Lameness in cattle: are we on the wrong track?

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Lameness and claw disorders constitute a significant health and welfare problem in modern dairy farming. Affected animals experience pain, are limited in their natural behaviour and can less easily meet their biological needs [8] [21]. Claw and locomotor problems have a multifactorial background. Research over the past 20 years suggests a variety of causal factors, which can be broadly classified into environmental (e.g. housing, nutrition, management) and animal-related (e.g. breed, production) factors. As the title suggests, the introduction in the late seventies of loose cubicle housing systems with concrete floors increased the prevalence of lameness and claw disorders in dairy cows. Cattle lameness originates in about 90% of the cases from claw disorders of which 90% occur at the hind feet, primarily on the lateral claw.

The majority of the 1.5 million dairy cows in The Netherlands are nowadays housed in cubicle houses with slatted or solid concrete stall floors. Under such housing conditions, over 80% of dairy cows suffer from at least one claw disorder at any time [11], (Figure 1). A small percentage of Dutch dairy cows are housed in straw yards. This housing system has a deep litter (straw-bedded) area where animals can rest collectively, accompanied by a concrete walking surface in front of the feed alley. Reduced figures in affected claws (58%) were found in cows housed in straw-yard systems.

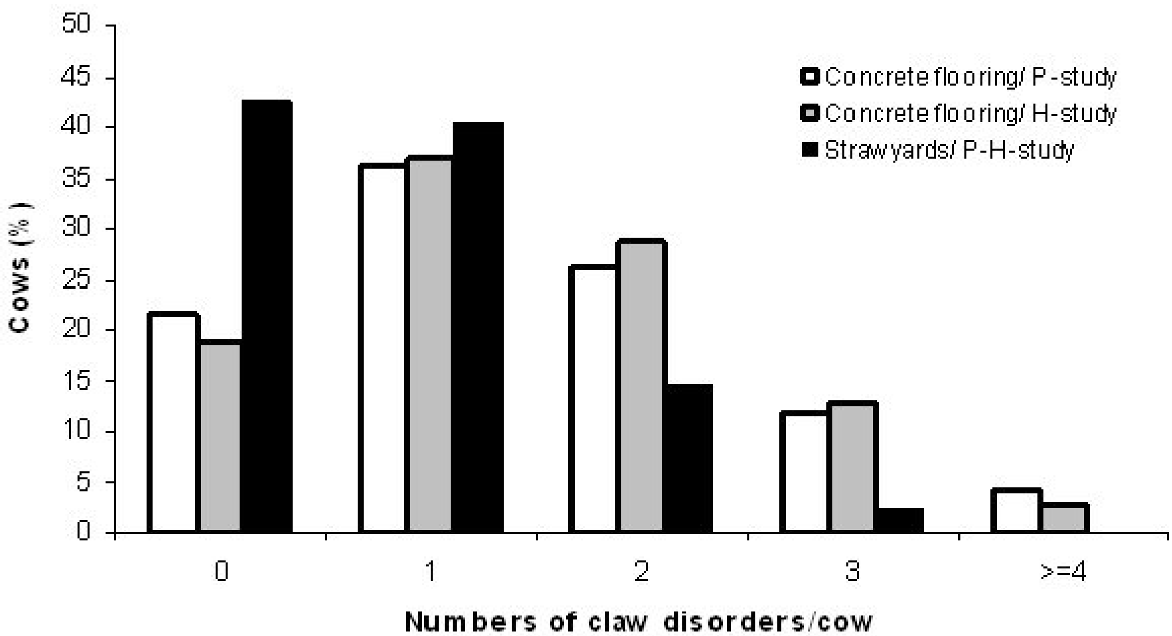

Figure 1. Distribution of number claw disorders in 6906 Dutch dairy cows housed on concrete floor systems in the pasture (referred to as P-study) or housing period (H-study), and in straw yard systems in both the pasture and housing period (P-H-study).

Under Dutch conditions, infectious claw lesions such as digital dermatitis (DD) and interdigital dermatitis and heel erosion (IDHE) are predominantly responsible for claw and locomotion problems in dairy herds. Environmental factors rather than nutritional elements are contributively to the development of these lesions [12] [13]. Cows kept in straw yard systems were significantly less affected by both chronic lesions. Especially, DD was remarkably less prevalent (4% versus 29% in cows on concrete floors).

In a follow-up study, the walking patterns of cows on different floor systems were determined [10]. Cows were locomotion scored using a 9-point scoring system described by Manson and Leaver [7] as summarized in table 1.

Locomotion characterization	Locomotion score	Interpretation
Minimal abduction/adduction, no unevenness of gait, no tenderness	1.0	Sound
Slight abduction/adduction, no unevenness of gait, no tenderness	1.5	Sound
Abduction/adduction present, uneven gait, perhaps tender	2.0	Sound
Abduction/adduction present, uneven gait, tenderness of feet	2.5	Tender
Slight lameness, not affecting behaviour	3.0	Slightly lame
Obvious lameness, difficulty in turning, not affecting behaviour	3.5	Slightly lame
Obvious lameness, difficulty in turning, behaviour affected	4.0	Severely lame
Some difficulty in rising, difficulty in walking, behaviour affected	4.5	Severely lame
Extreme difficulty in rising, difficulty in walking, behaviour affected	5.0	Severely lame

Table 1. Locomotion characterization according to the locomotion scoring of Manson and Leaver [7].

Lameness was defined as locomotion score above 2.5. To illustrate differences in locomotion scores, some movies of walking cows are inserted below (Figure 2).

Movie 1: grif.loco 1.5;

Movie 2: benn.loco 2.5;

Movie 3: loon score 3;

Movie 4: wag score 3.5;

Movie 5: loco4-4.5

Figure 2. Five movies of walking cows with the respective locomotion scores 1.5, 2.5, 3, 3.5 and 4.5 (see Table 1).

By far the best walking pattern was seen in cows in a straw yard. In more than 80 percent of cases, they walked normally. Less than 1 percent was lame. Cows on a concrete floor walked considerably less well. A quarter walked tenderly, whereas almost 30 percent of the animals exhibited some form of lameness. Only 45 percent walked normally in an unhindered manner. The poor walking was partly caused by painful feet as a consequence of claw disorders, but the hardness and slipperiness of the concrete floor may also be significant factors.

Straw yards were obviously more favorable than cubicle houses with concrete floors with respect to locomotion and sound claw health [10] [11]. Housing system and lameness are unarguably related, however, the causality remains to be an issue for discussion. The mechanism of how concrete floors eventuate in claw disorders for dairy cattle needs to be clarified. This review describes a biomechanical approach to analyze the mechanical interaction at the claw-floor interface.

Biomechanical approach

Given the current way of claw trimming (Dutch method) it seemed reasonable at the time to assume that the pressures exerted to the soles of cattle were equally distributed. To verify this assumption the pressures and forces were measured with the aid of force and pressure plates. During standing or walking, the cow exerts forces to the floor and ground "reacts" with a force equal in magnitude but opposite in direction: the so called Ground Reaction Force (GRF). The vertical component of this GRF is distributed over the contact area of the claws in a way that depends on the shape of the claws and how the cow has placed its claw on the floor. In turn, the vertical force and pressure distribution determines the degree of local compression of the horn and underlying tissues.

By means of a Kistler force plate (type Z4852, dimensions: 600 - 900 mm; Kistler Instrumente AG, Winterthur, Switzerland) combined with a pressure plate (footscan scientific version®, RsScan International, Olen, Belgium) sampled at 250 Hz the forces and pressures exerted to the cows foot were measured (Figure 3). The surrounding pathway and the measuring apparatus were covered with 5 to 6 mm thick rubber mat providing a level surface for the four feet and enough frictional force to prevent possible minor postural adjustments due to slipperiness.

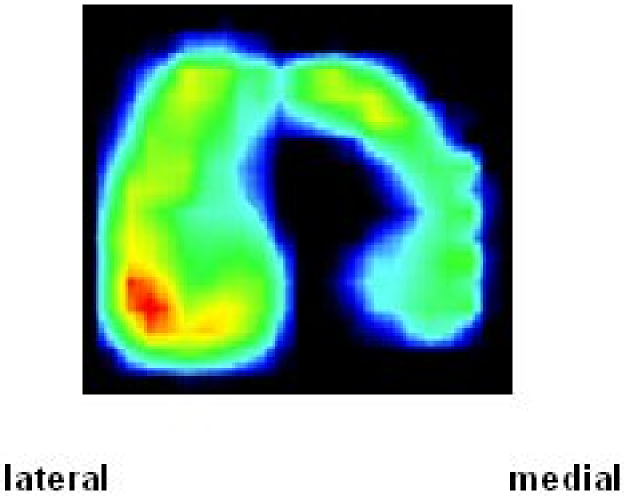

Figure 3. The pressure distribution while standing, an example of the left hind limb [18]. The colors represent the amount of pressure exerted to the contact-surface of the claws in N/cm^2, respectively: blue = 1 to 15, light blue = 15 to 30, green = 30 to 45, yellow = 45 to 60 and red = 60 to 75.

Standing

During standing, pressure concentrations occur in general on the medial front claw and lateral hind claw. The pressure distribution within each claw showed that the bulb areas were relatively loaded the most, with the exception of the medial hind claw, of which the sole is subjected to the highest pressure [18] (figure 4).

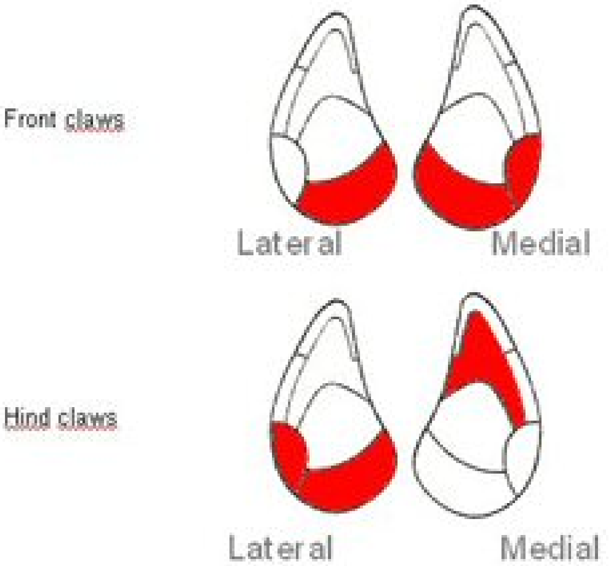

Figure 4. The maximum pressure distribution over the contact-surfaces of the claws (40 observations per limb). At the front limbs, 80% of the maximum pressures are exerted to the medial claws, while at the hind limbs 80% is exerted to the lateral claws. The regions within the claws subjected most often to the maximum pressure are colored red.

Medial front claws and the lateral hind claws bear the greater part of the weight applied to the limbs while standing [9] [14]. Although the average pressure may stay within acceptable limits, local pressure concentrations may cause tissue overloading. These pressure concentrations found in our studies correlate with sites of the claw capsule that are prone to mechanical trauma (haemorrhages, white line disease) and infectious claw diseases often seize at these locations.

Movie : wk 18 links voor

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Figure 5. The pressure distribution while walking the weight applied to the front limb was more or less equally distributed over both claws. However, at the hind limbs a remarkable difference occurred, the major part of the weight was exerted to the lateral

claws.

Walking

In general, it is known that during locomotion the GRF is about twice as high as while standing still, about 55-65% of the bodyweight is applied to a single front limb and approximately 50-55% to the hind limbs. For a cow of 700 kg this means a force of 4000 and 3500 Newton respectively. When the forces are doubled, it is obvious that pressures will increase likewise.

During walking, the weight applied to the front limb was more or less equally distributed over both claws. However, at the hind limbs a remarkable difference occurred, the major part of the weight was exerted to the lateral claws. At heel strike the total impact is exerted to the lateral claw (Figure 5) and this impact is mainly distributed to the lateral bulb area (Figure 6).

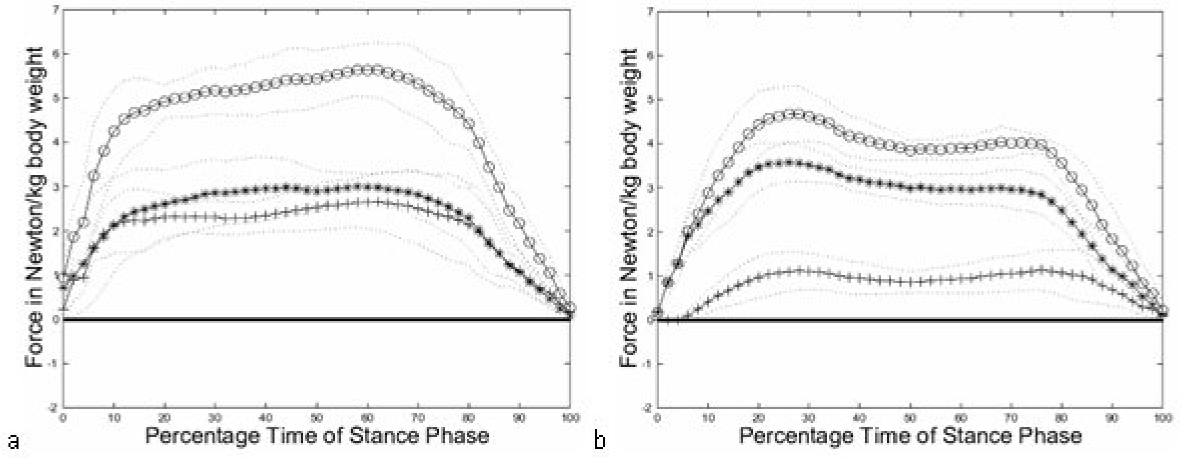

Figure 6. The force distribution of the right fore (a) and hind limb (b) between the lateral and medial claw during locomotion of recently trimmed dairy cows (9 cows times 5 trials; n = 45). o = total vertical force; * = lateral vertical force; + = medial vertical force; .... = ± SD.

Figure 6 shows unmistakably that the lateral hind claw (6b) is subject of the highest force during locomotion. However, pressure is determined by two factors; the amount of loading (Newton) and the size of the contact area of the claw (cm^2) with the floor. Therefore, one needs pressure distribution analysis to determine the amount of loading at the claw-floor interface at a certain time and location. It is known that the lateral hind claw provides a larger contact area, which potentially reduces pressure. This phenomenon explains figure 7, although a highest total load is applied to the lateral hind claw, the pressures exerted to the front and hind legs were not significantly different.

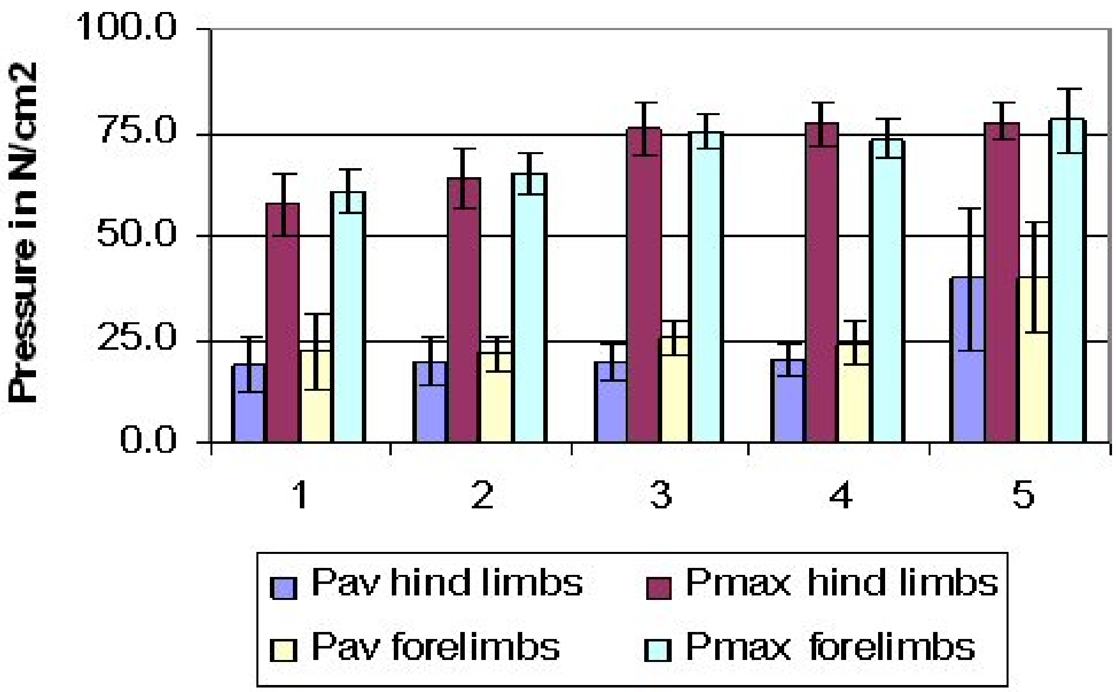

Figure 7. The pressure distribution at 5 moments during the stance phase (heel strike to push off) [19]; Pav = average pressure, Pmax = maximum pressure.

Horn fractures and infectious claw disorders

At first, these results did not make much sense. The pressures in front and hind claws are equal in magnitude. Hence, the question remained: Why are lateral hind claws more susceptible to infectious claw lesions such as DD and IDHE. It seems obvious that the cyclic compression of claw horn during standing and walking constitutes a risk for fracture caused by repeated loading, which in turn may play a role in the development of claw diseases and subsequent lameness. Therefore, it was interesting to express the measured pressures as a percentage of the ultimate yield stress of horn at these sites (Table 2).

Horn	limb	SD-hardness	Elasticity (N/mm^2)	Breaking strength (N/cm^2)	Loading (N/cm^2)	Relative loading
Wall	Front	70 à 75	643,4	800 à 900	200	20 à 25
	Hind	65,5	583,7	700 à 800	180	20 à 25
Sole	Front	50,0	162,3	400	130	30
	Hind	43,7		300	100	30
Bulb	Front	35,0	106,4	250	100	40
	Hind	31,0		200	100	50

Table 2. The relative loading at various sites of the claw capsule as percentage of the breaking strength. The breaking strength is extrapolated from literature of cattle, pigs and horses as explained in the text.

In cows the bulb area consists of the softest horn, sole samples are harder and wall-samples are hardest. The modulus of elasticity (E), a measure of stiffness of horn samples taken at the dorsal wall, abaxial wall and sole of the claws of all limbs were significantly higher at the forelimbs. Horn at the sole is about four to five times more elastic compared to wall horn [22]. In general, the claws at the forelimbs are significantly harder than at the hind limbs, and claws of lame cows are composed of softer horn by virtue of a higher horn-turnover. In summer claws are much harder than in winter [5].

Horn hardness and elasticity are influenced by animal condition, humidity, condition and chemical composition of the keratin [1]. Horn at the claw wall of pigs could be compressed to maximal pressures of 800 N/cm^2 [20]. If one makes the assumption that the difference between the elasticity of bulb, wall and sole horn is indicative for the compressive strength, the compressive strength of bulb horn would be four times less than the wall horn, i.e. 200-300 N/cm^2. The maximum pressures measured on the bulb of the lateral hind claw may increase up to 130 N/cm^2. Hence, these loading patterns can be considered a (sub)maximal repetitive strain. Faster locomotion and sudden movements may increase the GRF's per limb; uneven or partial support of the claw (*e.g.* grooved, slatted or profiled concrete) may decrease the bearing surface [3]. In both cases, pressures may increase to or beyond ultimate values and produce horn fractures. Table 2 shows that the stress, expressed as a percentage of the presumable yielding stress, is highest at the bulb, particularly of the hind claws. This finding correlates with a high incidence of horn damage in that area.

Laminitis, mechanically induced?

Although the common explanation for haemorrhages or discolorization of horn is subacute ruminal acidosis (SARA) and consequent laminitis, mechanical failure beyond the adaptive capacity of the claw dermis might provoke a (sterile) inflammation. Hence, accumulation of horn is hampered (*e.g.* of poor quality due to (blood) plasma mingling) and subsequent adverse wound healing of skin that easily provides routes for pathogens are likely to happen.

Acute laminitis is a condition associated with feeding regime, more specific the fibre-concentrate-ratio. Diets with too high amounts of concentrates, or drastic changes in diet are followed by acidosis in the rumen and the release of endotoxins in the blood. Moderate to high doses of endotoxine causes a dysfunction of the haemostatic system that damages the arterioles in the claw. The damage to these vessels reduces the blood supply to the horn-producing tissues as initially proposed by [2]. The clinical symptoms are hemorrhages and or discoloration of sole horn, most often seen at 80-110 days in lactation. In progressive state sole ulcers may develop at the typical site.

This mechanism is often extrapolated to the less acute forms of laminitis that not show the clinical sign of lameness. It is probably supported by epidemiological correlations of diets and the prevalence of claw disorders. However, as far as we know there are no experimental studies available to support this sub-acute laminitis hypothesis.

Epidemiological studies also showed that claw disorders occur frequently on (either slatted or solid) concrete flooring [11]. This relation has been confirmed in several biomechanical experiments, the loading patterns of the claw while standing and walking on concrete showed that the claw parts at risk for mechanical damage are prone to claw disorders like pits, fissures or ulcers [3] [4] [6] [17].

The repetitive loading of the claw might cause a sterile inflammation of the soft tissue within the claw capsule. This can either be the result of the compression of the soft tissue between the claw bone and the sole [16], or the high strain rates at impact during heel strike at the bulb of the lateral hind claw [17]. Swelling of soft tissues within the claw constricts the vessels within the claw capsule, subsequently the horn-producing cells are cut off their blood supply. This process will end up in poor horn production and might show similarities with sub acute laminitis.

Prevention of claw overloading

Floor system. The floor determines in strong degree the mechanical loading of the claws and locomotor apparatus, and is possibly crucial in the onset of locomotion disorders. A floor system of the future prevents mechanical overload, and offers sufficient grip. Hence, it enables the expression of natural behaviour. Many floor systems have been developed that do not or hardly enable natural behavior. An innovative floor will have the characteristics that will suit the biological requirements of cattle. New stable floors with potentially a positive impact on the movement apparatus and the mobility of cows need to be developed and tested in practice.

Management. Common practice is to trim claws of cattle 2 to 3 times a year, either preventively or curatively [15]. This way claw functioning is (temporarily) improved and lameness is prevented/treated. However, the current method seems inadequate. Loading patterns of trimmed cows showed pressure concentrations on the softer parts of the claws. Claw problems and lameness remain obviously present (Figure 2) [10]. Two weeks after trimming, already between 20 and 30% of the observed cows were lame, either slightly or severely. The lameness prevalence increased gradually with time after trimming. From 18 weeks onwards, however, lameness decreased up to the starting level at week (2 weeks after claw trimming). This may be explained by two reasons: 1) in some herds, the next claw trimming event occurred already between 18 and 22 weeks and 2) some farmers gave their cows access to pasture for some hours during day time. Hence, lameness levels observed at week 2 and 22 may be attributed to either suboptimal housing conditions or inadequate claw trimming method. Therefore, an alternative trimming method has been proposed by the authors. Current and alternative methods must be compared to maximize the effect of (preventive) trimming.

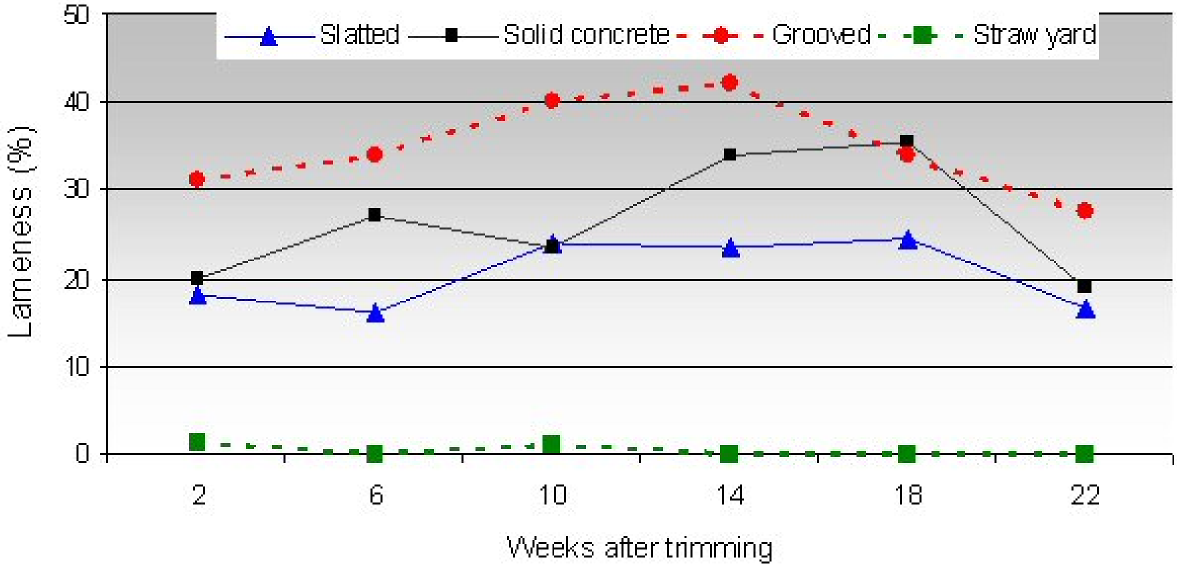

Figure 8. Prevalence of lameness by weeks after trimming in a longitudinal study among 240 dairy cows kept on different floor types: either slatted, solid or grooved concrete flooring or straw yard systems. Claws of all cows were trimmed at the start of the study (week 0). Then at 2, 6, 10, 14, 18 and 22 weeks after trimming, locomotion was observed on a 4-point scale; score 3 and 4 indicates lameness.

In summary, current high levels of claw disorders and lameness are associated with concrete floors. Our biomechanical research showed that actual stress levels during locomotion in these cows are dangerously close to the biological limits of the horn tissue, and that the parts of the claw usually affected by disorders are the ones that experience the highest stresses. Both findings suggest that mechanical stress is a major causative factor for the occurrence of claw disorders and lameness.

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