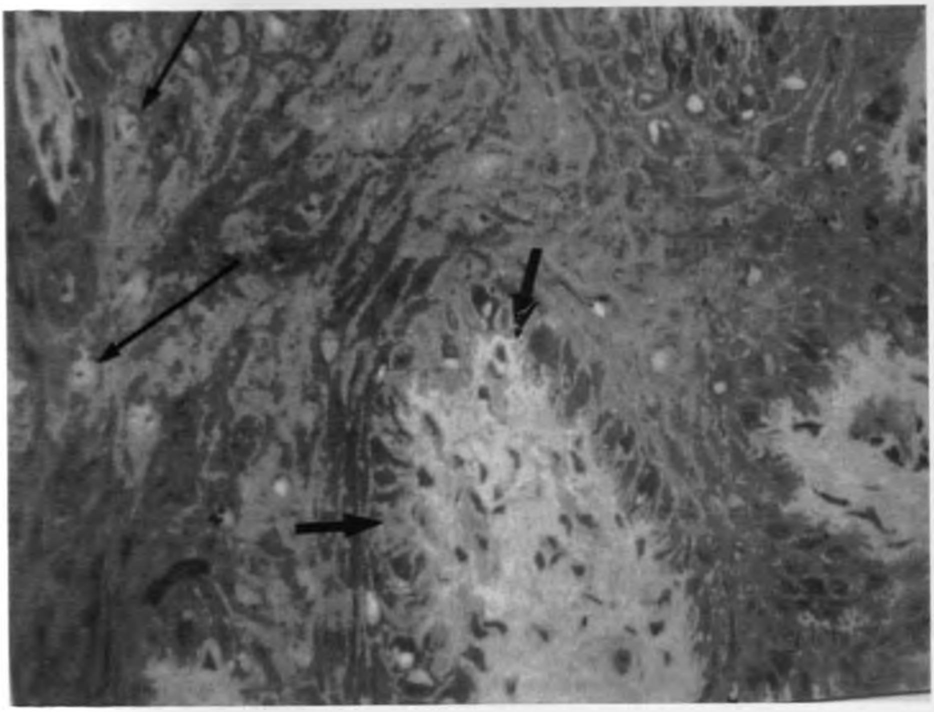


Figure 7.3: Dermal-Epidermal junction disruption. Note areas where cells are not compact and continuous with each other (short arrows). Areas of intracellular oedema (spongiosis) (long narrow arrow). These were seen in the histological sections of the corium of claws with subclinical and chronic laminitis in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). Toluidine blue stain, x 400.

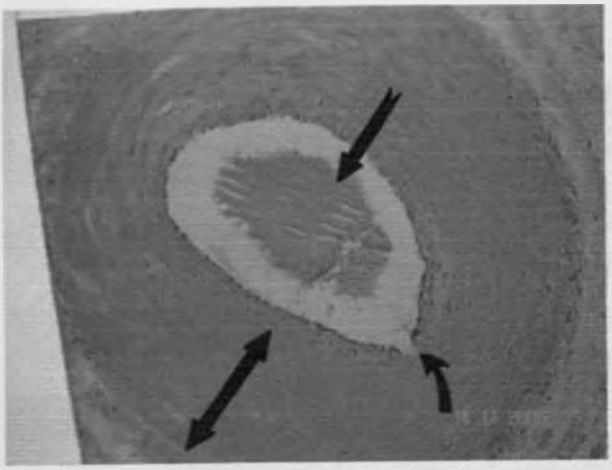


Figure 7.4: Vascular thrombus in the lumen of an artery (notched arrow), endothelial line rupture (curved arrow), and thickened tunica media (up-down arrow). These histological changes were seen in the corium of claws with subclinical and chronic laminitis in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). H&E, x400.

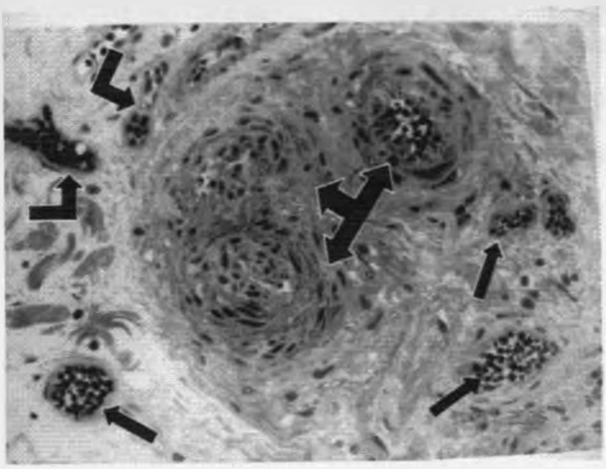


Figure 7.5: Vascular network showing capillaries (left-right-up arrow), arterioles (short straight arrows) and venules (short angled arrows) as seen in the histological sections of the corium of claws with subclinical laminitis in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). Toluidine blue stain, x 400

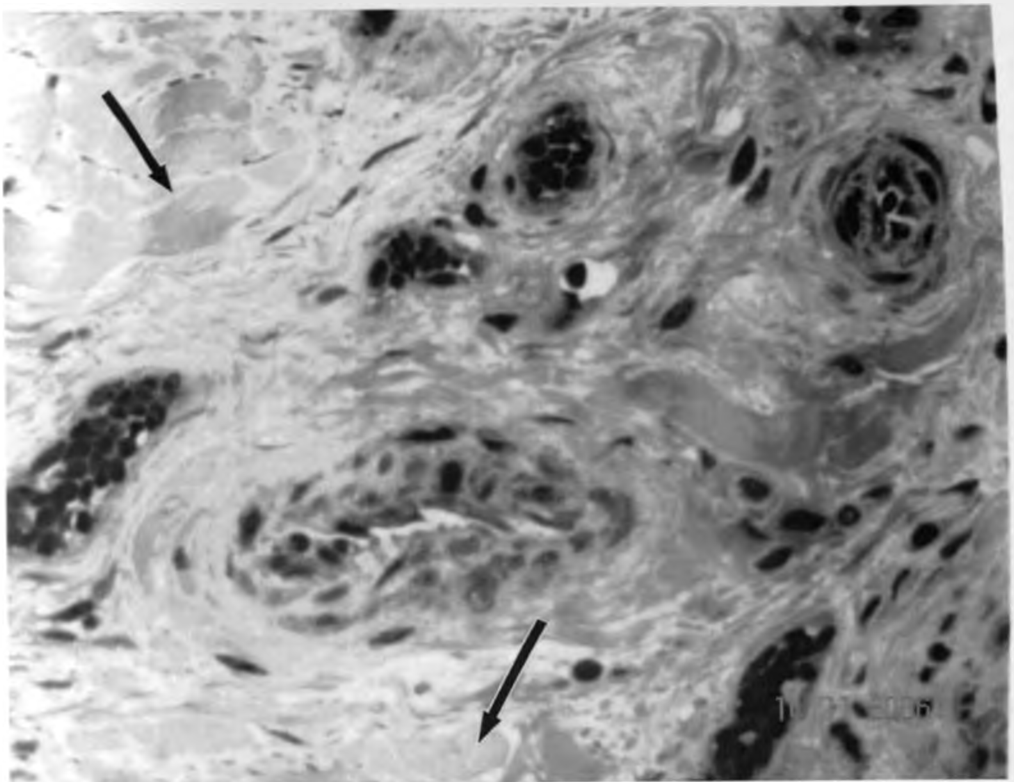


Figure 7.6: Connective tissue oedema (arrows) seen in the histological sections of the corium of claws with subclinical and chronic laminitis as seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 200 5-June 2006) (arrows).Toluidine blue, x 400

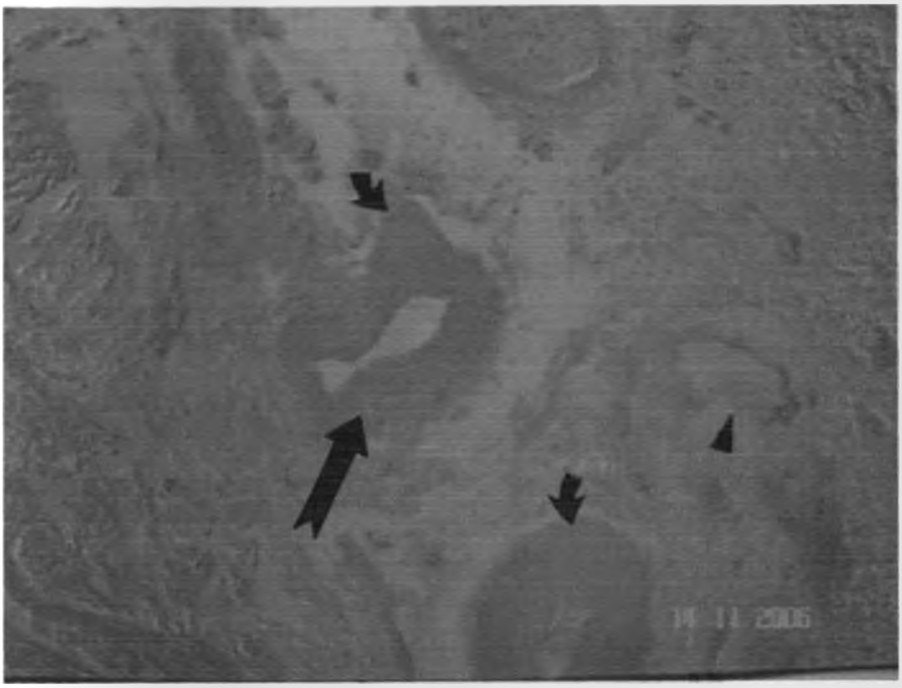


Figure 7.7: Arteriosclerosis particularly of tunica media (bold notched arrow) together with thickening of the vessel (short curved arrows). Venular destruction can be seen (arrow head). These changes were seen in the histological sections of the corium of claws with chronic laminitis in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). H&E, x200

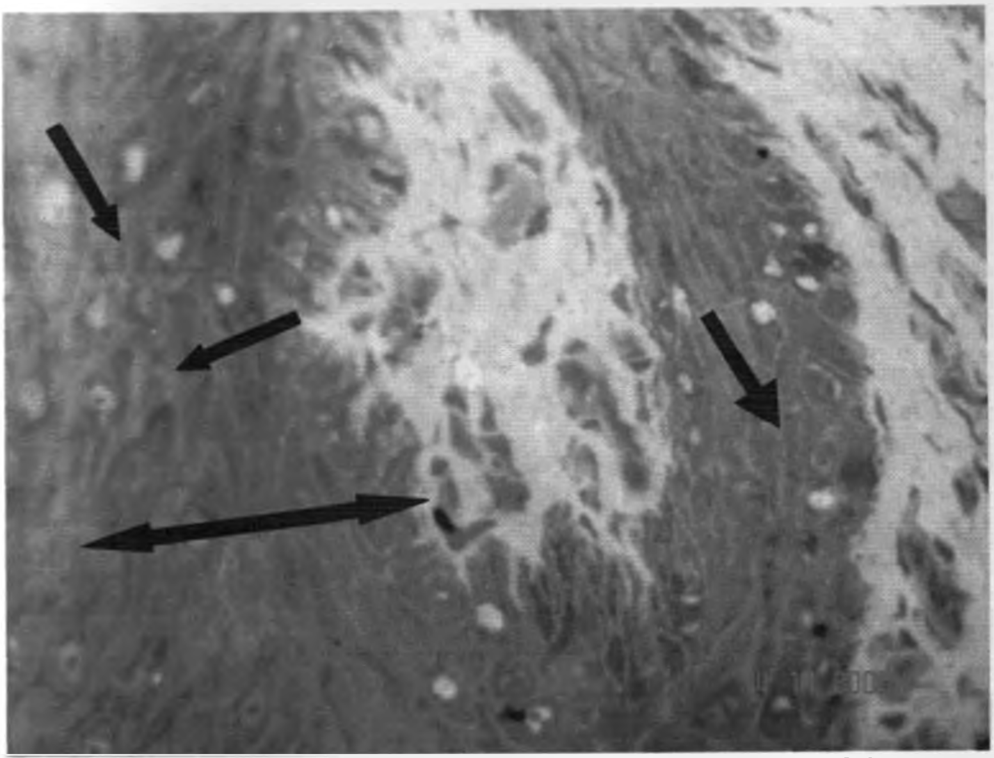


Figure 7.8: Areas of epidermal disruption with indistinct cells (straight arrows) and epidermal hyperplasia (left-right arrow) seen in the histological sections of the corium of claws mainly with chronic laminitis as seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). Toluidine blue stain, x400.

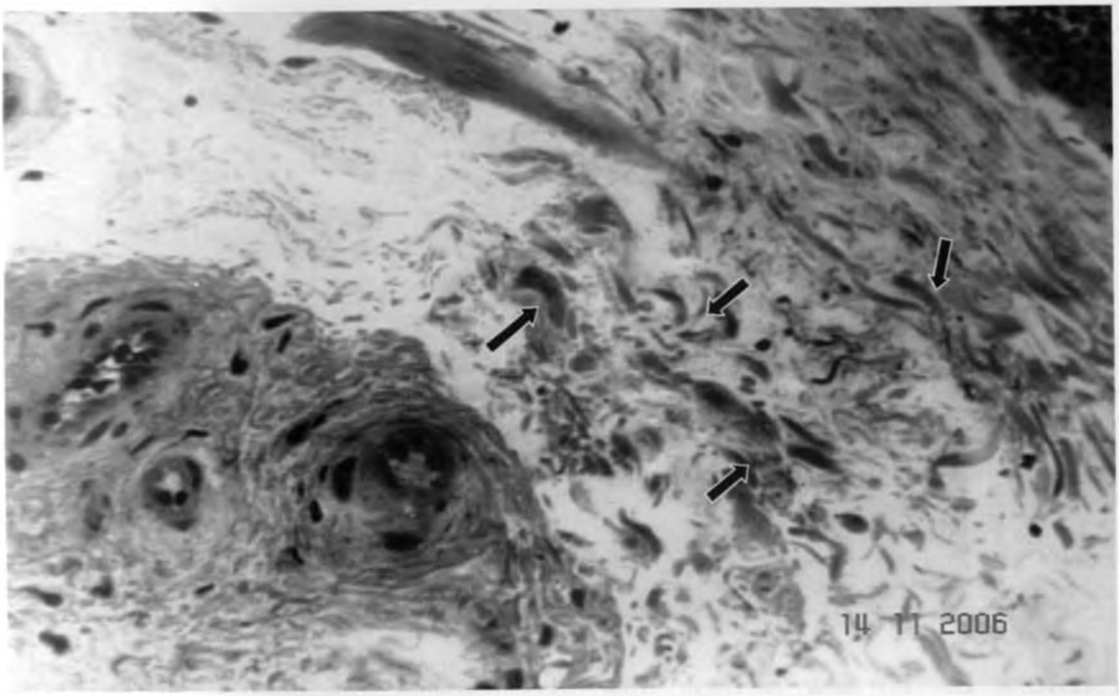


Fig.7.9: Connective tissue degeneration showing by deeply stained degenerated fibroblasts and fibres (arrows) in the histological sections of the corium of claws with chronic laminitis as seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). Toluidine blue stain, x200.

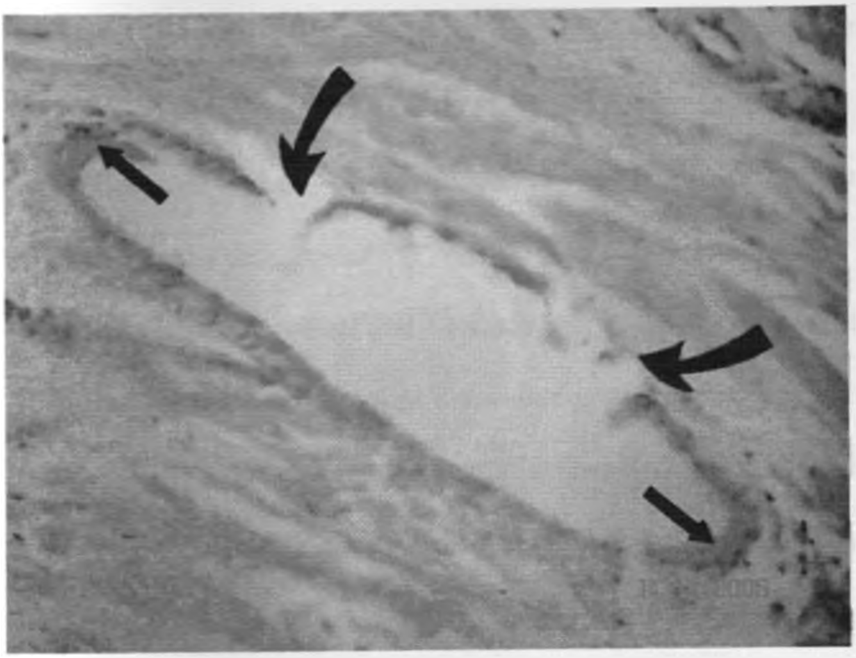


Figure7.10: A massively enlarged vein with ruptured wall (curved arrows) and atherosclerotic-like areas involving the whole venous wall (straight arrows) in the histological sections of the corium of claws with chronic laminitis as seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). H&E, x400.

7.3.2 Electron microscopic lesions

The fibroblasts within the collagen fibres had undergone degeneration. This was characterized by deep and uneven staining of the nuclei and reduction in the amount of granular cytoplasmic material (Figure 7.11). The granular appearance of chromatin within the nuclei was scarce, unevenly stained and difficult to see. There was vacuolization within the cytoplasm of the fibroblasts (Figure 7.12).

Extensive oedema was seen within and between the collagen fibres of the connective tissues. There was evidence of fibroblast degeneration and necrosis (Figure 7.13). Most of the blood vessels and particularly the arterioles had damaged endothelial lining and cells. The tunica media had undergone disruption that was evidenced by disoriented smooth muscle myofibrils of the vessel wall (Fig 7.14 A and B).

Disruption of the dermal-epidermal junction and degenerative changes within the epidermis were observed by absence of clearly demarcated epidermal epithelial cells and basement membrane. In general, the electron microscopic features were consistent with those observed at histopathology but revealed finer details.

A

B

Figure 7.11: Electron micrographs showing fibroblast degeneration and necrosis being demonstrated by the deep staining characteristics (straight arrows) and reduction in the granular chromatin material within the nucleus (angled arrows). These were seen in the corium of claws with chronic laminitis in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). A = x 4,380 B= x 63,400

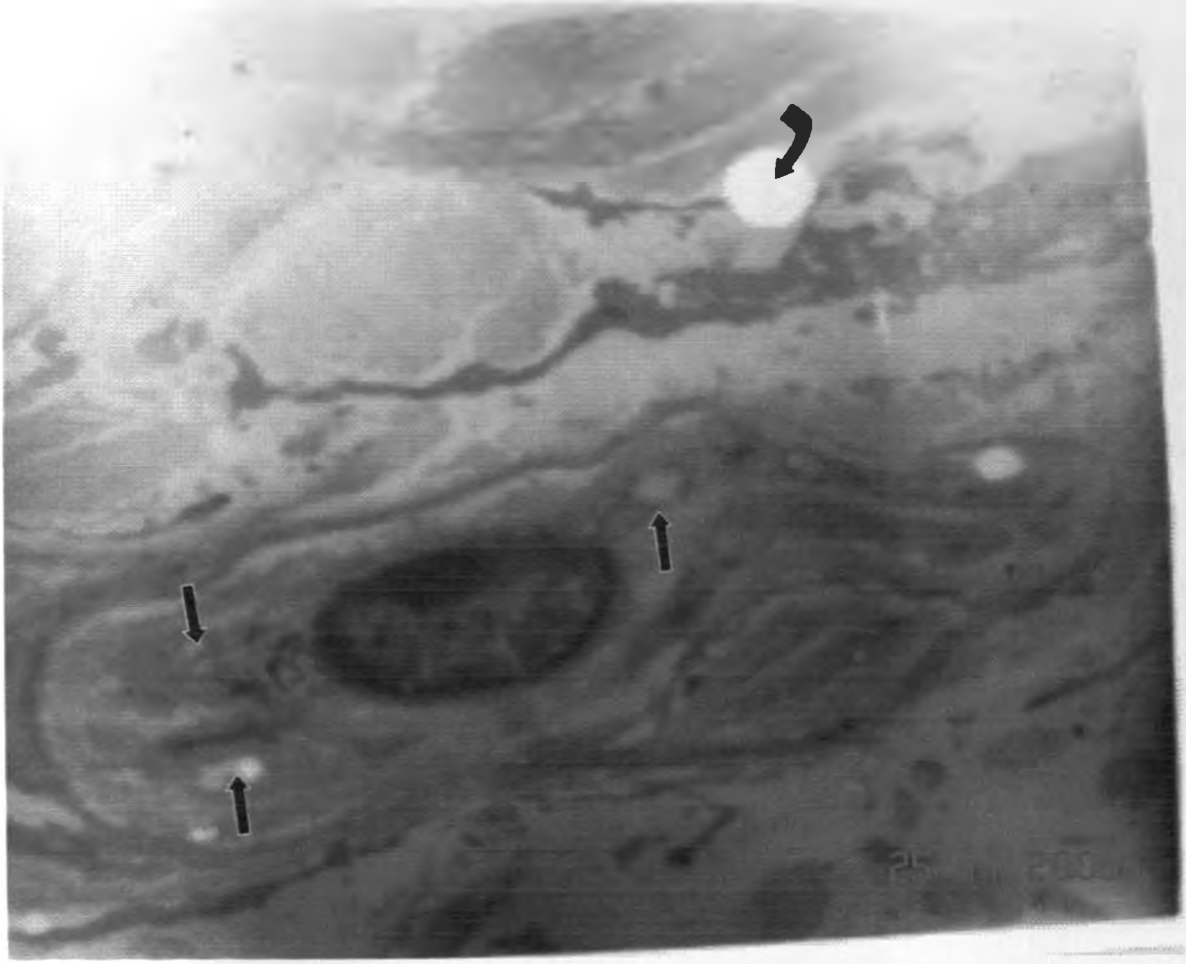


Figure 7.12: Electron micrograph showing extensive vacuolization within cytoplasm of the fibroblast (straight arrows) as seen in the corium of claws with chronic laminitis in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). x 13,900. Curved arrow shows an artifact.

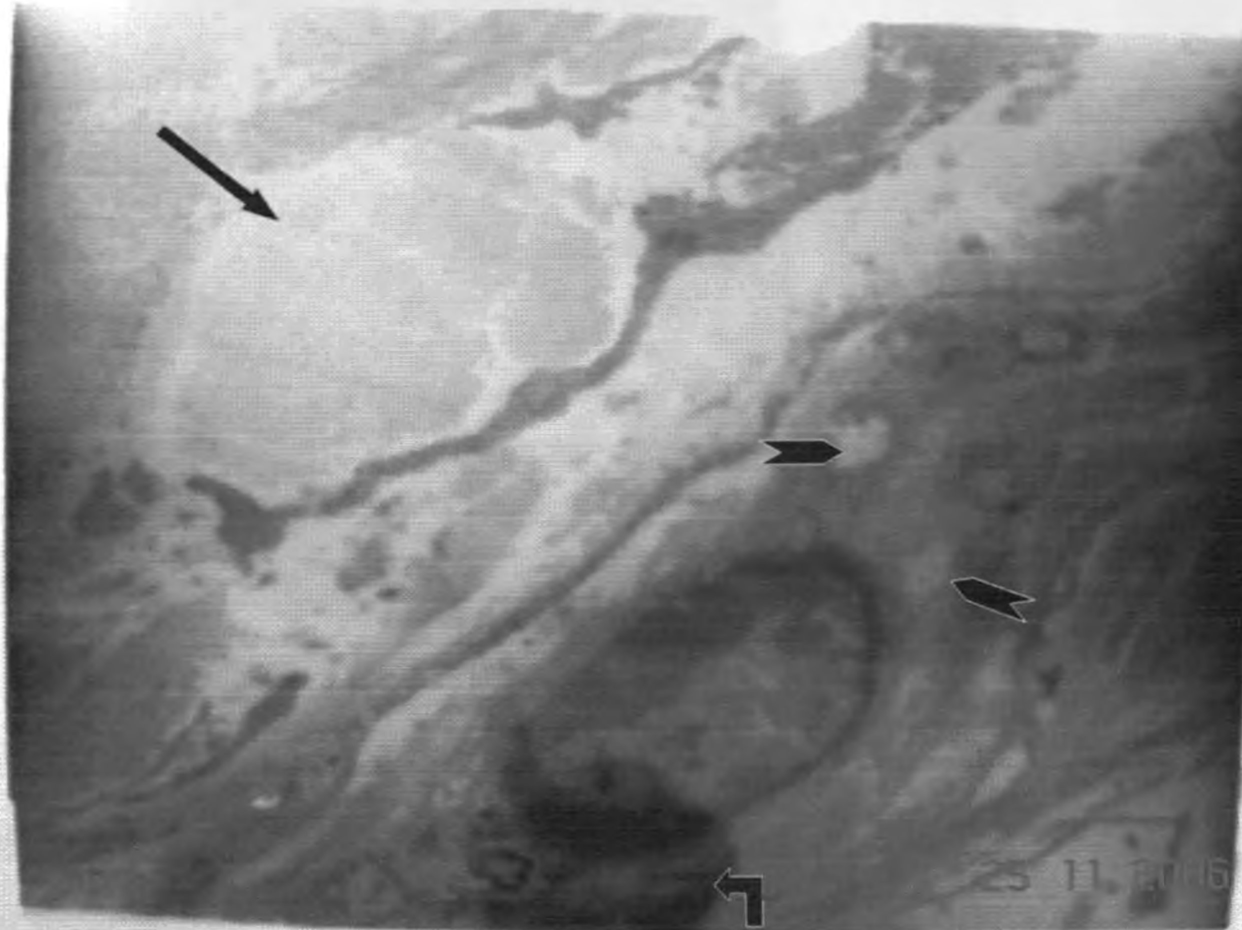


Figure 7.13: Electron micrograph showing oedema within the collagen fibres (straight arrow), vacuoles within the cytoplasm of fibroblast (chevrons) and deeply stained area of artifact (angled arrow) as seen in the corium of claws with chronic laminitis in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). x15,000

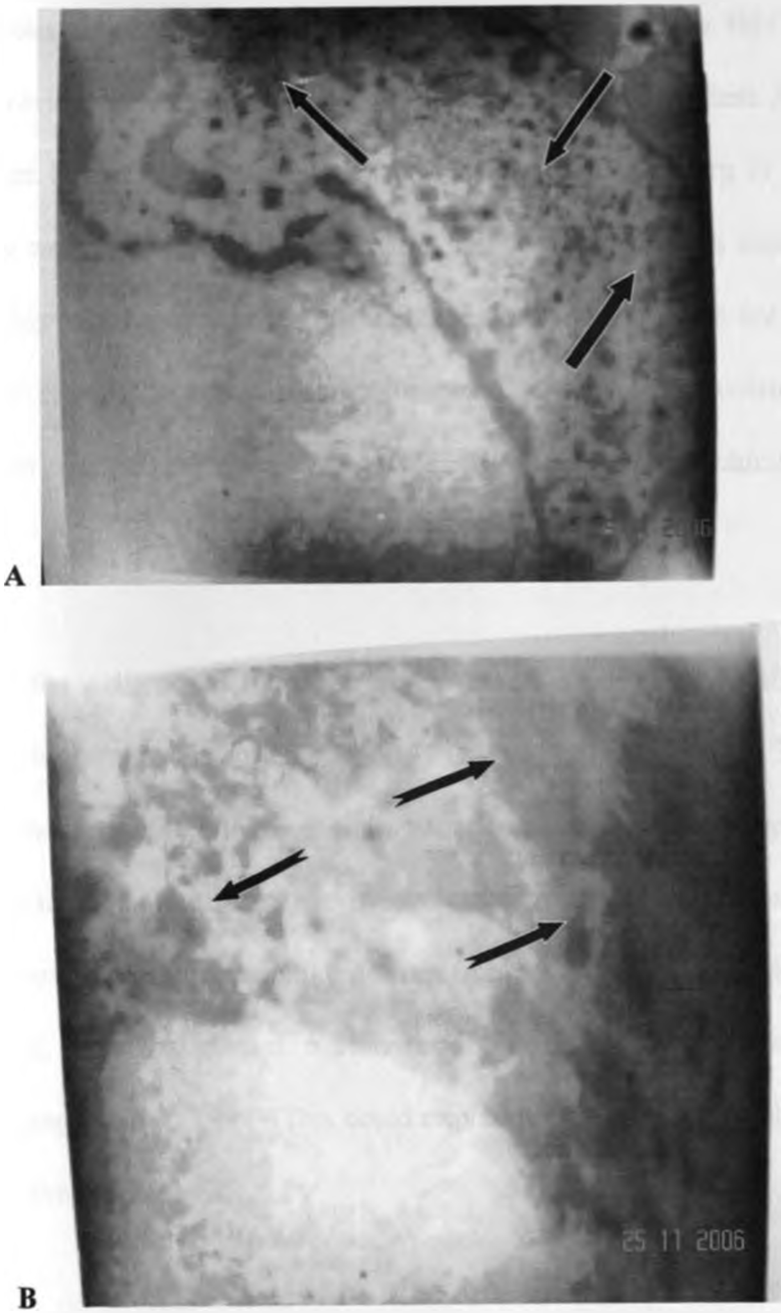


Figure 7.14: Electron micrograph showing: **A**- endothelial cell damage demonstrated by uneven staining of the granular chromatin material within the cell (straight arrows), and **B**-disruption of tunica media of an arteriole demonstrated by disoriented smooth muscle cells notched arrows). These were seen in the corium of claws with chronic laminitis in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006). X63,400

7.4 DISCUSSION

Arteriovenous shunts (AVs) that were commonly observed in this study have been reported previously (Vermunt and Leach, 1992; Nocek, 1997). These AVs were reported to be absent in the vascular system of healthy claws (Hirschberg *et al.*, 2001). In our study, they were seen to involve mainly the smaller blood vessels such as arterioles and venules. This could be attributed to the fact that narrower vessels are more likely to be affected by changes in blood pressure involved in the microcirculation of the corium (Christmann *et al.*, 2002), in which AVs form as an adaptive structural change (Mülling, 2004).

Damage to the walls of the blood vessels observed in this study as affecting mainly the dermal arteries has been reported previously (Hirschberg *et al.*, 2001). The reason for this damage is thought to be pressure build-up that results from intermittent vasodilation and vasoconstriction of the corium microvasculature (Nocek, 1997). The build-up of local blood pressure resulting from initial increase in blood flow and pooling within the corium capillary-bed. leads to vessel rupture and subsequent serum seepage as well as haemorrhaging (Nocek, 1997). This could explain the haemorrhages observed in cases of laminitis in the present study.

Thickened arterial and arteriolar walls especially the tunica media was similar to proliferation of the tunica intima, hypertrophy of tunica media and fibrosis of tunica adventitia that were reported by Andersson and Berman (1980). This change in the arterial wall is likely to interfere with function of the vessel. Occurrence of vascular thrombosis was not unusual but is a commonly reported feature in the corium of laminitic claws (Singh *et al.*, 1992; Nocek, 1997). Thrombus formation might probably result from pressure insults within the vessels, vascular endothelial damage, or vasoactive substances (Nocek, 1997; Bergsten and Mülling, 2004). Elaborate capillary network is a normal feature of the corium (Hirschberg *et al.*, 2001), but the observed vascular proliferation that culminated into increased capillary network was probably a response to coritis associated with aseptic pododermatitis (Bell, 2004).

The oedema seen in the solear corium and the connective tissue has been reported previously (Nocek, 1997). It results from an increased capillary pressure combined with post-capillary resistance that facilitates transvascular fluid movement followed by subsequent increased pressure within the tissues. Furthermore, digital venous constrictions are thought to be the initial step in these events (Christmann *et al.*, 2002). Consequently, oedema physically expands the corium which in-turn causes pain that leads to lameness in laminitis (Nocek, 1997; Shearer and van Amstel, 2000).

The observation of enlarged veins which remained widely open seemed like venous dilatation rather than venular wall thickening and was seen only in chronic laminitis. This feature has not been reported previously. Although chronic degenerative change in the bovine pododerm has histologically been observed in chronic laminitis (Boosman *et al.*, 1989a), the observation made in the current study of specific disruptive connective tissue damage particularly involving fibroblasts has not been reported. This disruption is thought to be a degenerative change associated with enzymatic action of matrix metalloproteinases (MMPs) and gelatinolytic protease "hoofase" (Tarlton and Webster, 2002). It could also imply altered biochemistry of the connective tissue (Tarlton *et al.*, 2002). This degenerative disruption of the connective tissue was seen in specimens from chronic laminitic claws.

Disruption of dermal-epidermal junction has been reported previously as an invariable histological finding in both subclinical and chronic laminitis due to compromise of corium microvasculature that reduces the nutrients and oxygen reaching the epidermal cells. This causes the stratum germinativum in the epidermis to breakdown, the corium becomes degenerated, and eventually a breakdown of the dermal-epidermal junction that results in separation of the strata germinativum and the corium (Shearer and van Amstel, 2000). Spongiosis and hyperplasia of the epidermis have not been reported previously. Both of these histological changes occurred in subclinical and chronic laminitis. They are probably due to inflammation triggered by pressure irritation on the soft tissues located between pedal bone and horn of the sole after the claw comes into contact with the ground when the cow is in standing posture or in locomotion.

The electron microscopic features were mainly degenerative and have been reported in histopathological studies (Boosman *et al.*, 1989a). These are thought to be enzyme-mediated by the enzymes metalloproteinase and gelatinolytic protease (Tarlton and Webster, 2002). As a result, degenerated tissues : Radiograph of a normal claw as seen in an abattoir study of characteristics of laminitis and other claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2005).
differ in staining intensities compared to the normal tissues. Vacuolization observed in the cytoplasm of fibroblasts. is similar to that reported in the stratum basale in chronic

laminitis (Boosman *et al.*, 1991). It is also thought to be caused by the effect of endotoxic substances that result from tissue necrosis and degeneration in chronic laminitis (Boosman *et al.*, 1989a and 1991).

The rest of the findings of electron microscopic study such as oedema in the connective tissues, vascular destruction, and disruption of dermal-epidermal junction can be attributed to pressure in the pododermal tissues resulting from transvascular fluid movement and inadequate nutrients and oxygen in the tissues due to compromise of microvasculature of the corium (Nocek, 1997; Shearer and van Amstel, 2000). Cellular level disruption was more elaborate under transmission electron microscopy than light microscopy.

CHAPTER 8

8.0 GENERAL DISCUSSION

Results of the current study revealed a high prevalence of claw lesions in dairy cows (over 80%) that have calved at least once. This closely agrees with the findings of Clarkson *et al*. (1996) and Weaver (2000) who reported that claw disorders account for 90 % of all lameness incidences. However, it is higher than 23% to 60% prevalence rate of claw lesions reported by other researchers (Manske *et al*., 2002; Cook *et al*., 2004). In over 60% of the cows, the claw lesions were subclinical, which means that if they are not managed at this stage, and when presence and persistence of interactive predisposing factors exist (Cook *et al*., 2004), they will gradually progress to cause clinical lameness by enhancing occurrence of other lameness causing lesions such as chronic laminitis, sole bruising, heel erosion, white line disease, sole ulcers and double soles (Nocek, 1997; Smilie *et al*., 1999; Belge and Bakir, 2005). These latter conditions will then cause remarkable functional damage to the claws and end up with reduced productivity in the affected cows (Hernandez e*t al*., 2005).

The results of retrospective study of claw lesions from hospital records indicated a high prevalence of infective lesions and a low prevalence of laminitis and associated claw lesions. The common occurrence of the infective foot lesions was probably enhanced by the prevailing unhygienic conditions such as wetness brought about by accumulation of slurry (manure). This subsequently provided favourable environment for growth of pathogenic bacteria that cause foot infections (Berry, 1999; Somers *et al*, 2005). However, this high prevalence of infective foot lesions does not reflect the true pattern of general occurrence of claw lesions in the field but could be influenced by the fact that farmers seem to recognize and report only cows with lesions that cause severe lameness, which in most cases are infective lesions (Hull, 1993; Rhebun and Pearson, 1982; Weaver, 1993). In contrast, laminitis and associated claw lesions are more mild and insidious (Nocek, 1997; Smilie *et al*, 1999; Belge and Bakir, 2005;) and therefore the affected cows are not noticed easily, hence the "low" prevalence. Moreover, this fact was confirmed by the results of the prospective study, which is more reliable in predicting the actual field status and whose findings revealed that the prevalence of infective claw lesions was low while that of laminitis and associated claw lesions was high.

From the prospective clinical and abattoir studies, subclinical and chronic laminitis were the most prevalent claw lesions occurring in over 70% of the dairy cows and abattoir claw samples examined. In addition to this, the prevalence of subclinical laminitis was 49.3% which was more than twice that of chronic laminitis. However, this was lower than what is reported by others who found subclinical laminitis to be very common with prevalence rates of over 60% (Smilie *et al*., 1999; Belge and Bakir, 2005). The higher prevalence of subclinical laminitis in comparison to chronic laminitis can probably be attributed to the fact that subclinical laminitis is considered to be the lesion preceding development of chronic laminitis (Nocek, 1997; Belge and Bakir, 2005). In addition, occurrence of chronic laminitis is reported to depend on the frequency and intensity of previous episodes of acute laminitis and the degree of corium damage caused by each of those episodes. Moreover, the possible spontaneous recovery of some of the subclinical and acute laminitis episodes could contribute to lower prevalence of chronic laminitis than subclinical laminitis (Nocek, 1997).

Results of the current prospective study revealed that presence sole haemorrhages were the most important indicator signs of laminitis in the claws. Although in some severe cases of chronic laminitis the haemorrhages were noticed without trimming of the horn of the sole, in most cases particularly those with subclinical laminitis, the haemorrhages were more discernible by thorough examination and trimming of a thin layer of the horn from the weight-bearing surface of the claw. Trimming also revealed the extent of occurrence of these haemorrhages on the zones of the weight-bearing surface of the claw which was important in categorizing laminitis as subclinical or chronic. Similar observations have been reported in by other researchers (Mgassa *et al.*, 1984; Enevoldsen and Gröhn, 1991; Bergsten, 1994; Nocek, 1997; Belge and Bakir, 2005). The linkage between occurrence of sole haemorrhages and laminitis is the fact that the initial phase in the pathogenesis of laminitis involves damage and changes in the pododermal microvasculature that results in transvascular seepage of serum with subsequent haemorrhagic discolouration of the sole (Nocek, 1997; Hirschberg and Plendl, 2005). In addition to this, the severity and distribution of haemorrhages is related to the intensity and duration of the insult that caused the vascular disruption (Nocek, 1997). Furthermore, the haemorrhages occur deep in the corium, but as the horn of the sole grows outwardly, these haemorrhages eventually become externalized in about 2 months (Greenough and Vermunt, 1991; Nocek, 1997) and are therefore noticeable on the surface of the sole or upon trimming of a thin layer of the horn of the sole.

Among the signs of laminitis, claw deformities were found to be highly associated with chronic laminitis. Such an association has been reported previously (Greenough, 1987; Ebeid, 1993; Weaver, 1993). Furthermore, the high relative risk (29.84) observed in the current study between claw deformities and chronic laminitis showed that claw deformities could be used to predict presence of chronic laminitis. Other reports indicate that claw deformities occurring with chronic laminitis cause extreme misshaping and crookedness of the claws (Rhebun and Pearson, 1982; Singh *et al.*, 1993a). Such claws are difficult to reshape and an attempt to do so is only palliative due to the difficulties of removing the underlying cause which is chronic laminitis (Rhebun and Pearson, 1982). Under normal conditions, the bovine claw capsule undergoes continuous turnover process in which horn-growth and horn-wear occur approximately at equal rates (Vermunt and Greenough, 1995). But when horn-growth exceeds horn-wear, regular claw overgrowth results and deforms the claw (Toussaint-Raven *et al.*, 1985; Blowey, 2002). However, findings of the current study indicated that concurrent presence of sole haemorrhages and claw deformities helps to distinguish claw deformities that occur in chronic laminitis from those that are due to regular overgrowth deformities which occur without haemorrhages. Moreover, all cows with laminitis have been reported to have sole haemorrhages (Manske *et al.*, 2002b). Additionally in the current study, regular claw overgrowth was found to have a high prevalence among other claw deformities. This could probably be attributed to lack of routine claw trimming programmes in the farms (personal information from the farms studied), which is contrary to the recommendation of mandatory preventive claw trimming (Toussaint Raven, 1985).

Other conditions that were observed as important indicators of presence of laminitis but not in all cases were sole bruising (erosion), heel erosion, white line separation and double (underrun) soles. Since these conditions are thought to develop sequel to subclinical laminitis, one or more such lesions are likely to manifest in some cases of laminitis (Nocek, 1997; Smilie *et al.*, 1999; Belge and Bakir, 2005). The results obtained in the current study indicated that among these laminitis associated claw lesions, sole bruising and heel erosion were the most prevalent and occurred either independent of each other or concurrently. However, the prevalence of heel erosion differs remarkably with that reported by Okwee-Acai and Acon (2005) who found a 79% prevalence rate for heel erosion in a study of cattle fed on high-level grains in Kampala, Uganda, while Gitau (1994) found a low incidence rate of 4.4% in a study of cattle in Kikuyu division, Kiambu district. Kenya. The difference in prevalence rates of heel erosion may probably be attributed to variations in levels of concentrate feeding and other predisposing factors in these studies. On the other hand, sole erosion was not reported in these previous studies. Heel erosion was more invasive than sole bruising and this could be associated with softer horn at the heel compared to the relatively harder horn of the sole (Berry, 1999).

In the current study, cows that had three or more parities were found to be at a higher risk of developing chronic laminitis. This closely agrees with the reports of others who found that chronic laminitis is more common in older cows while heifers are more prone to acute laminitis (Andersson and Lundstrom, 1981; Russell *et al.*, 1982). In addition, it has been reported that most cases of lameness in cattle are generally associated with third or higher parities (Offer *et al.*, 2000; Sogstad *et al.*, 2005b). It has been suggested that cattle suffering more lameness from claw lesions in latter parities are likely to have suffered lameness from such lesions during the first parity (Hirst *et al.*, 2002; Cook *et al.*, 2004). Espejo *et al.* (2006) reported further that prevalence of lameness increases on average at a rate of 8% units per subsequent lactation.

This study also showed that cows in the lactation stage of 90 to 180 days were more prone to developing chronic laminitis and those in lactation stage of 1-90 days were more prone to developing subclinical laminitis. This agrees with the reports that a strong positive association exists between the first 120 days post-partum and the presence of claw disorders (Rowlands *et al.*, 1985; Vermunt. 2004). It also agrees with the report that the peak scores for sole lesions occur 14 weeks after calving (offer *et al.*, 2000). These observations have been attributed to the high level of energy intake during the late pre-partum and early post-partum periods Vermunt, 2004)

Regular (2-3 times per day) feeding of cows with concentrates was found to be associated with occurrence of subclinical and chronic laminitis as reported previously (Blowey *et al*, 2004; Okwee-Acai and Acon. 2005). The reason for this is the destruction of microvasculature of the corium associated with lowered rumen pH sequel to subacute ruminal acidosis (SARA) phenomenon (Nocek. 1997; Cook *et al.*, 2004; Vermunt, 2004). However, from the results of this study, mineral supplementation seemed protective against occurrence of subclinical laminitis as reported previously that feeding cows with trace minerals tended to improve lesion scores, health and integrity of the claws

(Tomlinson *et al.*, 2004). Furthermore, it has been reported that failure to supplement lactating cows with vitamins and minerals was a risk factor for higher locomotion scores (Amory *et al.*, 2006). Regular concentrate feeding was also found to enhance occurrence of sole bruising and white line separation. This could be attributed to the phenomenon of SARA and development of subclinical laminitis which eventually predisposes to development of other claw lesions (Nocek, 1997; Cook *et al.*, 2004; Vermunt, 2004). However, mineral supplementation was also found to be protective against occurrence of sole bruising and white line separation and this is in conformity with reports that mineral supplements promote replacement of defective horn, thus improving healing and making it less likely for the claw to develop sole lesions from laminitis (Bergsten *et al.*, 2003).

Another farm-factor that was found in the current study to contribute to occurrence of chronic laminitis was overstocking (more cows than the number of cubicles). This agrees with the findings of others who observed such overcrowding and having uncomfortable stalls as an exacerbating factor to the development of claw lesions (Leonard *et al.*, 1994; Sogstad *et al.*, 2005a and b). This could be attributed to the stress of overcrowding and cow discomfort due to long hours of standing particularly on concrete alleys (Leonard *et al.*, 1994; Sogstad *et al.*, 2005a) from lack of enough cubicles to lie in.

In addition to other farm factors, the study showed that housing cows on earthen (soil) floors also enhanced development of chronic laminitis. Similar observations have been reported in connection with development of claw deformities (Rhebun and Pearson, 1982). The higher tendency of cows to develop chronic laminitis when raised on earthen floors could be attributed to the fact that such floors are soft and yielding and promote overgrowth and deformities of the claws (Rhebun and Pearson, 1982; Somers *et al.*, 2005). Subsequent to claw overgrowth and deformities, uneven redistribution of weight results in overloading the weaker zones of the claw, thus allowing transmission of excess pressure to the underlying corium and hence predisposing such claws to developing chronic laminitis (Sagues, 2002; Somers *et al.*, 2003; Neveux *et al.*, 2006). In contrast, earthen floors were found to be protective against development of sole bruising and this has not been reported previously. This finding is likely to be due to the fact that earthen floors are soft and non-abrasive (Somers *et al.*, 2003).

The study also revealed that lack of removal of slurry (less than once per day) from the walk alley of the cow house enhanced development of chronic laminitis. Presence of slurry creates wetness around the environment of the claws. This agrees with the findings of vermunt (2004) who reported that wet conditions soften the horn of the sole, which then predisposes them to abrasion from rough concrete floors and causing them to easily develop claw conditions that cause lameness. Furthermore, it has been shown that when exposed to wet environment, claws absorb water rapidly and when removed from wet environment the rate of water loss from the claws is much slower (Borderas *et al.*, 2004). Furthermore, it has been reported that softer claws tend to have more claw lesions than harder ones (Borderas *et al.*, 2004). This study confirmed that reducing wetness around the claws by removal of the slurry reduced the prevalence of white line separation.

Presence of a curb (kerb) was also found to enhance occurrence of chronic laminitis. This closely agrees with the reports that high rear curbs are related to increased risk of claw lesions and lameness (Leonard *et al.*, 1994; Philipot *et al.*, 1994; Faull *et al.*, 1996). This is probably associated with the stress of lifting the limbs over the curbs as the cow enters and exits the cubicle.

Prominent and dilated vascular channels within the pedal bones of claws with subclinical and chronic laminitis were consistent radiographic findings in this study and were more pronounced in the lateral than the medial claws. These observations agree with previous reports (Boosman *et al.*, 1989b).

Exostosis of the pyramidal process of pedal bones of laminitic claws has been reported (Maclean, 1970), but in the current study, it involved the apex and the medial aspect of the bone. No documentation is available on the cause of this exostosis, but it could be related to osteitis and periostitis, which are inflammatory responses to persistent irritants, in these cases being chronic inflammation of the corium in chronic laminitis. Periostitis is likely to result in irregular margins of the pedal bone after the chronic process.

In the current study, a remarkable narrowing of the pedal bone was seen involving claws affected by chronic laminitis and extreme deformities particularly twisting or upward turning of the toe. This radiographic feature has not been reported previously in laminitic claws. It could be caused by initial necrosis (osteosis) of the pedal bone as a result of compromised local blood supply that is precipitated by chronic laminitis and the extreme deformities of the claw. This is followed by osteoclastic resorption process to remove the necrotized part of the bone, thus the remaining normal bone becomes narrowed (Jubb *et al.*, 1993). This explanation could also apply for the radiographic observation of absence of the apex of the pedal bone that was seen in claws with similar gross disorders. Further observation made in this study that is probably associated with similar osteosis and osteoclastic resorption processes, is the radiolucent osteolytic areas of the pedal bone. However, Maclean (1970) reported that the general density of the pedal bone is reduced in chronic laminitis.

Distinct outgrowths of the distal parts of the pedal bones have not been reported previously. These were clearly distinct from exostoses and are most likely linked to osteolytic processes in which case the non-osteolysed distal parts of the pedal bones remain projected as outgrowths.

Dropped ("sinking") pedal bones has been reported previously as a radiographic feature in claws with chronic laminitis (Shearer and van Amstel, 2000), and is associated with weakened connective tissues that support the bones as well as dermal-epidermal junction destruction which eventually allows the laminar to separate (Shearer and van Amstel, 2000; Tarlton *et al.*, 2002). The "sinking" pedal bone phenomenon is positively associated with pathogenesis of laminitis (Nocek, 1997).

The consistent histological finding of arteriovenous shunts was in agreement with the observations of others (Vermunt and Leach, 1992; Nocek, 1997), but such shunts are reported to be absent in vascular system of normal claws (Hirschberg *et al.*, 2001). They are adaptive structural changes to develop collateral circulation (Bergsten and Mülling, 2004).

In the current study, vascular wall thickening was more pronounced in the tunica media of arteries. This could be explained by the ensuing pressure build-up in the microvasculature of the corium, caused by pooling of blood due to initial vasodilation followed by vasoconstriction, and eventually vascular wall damage occurs especially on the endothelium (Nocek, 1997; Hirschberg *et al.*, 2001). In addition, repeated pressure insults also lead to vascular wall thickening due to proliferation of tunica intima, hypertrophy of tunica media and fibrosis of tunica adventitia (Andersson and Berman, 1980). However, the venular enlargements that were observed did not show any signs of vessel wall thickening but instead appeared like dilatations. These dilatations were possibly in response to obstructive vascular thrombosis and pooling of blood in the veins. Moreover, thrombus formation has been observed by others in both subclinical and chronic laminitis and could be linked to intravascular pressure insult, vascular endothelial damage and vasoactive substances (Nocek, 1997; Bergsten and Mülling, 2004).

The oedema seen in the dermis and the connective tissue during the current electron microscopic study was documented previously under light microscopy (Nocek, 1997). It may be caused by increased capillary pressure due to post-capillary resistance that facilitates transvascular movement of fluids into the perivascular tissue (Nocek, 1997). In addition, the epidermal spongiosis that was observed has not been reported. This could have been caused by pressure extending to epidermal cells from the swollen corium which also resulted in varying degrees of cellular degeneration. The initial step in these events is likely to be digital venous constrictions (Christmann *et al.*, 2002). Eventually, occurrence of oedema in these tissues causes swelling of the corium that subsequently results in pain and clinical lameness during laminitis (Nocek, 1997: Shearer and van Amstel, 2000).

A consistent histological change observed in both subclinical and chronic laminitis is the disruption of dermal-epidermal junction as has been reported (Shearer and van Amstel, 2000). It is attributed to a reduced amount of nutrients and oxygen reaching the epidermal cells which leads to a breakdown within the stratum germinativum, degeneration of the corium and subsequent breakdown of the dermal-epidermal junction with ultimate separation of the stratum germinativum from the corium (Shearer and van Amstel, 2000).

The electron microscopic studies revealed fibroblasts that were severely degenerated and vacuolated, an observation that has not been reported previously. The only vacuolation that has been reported previously was observed under light microscopy in the stratum basale and was attributed to endotoxins produced after tissue necrosis in chronic laminitis (Boosman *et al.*, 1989a and 1991). However, degeneration is thought to be enzymatic and is possibly linked to matrix metalloproteinase and gelatinolytic protease (Tarlton and Webster, 2002). Most of the histological changes seen under electron microscopy in this study were degenerative in nature and are most likely enzyme-mediated (Tarlton and Webster, 2002) and endotoxic processes (Boosman *et al.*, 1989a and 1991).

CHAPTER 9

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The results of this study led to the following conclusions:

9.1.1 The prevalence of claw lesions is high and the lesions affect over 80% of dairy cows that have calved at least once. Over 60 % of the lesions are subclinical, which if not managed at this stage, might progress to cause clinical lameness that eventually affect productivity of the cows and damage the claws.

9.1.2 The prevalence of claw lesions as determined from hospital records (retrospective study) does not reflect the true pattern of occurrence in the field due to the fact that farmers report only cows with lesions causing lameness which in most cases are infective ones.

9.1.3 Subclinical and chronic laminitis are the most prevalent claw lesions and occurred in 70% of the dairy cows examined.

9.1.4 The prevalence of infective claw lesions such as interdigital necrobacillosis (foot rot), sole abscess and septic arthritis of the interphalangeal joints is low.

9.1.5 Sole haemorrhage is the most important sign that indicates presence of laminitis syndrome in the claw, and is more discernible by thorough examination of the weight-bearing surface of the claw which includes trimming of the horn of the sole.

9.1.6 Trimming of the claw particularly the horn of the sole is paramount in diagnosis of laminitis and as remedial and preventive procedure for claw lesions.

9.1.7 Other general signs of laminitis are presence of sole bruising (erosion), heel erosion and white line separation. Among these, sole bruising and heel erosion are highly prevalent in dairy herds.

9.1.8 Extreme gross misshaping and crookedness of the claw such as irregular widening, concavity and turning of vertical claw wall towards the sole to become part of the tread surface is mostly a result of chronic laminitis.

9.1.9 Digital dermatitis (hairy warts) is also present in some Kenyan dairy herds under intensive production systems.

9.1.10 The cow-level factors that enhance occurrence of laminitis and associated claw lesions are three or more parities and the stage of lactation from 90 to 180 days.

9.1.11 The farm-level factors that enhance occurrence of laminitis are regular (2 to 3 times per day) feeding of concentrates, concrete floors (for subclinical laminitis), earthen (soil) floors (for chronic laminitis), overstocking or overcrowding and infrequent removal of manure from the walk alleys of the cow house.

9.1.12 Dilatations of the vascular channels within the distal phalanx occur in both subclinical and chronic laminitis as demonstrated radiographically.

9.1.13 The main radiographic changes affecting osseous tissue occur in chronic laminitis. They include osteolysis as detected by focal or diffuse radiolucent areas, and reduced size of some parts of the distal phalanx seen as narrowing or absence of part of the bone.

9.1.14 In subclinical and chronic laminitis, the most prominent histological changes seen under light and transmission electron microscopy affect blood vessels and include arteriovenous shunts, vascular wall damage and vascular thrombosis.

9.1.15 Dermal-epidermal junction disruption is also a consistent histological finding in subclinical and chronic laminitis.

9.1.16 Fibroblast degeneration and vacuolization of its cytoplasm, connective tissue degeneration as well as epidermal spongiosis and hyperplasia occur in chronic laminitis as detected histologically.

9.1.17 Other new findings include: bilateral medio-dorsal spiraling of the axial wall of the medial claws with the claw treading on the lateral aspect of the abaxial wall, an extensively enlarged loose subcutaneous skin fold extending through the interdigital space, whitish soft crumbling horn of the sole in chronic laminitis and radiographic pedal bone outgrowth at the apex.

9.2 Recommendations

The following recommendations are made from the study as intervention measures to reduce the incidence of laminitis and associated claw lesions and consequently the incidence of lameness in dairy herds:

9.2.1 Veterinarians should consider it a necessity to examine the weight-bearing surfaces of claws of dairy cows during herd health visits as well as advice preventive and corrective trimming of the claws regularly (once per year).

9.2.2 Concentrate feeding should be introduced gradually (3 to 4 low-level feedings per day instead of one heavy feeding) to allow the cows to adapt to levels of rumen acid production. An inclusion of vitamin and mineral mixtures as well as some fibre in the form of mature forage will help in reducing the incidence of claw lesions. This rationale of feeding should be practiced particularly during the first 180 days in lactation.

9.2.3 Cow house should have adequate room for movement and for lying down. There should be a cubicle for each cow in order to avoid overstocking.

9.2.4 Manure (slurry) should be removed from concrete floors regularly (at least once per day) to avoid continuous wetness from the claw environment.

9.2.5 Occasional continuing education programmes on foot care in cattle should be conducted for veterinarians and animal health workers. This could be extended to dairy farmers through farmers' training seminars.

9.2.6 Regular use of foot wash or foot-bathing with 5% copper sulphate or 2.5%-3% formalin or 20% zinc sulphate solutions that are universally used will help reduce and prevent incidences of infective foot conditions such as digital dermatitis and foot rot.

9.3 Areas of further research

There is need to carry out further research in the following areas related to the current study.

9.3.1 Controlled experimental studies to verify levels of concentrate feeding and rumen acidosis that trigger development of laminitis.

9.3.2 Controlled experimental studies to verify levels of mineral supplementation that can alleviate development of laminitis.

9.3.3 Controlled experimental studies to verify interactive role of various risk factors such as rumen acid, vasoactive substances (endotoxins, histamine) and peri-parturient hormones (oestrogens, prostaglandins).

9.3.4 Evaluation of differences in blood chemical levels between cows with and without laminitis.

9.3.5 Evaluation of the effect of lameness on various reproductive parameters in the dairy cow.

CHAPTER 10

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CHAPTER 11

11.0 APPENDICES

Appendix 1: Parameters and codes used to collect clinical data and cow-level factors during examination of the hind limbs of 300 dairy cows in the study of digital characteristics of lamininits and related claw lesions in Nairobi and its environs (December 2005-June 2006.

1. Farm identity: 1 = Zero-grazed, 2 = Pasture-grazed, 3 = Mixed.

2. Animal breed: 1 = Friesian, 2 = Ayrshire, 3 = Guernsey, 4 = Jersey, 5 = dairy cross breed.

3. Body condition: 1 = poor, 2 = fair, 3 = good.

4. Heart girth: 1 = small, 2 = median, 3 = large.

5. Parity: 1 = first, 2 = second, 3 = third, 4 = > three.

6. Lactation stage: 1 = dry, 2 = 1-90 days, 3 = 90-180 days, 4 = >180 days.

7. Milk yield: 1 = <15kg/day, 2 = 15-25kg/day, 3 = >25kg/day.

8. Locomotion score: 1 = normal, 2 = mildly lame, 3 = moderately lame, 4 = lame, 5 = severely lame

9. Haemorrhages:

9a) Score —1=slight, 2 = moderate, 3 = severe, 4 = exposed corium.

9b) Zone --- 1 = toe white line, 2 = abaxial white line, 3 = abaxial wall-bulb junction, 4= sole-bulb junction, 5 = apex of the sole, 6 = bulb.

10. Claw deformity: 1 = sole overgrowth, 2 = corkscrew claw, 3 = flattened claws, 4 = concave claws, 5 = splayed claws, 6 = prominent hardship grooves.

11. Laminitis stage: 1 = subclinical, 2 = acute, 3 = chronic.

12. Laminitis-related lesions: 1 = sole ulcer, 2 = sole bruising, 3 = white line separation/disease, 4 = heel erosion, 5 = double sole, 6 = toe ulcer.

13. Category unrelated to laminitis: 1 = infectious, 2 = traumatic, 3 = growths.

14. Involved claw: 1 = medial, 2 = lateral.

Appendix 2: Codes used in taking claw measurements during a clinical and an abattoir study of digital characteristics of laminitis and related claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006)

40. Claw length: 1=RL____, 2=RM____, 3=LL____, 4=LM____

41. Claw height: 1=RL____, 2=RM____, 3=LL____, 4=LM____

42. Claw diagonal: 1=RL___,2=RM____, 3=LL____, 4=LM____

43. Heel height: 1=RL____, 2=RM____, 3=LL____, 4=LM_____

44. Toe angle: 1=RL_____, 2=RM____, 3=LL_____, 4=LM____

45. Claw width: 1=RL____, 2=RM_____, 3=LL_____, 4=LM____

46. Digit width: 1=RL_____, 2=RM_____, 3=LL_____, 4=LM____

<u>**Key:**</u> RL=right lateral, RM=right medial, LL=left lateral, LM=left medial.

Appendix 3: Codes used in collecting farm-level factors data during the farm survey of characteristics of laminitis and related claw lesions in dairy cows in Nairobi and its environs (December 2005-June 2006

1. Farm ID: 1 = zero-grazed, 2 = pasture-grazed, 3 = mixed.

15. Floor type: 1 = good concrete, 2 = concrete with holes/loose stones. 3 = over-smooth concrete, 4 = wooden, 5 = earthen, 6 = straw/grass.

16. Cubicles: 1 = none, 2 = one per animal, 3 = > animal number, 4 = < animal number.

17. Beddings: 1 = none, 2 = sawdust, 3 = soil, 4 = sand, 5 = grass/straw, 6 = wood shavings, 7 = mattress, 8 = concrete.

18. Neck rail: 1 = none, 2 = proper level, 3 = too high, 4 = too low.

19. Lunging space: 1 = none, 2 = inadequate, 3 = adequate.

20. Bob zone: 1 = none, 2 = inadequate, 3 = adequate.

21. Kerb: 1 = none, 2 = good level, 3 = too high.

22. Floor slope: 1 = none, 2 = slight, 3 = moderate, 4 = steep.

23. Stocking percentage: 1 = under- stocked, 2 = stocked to capacity, 3 = over-stocked

24. Feeding bunk space: 1 = inadequate, 2 = adequate.

25. Manure: 1 = removed at least once per day, 2 = removed > once per day,

3 = remains unremoved > a day.

26. Concentrates: 1 = none, 2 = occasional, 3 = regular.

27. Fodder: 1 = dry, 2 = withered mature, 3 = fresh mature, 4 = withered succulent, 5 = fresh succulent, 6 = silage.

28. Mineral supplement: 1 = none, 2 = occasional, 3 = regular, 4 = ad libitum.

29. Other supplements: 1 = none, 2= occasional, 3 = regular.

Appendix 4: Codes of the macroscopic data taken during an abattoir study of digital characteristics of laminitis and related claw lesions in claws of dairy cows in Nairobi and its environs (December 2005-June 2006)

30. Abattoir claw deformity: 1=none, 2=present.

31. Evidence of subclinical laminitis: 1=negative, 2=positive.

32. Evidence of chronic laminitis: 1=negative, 2=positive.

33. Sole ulcer: 1=none, 2=present.

34. Double sole: 1=none, 2=present.

35. Sole bruising: 1=none, 2=present.

36. White line separation: 1=none, 2=present.

37. Heel erosion: 1=none, 2=present.

38. Foreign body penetration: 1=none, 2=present.

39. Phalanx lesions: 1=none, 2=exostoses, 3=dropped, 4=rotated, 5=missing apex, 6=osteolysis.

Appendix 5: Data entry sheet for retrospective study of cases treated for foot conditions in the Large Animal Hospital of the Faculty of Veterinary Medicine, University of Nairobi, Kenya between 1981 and 2006.

Date	Case No.	Breed	Sex	Diagnosis	Findings	Treatment	Outcome