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Assessment of conformation scoring of the limbs as a potential explanatory factor for claw health in dairy cows

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Inhaltsverzeichnis

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Assessment of conformation scoring of the limbs as a potential explanatory factor for claw health in dairy cows

The selection of breeding animals is critical for a robust livestock population. Conformation trait scoring represents a practical approach to evaluate a cow's potential for productivity, longevity, and suitability for breeding. The scored traits are assigned to four subsections: frame and capacity, pelvis, limbs, and udder. Previous studies examining associations between specific limb conformation traits and the incidence of claw lesions have found low to moderate associations. This study (n = 21,145 cows) investigates associations between claw health and the score encompassing all traits of the 'limbs' subsection as well as the final score per cow. This approach aims to capture potential associations between limb conformation and claw health that may not be linked to a single trait, but the overall limb conformation. Claw health data were recorded by professional claw trimmers participating in the Swiss Claw Health Project and aggregated to three outcome values. For each recording, disorder occurrence and severity were combined to a value representing claw health in general encompassing all claw lesions. Also, two sub values were created, one encompassing the stages of digital dermatitis only, the other claw horn lesions only. The score for the 'limbs' subsection was associated with the occurrence of claw lesions in general and claw horn lesions. The effect sizes were small and ranged from 10 to 59 % increased odds across score categories for the occurrence of lesions of the digits in general and 10-104 % for the occurrence of claw horn lesions. The effect sizes reflect the multifactorial nature of claw health. The study concludes that limb conformation scoring can only be a supportive tool in assessing a cow's potential for future claw health.

Keywords: animal welfare, limb conformation, phenotype scoring, claw lesion

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Analyse des Zusammenhangs zwischen Exterieurmerkmalen der Gliedmassen und der Klauengesundheit bei Milchkühen

Die Selektion von gesunden Zuchttieren ist von grosser Bedeutung für einen robusten Tierbestand. Die Beurteilung des Exterieurs ist ein gut etablierter Ansatz, um das Potential einer Kuh mit Blick auf Leistung und Zuchteignung einzuschätzen. Die Merkmale werden vier Kategorien zugeordnet, worunter ‘Gliedmassen’. Bisherige Studien zu Assoziationen zwischen spezifischen Gliedmassenmerkmalen und der Inzidenz von Klauenerkrankungen wiesen höchstens moderate Assoziationen nach. Diese Studie (n = 21,145 Kühe) setzt auf übergeordneter Ebene an und sucht nach Assoziationen zwischen der Klauengesundheit und der Teilnote für die Kategorie ‘Gliedmassen’, sowie der Gesamtnote je Kuh. Dieser Ansatz zielt darauf ab, Assoziationen nachzuweisen, die nicht an ein einzelnes Merkmal geknüpft sind, sondern an die gesamte Gliedmassenkonformation. Die Daten aus dem Schweizer Klauengesundheitsprojekt wurden zu drei Outcome-Werten zusammengefasst: Je Eintrag wurden das Auftreten von Klauenerkrankungen und die Schweregrade zu einem Wert zusammengefügt, der alle Klauenerkrankungen umfasst. Zusätzlich wurden zwei Unterwerte errechnet, einer für Dermatitis Digitalis und ein zweiter nur für Klauenhorn-Läsionen. Die Effektstärken sind gering und liegen je nach Score-Kategorie bei einer um 10 bis 59 % erhöhten Wahrscheinlichkeit für das generelle Auftreten von Klauenerkrankungen sowie bei einer um 10 bis 104 % erhöhten Wahrscheinlichkeit für das Auftreten von Klauenhorn-Läsionen. Dies passt zu den vielfältigen Einflüssen auf die Klauengesundheit. Wir schlussfolgern, dass die Beurteilung der Gliedmassenkonformation nur ein unterstützendes Tool für die Einschätzung der zu erwartenden Klauengesundheit sein kann.

Keywords: Tierwohl, Tierzucht, Lineare Beschreibung, Klauenerkrankungen

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Assessment of conformation scoring of the limbs as a potential explanatory factor for claw health in dairy cows

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ABSTRACT

The selection of breeding animals is critical for a robust livestock population. Conformation trait scoring represents a practical approach to evaluate a cow's potential for productivity, longevity, and suitability for breeding. The scored traits are assigned to 4 subsections: frame and capacity, pelvis, limbs, and udder. Previous studies examining associations between specific limb conformation traits and the incidence of claw lesions have found low to moderate associations. This observational study (n = 21,145 cows) investigates associations between claw health and the score encompassing all traits of the "limbs" subsection and the final score per cow encompassing all subsections. This approach aims to capture potential associations between limb conformation and claw health that may not be linked to a single trait but the overall limb conformation. Claw health data were recorded by professional claw trimmers participating in the Swiss Claw Health Project. The claw health data were aggregated to 3 outcome values. For each recording, disorder occurrence and severity were combined to a value representing claw health in general encompassing all claw lesions. Also, 2 subvalues were created, one encompassing the stages of digital dermatitis only, the other one claw horn lesions only. The score for the "limbs" subsection showed significant associations with the occurrence of claw lesions in general and mechanical-metabolic lesions. The effect sizes, however, are small, ranging 10% to 59% increased odds across score categories for the occurrence of lesions of the digit in general and 10% to 104% for the occurrence of claw horn lesions. For cows with the lowest rating in the "limbs" trait subsection, the odds for higher lesion severity increases by 66%. To contextualize and compare these effect sizes, "parity" and "breed" were included based on previous studies. "Herd size" and "claw trimming frequency" were incorporated to represent management context. In higher parities, claw lesions in general and mechanical-metabolic lesions showed increased prevalences but prevalences of digital dermatitis decreased. Holstein-Friesian cows exhibited higher prevalences of most claw lesions compared with Brown Swiss, the difference being particularly pronounced for digital dermatitis. Larger herd size is associated with higher odds for claw disorders in general and digital dermatitis, and increased claw trimming frequency is associated with higher odds for digital dermatitis. The study concludes that limb conformation scoring can be a supportive tool in assessing a cow's potential for future claw health. To justify its use in breeding selection, further research on trait h^2 is needed. The small effect sizes reflect the multifactorial nature of claw health.

Key words: animal welfare, limb conformation, phenotype scoring, claw lesion

INTRODUCTION

Robust livestock health is required for sustainable production, the improvement of farm animal welfare, and the reduction of antimicrobial use by decreasing the necessity of treatments (Trevisi et al., 2014; Doyle et al., 2021). To ensure a healthy livestock population, it is crucial to optimize the selection of breeding animals (Miglior et al., 2017; Brito et al., 2020). Claw lesions and resulting lameness have major effects on animal welfare and result in considerable economic losses (Katsoulos and Christodoulopoulos, 2009; Bruijnis et al., 2012). Claw disorders can be categorized into 3 main groups based on their etiology: infectious claw disorders, mechanical-metabolic claw horn lesions, and genetically determined claw alterations (Kofler et al., 2024). Some of the claw disorders discussed in this article affect not only the claw horn but also other anatomical structures

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The list of standard abbreviations for JDS is available at adsa.org/jds-abbreviations-25. Nonstandard abbreviations are available in the Notes.

and tissues of the digit. The commonly used term "claw disorders" was kept throughout this article.

Conformation trait scoring is widely used in many countries, for example, in the United States (Holstein Association USA, 2025; https://www.holsteinusa.com/genetic_evaluations/ss_linear.html), the Netherlands (Coöperatie Rundveeverbetering, 2023; https://www.cooperatie-crv.nl/wp-content/uploads/2023/04/E_08-Exterieur-April-2023-1.pdf), and Finland (Finnish Animal Breeding Association, 2024; https://faba.fi/fi/lihakarjan-jalostusarvot), with the protocols varying among countries. In Switzerland, linear scoring of body conformation is conducted for cows that are registered with an official breeding association and are signed up for scoring by the breeding association. The scoring of conformation traits is employed as an assessment scheme and approached as a predictor for the anticipated health and productivity of dairy cows and suckler cows. This scoring method serves as a standardized evaluation tool for the anatomical traits that might be indicative of a dairy cow's potential productivity and longevity (Manafiazar et al., 2016). Conformation trait scoring also aims to assess the potential of the subsequent generations. In Switzerland, linear conformation scoring and classification, called "Lineare Beschreibung und Einstufung" (**LBE**), is performed by the company LINEAR AG (Posieux, Switzerland) for most breeds (LINEAR AG, 2013), and by the Braunvieh breeding association (Braunvieh Schweiz, Zug, Switzerland) for Brown Swiss and related breeds (Braunvieh Schweiz, 2023). The scored traits are assigned to 4 subsections: frame and capacity, pelvis, limbs, and udder.

The Swiss Claw Health Project "Gesunde Klauen–das Fundament für die Zukunft" ("Healthy Claws–the Foundation for the Future") is a government-funded project to improve claw health of cattle in Switzerland. Within the project, claw health data are recorded by participating claw trimmers. The objective of this study is to investigate associations between conformation trait scoring and the occurrence of claw disorders, using the LBE scoring data and the claw health data recorded within the project. The score for limb conformation and the final score per animal will be assessed as explanatory variables with possible association with the occurrence and severity of claw lesions. This aims to test the reliability of their intended implication for the cow's anticipated health. We hypothesized that higher LBE scores are negatively associated with the occurrence of claw lesions in general and, specifically, the occurrence of digital dermatitis. In addition, we hypothesized that the LBE scores are not associated with mechanical-metabolic claw disorders because the influence of external factors, that is, housing, nutritional, and environmental, predominates there.

MATERIALS AND METHODS

Reporting of this retrospective, observational study was conducted according to the guidelines of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE)-Vet statement (Sargeant et al., 2016). As this research exclusively involved secondary analysis of existing data, ethical approval was not required.

Data Management

The LBE-classifiers are trained to follow a strict protocol while measuring and classifying anatomical characteristics. The LINEAR AG limits the risk of interobserver bias through continuous monitoring of entered data and mandates supplementary training if the scoring data of a single classifier deviates strongly from expected values.

The subsections each constitute a specific percentage of the final score: frame and capacity 25%, pelvis 10%, limbs (feet and leg conformation) 25%, and udder 40%. The subsection "limbs" includes the following anatomical characteristics: front legs angle, rear legs angle, foot angle, heel height, bone quality, rear legs set, and locomotion. The recorded measurements are documented in a software application (LBE Mobile version 2.0, LINEAR AG) allocating points ranging from 1 to 9 for each trait. In addition, point deductions apply if any of the predefined anatomical defects are present. These points are subsequently used to derive the score for each subsection through an algorithmic process.

The linear scoring schemes exist for specific breeds only, with slight variations in the weighting of individual traits. Therefore, only cows belonging to these breeds were included in the study. They were assigned to 3 breed groups. The first group exclusively comprises the Holstein-Friesian breed (**HF**), for which the LBE scheme developed by LINEAR AG specifically for HF cows is used. The second group includes Brown Swiss, Rhaetian Grey, and Original Brown Swiss (**BS**). These breeds are scored using the LBE scheme established by the Braunvieh breeding association. The third breed group comprises Swiss Fleckvieh and Montbéliarde (**SF/MB**). The LBE schemes for these breeds are similar, as they are both designed for dual-purpose breeds. Within the subsection "limbs" they are identical.

The LBE data were provided by a data technology company responsible for the databases of various Swiss breeding organizations (Qualitas AG, Zug, Switzerland). Only scoring data belonging to the subsection "limbs" (score limbs [**SL**]) and the overall grade per cow encompassing all subsections (score final [**SF**]) were requested.

Claw health data were recorded over the course of 3 yr and 10 mo (February 13, 2022–December 31, 2023) using hard- and software (KLAUE version 3.3.0, dsp-

Agrosoft GmbH, Ketzin/Havel, Germany) provided to the claw trimmers by the Swiss Claw Health Project. As described by Strauss et al. (2021) and Weber et al. (2023), the participating claw trimmers received specific training in identifying and classifying disorders of the digits, using the standardized diagnoses described in the *ICAR Claw Health Atlas* (Egger-Danner et al., 2020) and its Appendix 1 (Kofler et al., 2020). To validate the data and minimize interrater bias, data were used only after the recording claw trimmers had passed an exam. That exam consisted of diagnosing claw lesions with sufficient matching diagnoses to a simultaneously recording veterinary expert, meeting the requirement of κ-values ≥0.61.

As described by Kofler (2013), specific values were assigned to all claw disorders and their degrees of severity. These values are based on the estimated painfulness of the disorder, the expected lameness, and the infectiousness. The aggregate of these values per separate claw health recording is used to calculate the claw pathology index (**CPI**), as reported by Fürmann et al. (2024).

Additionally, 2 other indices were created including only a subset of disorders. As bovine digital dermatitis (**DD**) is one of the most important infectious disorders in dairy cows worldwide (Losinger, 2006; Bruijnis et al., 2012), that disease was assessed separately. The DD index (**DDI**) was formed including only the values attributed to the different stages of DD (M1, M2, M3, M4, M4.1). The mechanical index (**MI**) was formed including only the values attributed to claw horn lesions. This includes ulcers, white line lesions, sole hemorrhages, horn fissures, toe necroses, double soles, and concave dorsal walls.

All claw health data originated from farms participating in the Swiss Claw Health Project. Only data from farmers who provided written informed consent for the use of their claw health data for research purposes were included. To avoid recording the same lesion 2 times, claw health recordings of a single cow obtained at an interval <14 d were considered a follow-up visit and therefore excluded. Then, only the first recording was maintained. Each recording was assigned to the corresponding parity of the respective cow at the time of recording, using calving data provided by the company managing the central animal traceability database for Swiss livestock identification and registration (Identitas AG, Bern, Switzerland). Herd size information was added using data provided by Identitas AG, defined as the number of lactating cows on each farm on the day of each claw health recording. Claw trimming frequency was defined as the number of routinely conducted herd trims per year, defined as trims where at least 80% of the herd was examined/trimmed by the claw trimmer. For farms that never met this criterion, the frequency was set to 0. All recordings were maintained, regardless of whether they belonged to a herd trim or trimming of individual cows or small groups.

When several LBE scores per cow were available, the earliest LBE score per cow was used. All continuously recorded claw health data per cow documented after the earliest LBE score were kept, including recordings with no lesions detected.

Descriptive Statistical Analysis

The dataset included variables that provided general information about each cow, namely, cow and farm ID, breed, and date of birth. It also contained variables related to the linear scoring of the cows, namely, the date of scoring, SL, and SF. The variables describing the occurrence and severity of claw lesions comprised the outcome variables CPI, DDI, and MI. For each recording, the date and the parity at the time of recording were available.

Both data management and descriptive statistical analyses were conducted using R software (version 4.4.2; https://www.r-project.org/), using tidyverse packages (dplyr, ggplot2) and data.table. The frequency distribution of the number of claw health recordings per cow, herd size, and the age at the date of linear scoring were assessed using histograms and the Shapiro–Wilk Normality test. The interval between conformation scoring and claw health recordings was calculated using a 2-step process. First, the median time since conformation scoring was computed for each individual cow. Subsequently, an overall median was derived from these individual cow averages.

The distributions of the claw health indices by parity, breed, SL, and SF were investigated in a graphical approach using stacked bar plots. The outcomes (i.e., CPI, MI, DDI) were first assessed grouped by parity, classified as follows: 1 to 2, 3 to 4, 5 to 6, and 7+. The parity was chosen as an appropriate variable to reflect the course of time. This choice was made because it represents the age and corresponding duration of use for each cow, and due to its high correlation (r = 0.96) with the time elapsed since linear scoring. Second, the distributions of the outcomes were assessed regarding breed, using the established breed groups HF, BS, and SF/MB. Finally, the distributions of the 3 outcomes were assessed relating to conformation trait scoring, using the categories of SL and SF as predefined.

The original CPI, DDI, and MI were further grouped into 4 categories to represent the severity degrees (**CPI_ord**, **DDI_ord**, and **MI_ord**), according to suitable thresholds as described in the following. The categories considered in the present study were chosen to align with clinical aspects, such as painfulness and resulting lameness, and in the case of DD, to take the infectivity of active M-

Table 1. Categories of claw health indices, representing the severity of claw pathologies in 21,145 Swiss cows participating in a nationwide project to improve claw health, 2020 to 2023[1]

Item		0 (healthy)	1 (mild)	2 (moderate)	3 (severe)
Claw health index					
CPI_ord		0	1–16	17–64	65–max
DDI_ord		0	1–8	9–32	33–max
MI_ord		0	1–8	9–64	65–max
Conformation score[2]	**5 (Poor)**	**4 (Fair)**	**3 (Good)**	**2 (Good plus)**	**1 (Very good to excellent)**
SL	Min–69	70–74	75–79	80–84	85–max
SF[3]	Min–74		75–79	80–84	85–max

[1]CPI_ord = claw pathology index sorted into categories; DDI_ord = digital dermatitis index sorted into categories; LBE = "Lineare Beschreibung und Einstufung" (conformation trait scoring); MI_ord = mechanical index sorted into categories; SF = score final categorical (final, overall grade per cow, points sorted into score categories); SL = score limbs categorical (score for the subsection "limbs," points sorted into score categories); min = minimum; max = maximum. CPI_ord max = 392; DDI_ord max = 128; MI_ord max = 360; SL min = 56, SL max = 96; SF min = 60, SF max = 92.

[2]Conformation score data (the final conformation score of all traits and the limbs conformation score as assessed through "linear conformation scoring") sorted into categories by the quality of the assessed anatomical traits. In Switzerland, linear conformation scoring and classification, called "Lineare Beschreibung und Einstufung" (LBE), is performed by LINEAR AG (Posieux, Switzerland) for most breeds (LINEAR AG, 2013) and for Brown Swiss and related breeds by the Braunvieh breeding association (Braunvieh Schweiz, Zug, Switzerland; Braunvieh Schweiz, 2023) to prospectively assess future health and productivity of dairy cows.

[3]Poor and Fair categories were merged for SF.

stages into account. Originally, 5 categories per outcome had been chosen to clinically align with the 5 degrees of lameness established in the Sprecher locomotion scoring system (Sprecher et al., 1997). For the multilevel regression models to produce reliable results, a large enough number of observations is needed per category. Therefore, to achieve a sufficient number of observations per category, the 2 highest categories were merged, as only very few cases of degree 5 lameness were recorded. Each index was also considered as a binary outcome variable (healthy vs. diseased) **CPI_bin**, **DDI_bin**, and **MI_bin**. The categories of SF and SL represent the score categories as defined by LINEAR AG (2013). Again, to achieve a sufficient number of observations, the 2 highest score categories of both scores and the 2 lowest categories of SF were merged. An overview of all variable levels is presented in Table 1.

Multilevel Regression Models

The experimental unit was the individual cow, outcome variables were the claw health indices, and potential explanatory variables were parity, breed, herd size (small <30 and large ≥30), claw trimming frequency (low <1.5 and high ≥1.5), SL, and SF. Either SL or SF were offered to the models, whereas all other potential explanatory variables were included in all models due to clinical relevance.

The models assessing the association between claw health and the potential explanatory variables were run in Stata (StataCorp, 2023; Stata 18). Claw health as binary outcomes (i.e., presence or absence of a disorder of the digit) was analyzed using multilevel mixed-effects logistic regression models. Claw lesion severity was analyzed using multilevel mixed-effects ordered logistic regression models in affected cows only (CPI, DDI, or MI >0).

The equation of the binary models is

$$\Pr(y_{ij} = 1|x_{ij}, u_j) = H(x_{ij}\beta + \mathbf{z}_{ij}u_j).$$

This equation models the probability Pr(×) that the binary outcome (y_{ij}) is 1 (cow with ≥1 claw lesion). The model is conditional on fixed effects x_{ij} (parity, breed group, herd size, and claw trim frequency). The cow and farm ID were set as random effects u_j. The function $H(\times)$ denotes the logistic cumulative distribution function. The vector $\mathbf{z}_{ij}$ contains the independent variables corresponding to the random effects for the ith observation in the jth group (StataCorp, 2023).

The equation of the ordered models is

$$\Pr(y_{ij} > k|x_{ij}, \boldsymbol{\kappa}, u_j) = H(x_{ij}\beta + z_{ij}u_j - \kappa_k).$$

This equation represents the probability Pr(×) of an ordered outcome (y_{ij}) exceeding reference severity degree (k). The cut points for k are defined by vector $\boldsymbol{\kappa}$, the reference category is severity degree 1 (mild). The consideration of fixed effects (x_{ij}) and random effects (u_j) is analogous to the models described previously, including the same variables and hierarchical data structure (StataCorp, 2023).

The models showing significant associations ($1 \notin 95\%$ CI; $P < 0.05$) between lesion occurrence and limb con-

Table 2. Descriptive statistics of claw health indices in 21,145 Swiss cows participating in a nationwide project to improve claw health, 2020 to 2023[1]

Item[2]	Mean	Minimum	25%	Median	75%	Maximum
Claw health index						
CPI	19.51	0.00	0.00	8.00	20.00	392.00
DDI	6.97	0.00	0.00	0.00	0.00	128.00
MI	5.65	0.00	0.00	0.00	0.00	360.00
Conformation score						
SL	79.87	56.00	78.00	80.00	82.00	96.00
SF	79.73	60.00	78.00	80.00	82.00	92.00

[1]Descriptive statistics of conformation score data (the final conformation score of all traits and the limbs conformation score as assessed through "linear conformation scoring"; refer to Table 1) sorted into categories by the quality of the assessed anatomical traits.

[2]CPI = claw pathology index; DDI = digital dermatitis index; LBE = "Lineare Beschreibung und Einstufung" (conformation trait scoring); MI = mechanical index; SF = score final (final, overall grade per cow); SL = score limbs (score for the subsection "limbs").

formation were assessed by receiver operating characteristic curve (**ROC**) application and confusion matrix reporting to report sensitivity and specificity as predictive accuracy parameters. The models showing significant associations between lesion severity and limb conformation were assessed using margin plots.

RESULTS

Descriptive Statistical Analysis

The dataset encompassed 731 distinct farms and 21,145 individual cows. The cow population comprised 9,429 HF cows, 8,771 cows of the BS breed group, and 2,945 cows of the breeds SF/MB.

Each cow had a minimum of 1 claw health recording, with 92% of the cows having between 1 and 5. This distribution resulted in a median of 2 (range 1–18, 25th–75th percentile: 1–4) claw health recordings per cow. The mean age at the date of first linear scoring was 31.8 ± 5.5 mo. The median of the median interval between conformation scoring and claw health recordings was 21.88 mo (range 0.03–219.19, 25th–75th percentile: 9.63–43.86). The median herd size was 28 lactating cows (range 1–178, 25th–75th percentile: 19–43). Of the total 731 farms, 342 (46.8%) had a herd size ≥30 lactating cows, and 389 farms (53.2%) had <30 lactating cows. The median frequency of routinely conducted herd claw trimming per year was 1 (range 0–3, 25th–75th percentile: 1–1.67). On 466 farms (63.7%), herd claw trimming interval was >8 mo, whereas on 265 farms (32.3%), the interval was ≤8 mo. Most claw health recordings were recorded during the second lactation (13,104), followed by the first (11,020) and third (10,632) lactations. The numbers decreased progressively in subsequent lactations, with lactations 11 through to 18 collectively accounting for only 341 recordings. A total of 55,753 claw health recordings was obtained. Among these, 20,084 recordings (36%) were classified as healthy (CPI = 0), whereas for 35,669 recordings (64%), at least 1 lesion was recorded (CPI >0). For DD, 46,784 recordings (84%) were categorized as healthy, and in 8,969 recordings (16%), at least 1 DD stage was detected. For mechanical-metabolic lesions, 42,464 recordings (76%) were categorized as healthy, whereas in 13,289 recordings (24%), at least 1 lesion was detected.

The distribution of LBE scores for the subsection "limbs" is as follows: 212 cows (1%) were rated as "Poor," 1,165 (5.5%) as "Fair," 7,086 (33.5%) as "Good," 11,610 (55%) as "Good Plus," and 1,060 (5%) as "Excellent."

The distributions of the 3 claw health indices as well as the distribution of the variables representing conformation trait scoring are presented in Table 2.

The distributions of the 3 ordered outcomes across parity groups are presented in Figures 1A–1C, across breed groups in Figures 1D–1F, across SF categories in Figures 1G–1I, and across SL categories in Figures 1J–1L, respectively. Corresponding tables are provided in the supplemental materials (Supplemental Tables S1–S4, see Notes).

Multilevel Regression Models

The mixed-effects (ordered) logistic regression models show a substantial improvement in log-likelihood compared with the initial fixed-effects models (Wald chi2, $P < 0.001$ in all 12 cases). In congruence with the likelihood ratio test, these results suggest that the mixed-effects model fits the data better than the restricted model (fixed-effects-only logistic regression), justifying the choice of model. Details about model assessment are provided in the supplemental materials (Supplemental Table S5, see Notes).

The analysis revealed substantial variance in claw health across all models, both at the interfarm and intercow levels.

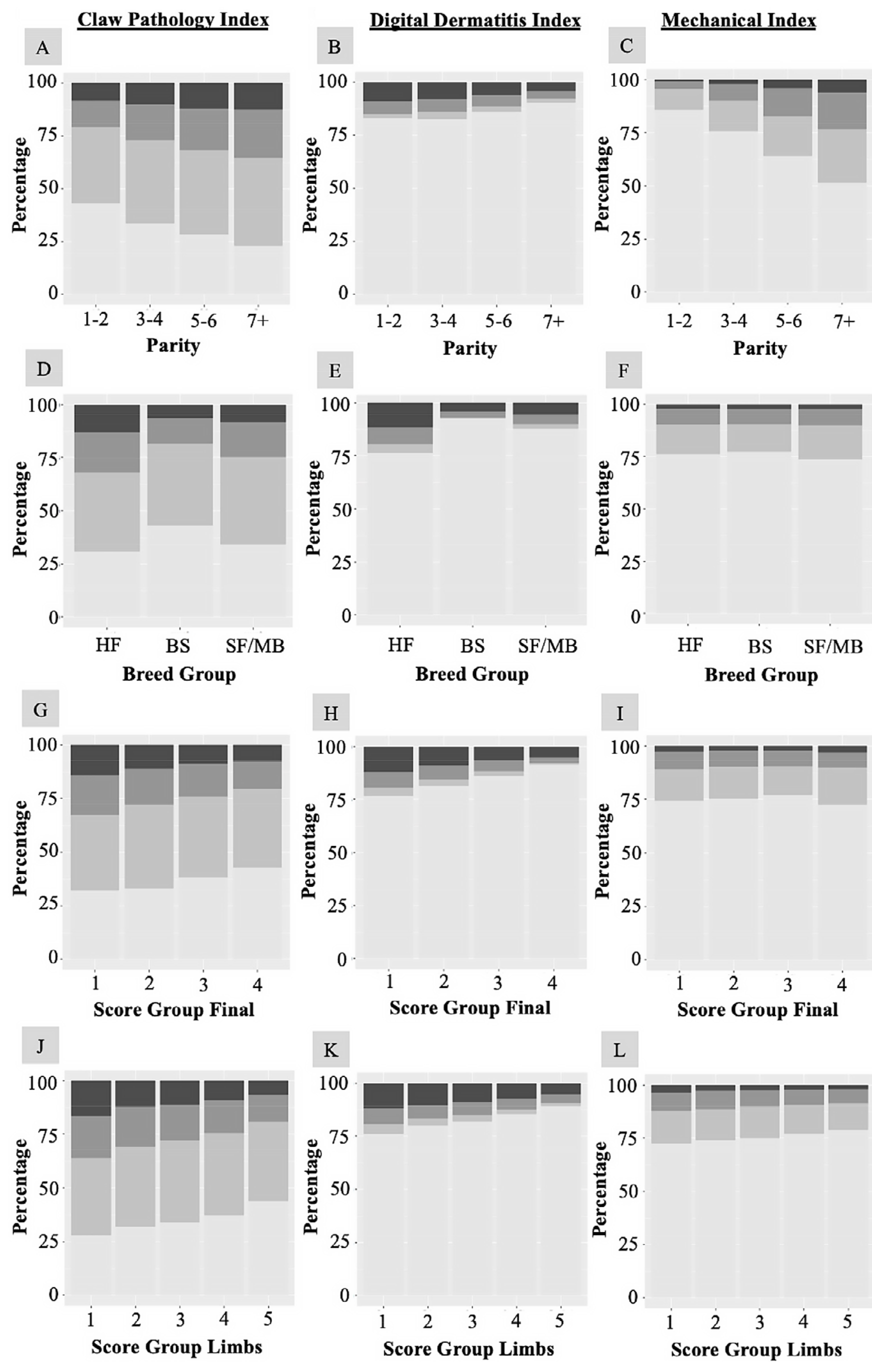

Figure 1. Distribution of claw health indices (4 categories) in 21,145 Swiss dairy cows participating in a nationwide project to improve claw health, 2020 to 2023 (grayscales represent the severity of the claw pathologies of the respective claw health indices: dark gray = severe, deep gray = moderate, medium gray = mild, light gray = healthy. (A–C) Distribution of severities of claw lesions across different parity groups, where (A) is claw pathology index by parity, (B) is digital dermatitis index by parity, and (C) is mechanical index by parity; (D–F) distribution of severities of claw lesions across different breed groups, where (D) is claw pathology index by breed group, (E) is digital dermatitis index by breed group, and (F) is mechanical index by breed group; (G–I) distribution of severities of claw lesions across the different categories of the final conformation score of all traits assessed through "linear conformation scoring" (in Switzerland, linear conformation scoring and classification, called "Lineare Beschreibung und Einstufung" [LBE], is performed by LINEAR AG (Posieux, Switzerland) for most breeds (LINEAR AG, 2013) and for Brown Swiss and related breeds by the Braunvieh breeding association (Braunvieh Schweiz, Zug, Switzerland; Braunvieh Schweiz, 2023) to prospectively assess future health and productivity of dairy cows), where (G) is claw pathology index by score final, (H) is digital dermatitis index by score final, and (I) is mechanical index by score final; and (J–L) distribution of severities of claw lesions across the different categories of the limbs conformation score, where (J) is claw pathology index by score limbs, (K) is digital dermatitis index by score limbs, and (L) is mechanical index by score limbs. BS = Brown Swiss, Rhaetian Grey, and Original Brown Swiss; HF = breed group comprising Holstein-Friesian; SF/MB = breed group comprising Swiss Fleckvieh and Montbéliarde.

Table 3. Results of multilevel mixed logistic regression models for the occurrence of lesions of the digit listed in the *ICAR Claw Health Atlas* (Egger-Danner et al., 2020) in 21,145 Swiss cows participating in a nationwide project to improve claw health, 2020 to 2023[1]

	Potential explanatory factor: Score final		Potential explanatory factor: Score limbs	
Item[2]	Odds ratio (95% CI)	*P*	Odds ratio (95% CI)	*P*
Breed group				
HF	Referent		Referent	
BS	0.61 (0.53–0.71)	<0.001	0.62 (0.53–0.72)	<0.001
SF/MB	1.13 (1.00–1.27)	0.036	1.14 (1.01–1.28)	0.029
Parity				
1–2	Referent		Referent	
3–4	1.65 (1.56–1.75)	<0.001	1.66 (1.57–1.75)	<0.001
5–6	2.49 (2.30–2.69)	<0.001	2.51 (2.33–2.71)	<0.001
7+	3.92 (3.52–4.37)	<0.001	3.96 (3.56–4.40)	<0.001
Herd size				
Small	Referent		Referent	
Large	1.67 (1.44–1.95)	<0.001	1.67 (1.44–1.94)	<0.001
Claw trimming frequency				
Low	1.00		1.00	
High	0.91 (0.70–1.20)	0.512	0.92 (0.70–1.20)	0.526
Score final				
1	Referent			
2	1.04 (0.85–1.28)	0.679		
3	1.05 (0.85–1.29)	0.658		
4	1.08 (0.84–1.37)	0.556		
Score limbs				
1	Referent			
2	1.10 (0.97–1.24)	0.140		
3	1.18 (1.03–1.34)	0.015		
4	1.26 (1.06–1.48)	0.007		
5	1.59 (1.18–2.12)	0.002		
Variance at farm level	2.85 (2.50–3.24)		2.84 (2.49–3.23)	
Variance at cow level	0.71 (0.63–0.79)		0.70 (0.63–0.79)	

[1]The final conformation score of all traits and the limbs conformation score as assessed through "linear conformation scoring". In Switzerland, linear conformation scoring and classification, called "Lineare Beschreibung und Einstufung" (LBE), is performed by LINEAR AG (Posieux, Switzerland) for most breeds (LINEAR AG, 2013) and for Brown Swiss and related breeds by the Braunvieh breeding association (Braunvieh Schweiz, Zug, Switzerland; Braunvieh Schweiz, 2023) to prospectively assess future health and productivity of dairy cows.

as assessed through "linear conformation scoring"). The final conformation score is assessed as potential explanatory factor, and the limb conformation score is assessed as potential explanatory factor.

[2]BS = Brown Swiss, Rhaetian Grey, and Original Brown Swiss; HF = breed group comprising Holstein-Friesian, (Rhaetian) Grey and Original Brown Swiss; SF/MB = breed group comprising Swiss Fleckvieh and Montbéliarde.

The results for parity, breed, herd size, and claw trimming frequency showed only very slight differences when changing SF for SL in all models. Therefore, only the respective larger effect size within the 2 variants of each model is reported.

The results for the models for CPI_bin are presented in Table 3 (SF as the potential explanatory variable, and SL as the potential explanatory variable). The odds for lesion occurrence increased monotonically with parity up to 3.96 times (95% CI: 3.56–4.40; $P < 0.001$) for the highest parity category. The CPI_bin was associated with breed. The BS breed group demonstrated 0.61 times (95% CI: 0.53–0.71; $P < 0.001$) lower odds and the dual-purpose breeds (SF/MB) 1.14 times (95% CI: 1.01–1.28; $P = 0.029$) higher odds of lesion occurrence than HF cows. For claw trimming frequency, the effect sizes were small, and zero effect could not be excluded in the 95% CI (odds ratio: 0.91; 95% CI: 0.7–1.2; $P = 0.512$). Larger herds exhibited 1.67 times higher odds of lesion occurrence (95% CI: 1.44–1.95; $P < 0.001$). Whereas the effect sizes for SF were close to 1, and zero effect could not be excluded in the 95% CI, the results for SL showed an increasing risk of lesion occurrence with lower rated conformation scores. The odds ratios increased across all categories of SL, reaching a maximum of 1.59 (95% CI: 1.18–2.12; $P = 0.002$) for category 5. Although the odds ratios for SL appear higher, the CI for SF and SL mostly overlap. Therefore, we cannot conclude that SL has a stronger association than SF, or that SF has no association.

The results for the models for DDI_bin are presented in Table 4 (SF as the potential explanatory variable, and SL as the potential explanatory variable). The odds for a cow to be affected by DD decreased with higher

Table 4. Results of multilevel mixed logistic regression models for the occurrence of digital dermatitis in 21,145 Swiss cows participating in a nationwide project to improve claw health, 2020 to 2023[1]

	Potential explanatory factor: Score final		Potential explanatory factor: Score limbs	
Item[2]	Odds ratio (95% CI)	P	Odds ratio (95% CI)	P
Breed group				
HF	Referent		Referent	
BS	0.33 (0.27–0.41)	<0.001	0.34 (0.28–0.41)	<0.001
SF/MB	0.79 (0.67–0.93)	0.005	0.80 (0.68–0.94)	0.006
Parity				
1–2	Referent		Referent	
3–4	0.99 (0.91–1.06)	0.713	0.99 (0.92–1.07)	0.795
5–6	0.75 (0.67–0.84)	<0.001	0.76 (0.68–0.85)	<0.001
7+	0.54 (0.46–0.64)	<0.001	0.55 (0.47–0.65)	<0.001
Herd size				
Small	Referent		Referent	
Large	3.41 (2.76–4.21)	<0.001	3.40 (2.75–4.20)	<0.001
Claw trimming frequency				
Low	1.00		1.00	
High	1.44 (1.09–1.90)	0.009	1.45 (1.10–1.91)	0.009
Score final				
1	Referent			
2	0.93 (0.64–1.35)	0.707		
3	0.89 (0.61–1.30)	0.537		
4	0.79 (0.52–1.19)	0.257		
Score limbs				
1	Referent			
2	1.02 (0.82–1.27)	0.858		
3	1.05 (0.84–1.32)	0.643		
4	0.93 (0.71–1.22)	0.618		
5	1.07 (0.71–1.61)	0.743		
Variance at farm level	2.28 (1.91–2.73)		2.28 (1.90–2.73)	
Variance at cow level	1.96 (1.96–2.34)		2.14 (1.96–2.34)	

[1]The final conformation score is assessed as potential explanatory factor, and the limb conformation score is assessed as potential explanatory factor.

[2]BS = Brown Swiss, Rhaetian Grey, and Original Brown Swiss; HF = breed group comprising Holstein-Friesian; SF/MB = breed group comprising Swiss Fleckvieh and Montbéliarde.

parity (parity >5) to around 0.54 (95% CI: 0.46–0.64; $P < 0.001$). The BS breed group had up to 0.33 times (95% CI: 0.27–0.41; $P < 0.001$) lower odds, whereas the odds ratio for the dual-purpose breeds was 0.79 (95% CI: 0.67–0.93; $P = 0.005$). Higher claw trimming frequency was found to be linked to 1.45 times (95% CI: 1.10–1.91; $P = 0.009$) higher odds for DD. Larger herds exhibited up to 3.4 times (95% CI: 2.76–4.21; $P < 0.001$) higher odds. The effect sizes for the association of the occurrence of DD with SF or SL were small, and zero effect was not excluded in the 95% CI.

The results for the models for MI_bin are presented in Table 5 (SF as the potential explanatory variable, and SL as the potential explanatory variable). The odds for lesion occurrence increased monotonically with parity up to 10.34 times (95% CI: 9.27–11.55; $P < 0.001$) for the highest parity category. The odds for lesion occurrence were up to 1.17 times (95% CI: 1.03–1.34; $P = 0.013$) higher for the dual-purpose breeds than for HF cows. The effect sizes for the association of occurrence of mechanical-metabolic lesions with claw trimming frequency and herd size were small, and zero effect was not excluded in the 95% CI. The odds for the occurrence of mechanical-metabolic lesions were 1.46 times (95% CI: 1.09–1.95; $P = 0.011$) higher for SF category 4 than for the reference category. The odds for the association with SL increased across all categories with odds ratios ranging from 1.19 (95% CI: 1.01–1.39; $P = 0.033$) to 2.04 (95% CI: 1.45–2.85; $P < 0.001$).

The results of the models for CPI_ord are presented in Table 6 (SF as the potential explanatory variable, and SL as the potential explanatory variable). The odds for lesion occurrence increased monotonically with parity up to 1.89 times (95% CI: 1.70–2.10; $P < 0.001$) for the highest parity category. The BS breed group had an odds ratio of 0.61 (95% CI: 0.53–0.70; $P < 0.001$) for higher severities, and for the dual-purpose breeds, the odds ratio was 0.83 (95% CI: 0.73–0.94; $P = 0.003$) compared with HF cows. The CPI_ord was associated with herd size, the odds for higher levels of lesion severity being 1.36 times (95% CI: 1.18–1.56; $P < 0.001$) higher in larger herds. The effect sizes for higher lesion severity with

Table 5. Results of multilevel mixed logistic regression models for the occurrence of mechanical-metabolic claw lesions in 21,145 Swiss cows participating in a nationwide project to improve claw health, 2020 to 2023[1]

	Potential explanatory factor: Score final		Potential explanatory factor: Score limbs	
Item[2]	Odds ratio (95% CI)	*P*	Odds ratio (95% CI)	*P*
Breed group				
HF	Referent		Referent	
BS	0.91 (0.78–1.05)	0.189	0.90 (0.78–1.04)	0.165
SF/MB	1.17 (1.03–1.33)	0.014	1.18 (1.03–1.34)	0.013
Parity				
1–2	Referent		Referent	
3–4	2.24 (2.09–2.39)	<0.001	2.24 (2.09–2.39)	<0.001
5–6	5.08 (4.67–5.54)	<0.001	5.08 (4.66–5.53)	<0.001
7+	10.34 (9.27–11.55)	<0.001	10.31 (9.24–11.50)	<0.001
Herd size				
Small	Referent		Referent	
Large	1.07 (0.93–1.23)	0.362	1.06 (0.93–1.22)	0.383
Claw trimming frequency				
Low	Referent		Referent	
High	0.97 (0.81–1.17)	0.717	0.97 (0.80–1-16)	0.711
Score final				
1	Referent			
2	1.06 (0.83–1.36)	0.619		
3	1.17 (0.91–1.50)	0.227		
4	1.46 (1.09–1.95)	0.011		
Score limbs				
1	Referent			
2	1.19 (1.01–1.39)	0.033		
3	1.35 (1.15–1.60)	<0.001		
4	1.39 (1.13–1.71)	0.002		
5	2.04 (1.45–2.85)	<0.001		
Variance at farm level	1.15 (0.99–1.34)		1.14 (0.98–1.33)	
Variance at cow level	1.42 (1.30–1.54)		1.41 (1.30–1.54)	

[1]The final conformation score is assessed as potential explanatory factor, and the limb conformation score is assessed as potential explanatory factor.

[2]BS = Brown Swiss, Rhaetian Grey, and Original Brown Swiss; HF = breed group comprising Holstein-Friesian; SF/MB = breed group comprising Swiss Fleckvieh and Montbéliarde.

respect to claw trimming frequency and SF were small, zero effect was not excluded in the 95% CI. The odds increased monotonically across SL categories up to 1.66 times (95% CI: 1.21–2.27; $P = 0.002$) for SL category 5.

The results of the models for DDI_ord are presented in Table 7 (SF as the potential explanatory variable, and SL as the potential explanatory variable). Odds decreased with increasing age down to 0.61 times (95% CI: 0.49–0.76; $P < 0.001$) for the highest parity category. The BS breed group showed 1.41 times (95% CI: 1.12–1.78; $P = 0.003$) higher odds for higher severities. For the dual-purpose breeds, the odds ratio was close to 1, for claw trimming frequency, herd size, and SL, zero effect was not excluded in the 95% CI. The odds for higher severities decreased along the categories of SF, again, zero effect was not excluded.

The results of the models for MI_ord are presented in Table 8 (SF as the potential explanatory variable, and SL as the potential explanatory variable). Increasing age showed high relevance, with odds for higher lesion severities increasing across all categories up to 3.06 times (95% CI: 2.63–3.56; $P < 0.001$) for the highest parity category. For breed, herd size, and claw trimming frequency, as well as both SL and SF, zero effect could not be excluded in the 95% CI.

The ROC curves assessing the association of CPI_bin and SL and the association of MI_bin and SL did not support practical relevance, as the areas under the ROC curve were very small (0.53; 0.52). The confusion matrix for CPI_bin and SL revealed both low sensitivity (88.85%) and specificity (68.27%), the confusion matrix for MI_bin and SL revealed high specificity (96.60%) but low sensitivity (46.30%). The margin plot assessing the association of CPI_ord and SL revealed no meaningful differences between score levels, although the minimally reduced odds of severe lesions in the highest SL score group are visually discernible in the plot. The corresponding tables and figures are provided in the supplemental materials (Supplemental Tables S6 and S7 and Figures S1–S3, see Notes).

Table 6. Results of multilevel mixed ordered logistic regression models for the severity of 35,669 claw lesions listed in the *ICAR Claw Health Atlas* (Egger-Danner et al., 2020) in Swiss cows participating in a nationwide project to improve claw health, 2020 to 2023[1]

	Potential explanatory factor: Score final		Potential explanatory factor: Score limbs	
Item[2]	Odds ratio (95% CI)	*P*	Odds ratio (95% CI)	*P*
Breed group				
HF	Referent		Referent	
BS	0.61 (0.53–0.70)	<0.001	0.62 (0.54–0.72)	<0.001
SF/MB	0.83 (0.73–0.94)	0.003	0.83 (0.74–0.94)	0.003
Parity				
1–2	Referent		Referent	
3–4	1.17 (1.10–1.25)	<0.001	1.18 (1.11–1.26)	<0.001
5–6	1.55 (1.43–1.69)	<0.001	1.56 (1.44–1.70)	<0.001
7+	1.87 (1.69–2.08)	<0.001	1.89 (1.70–2.10)	<0.001
Herd size				
Small	Referent		Referent	
Large	1.36 (1.19–1.57)	<0.001	1.36 (1.18–1.56)	<0.001
Claw trimming frequency				
Low	Referent		Referent	
High	1.00 (0.84–1.20)	0.985	1.01 (0.84–1.21)	0.938
Score final				
1	Referent			
2	1.10 (0.85–1.41)	0.462		
3	1.03 (0.79–1.33)	0.830		
4	1.17 (0.88–1.57)	0.286		
Score limbs				
1	Referent			
2	1.22 (1.04–1.42)	0.016		
3	1.26 (1.07–1.49)	0.006		
4	1.29 (1.06–1.58)	0.012		
5	1.66 (1.21–2.27)	0.002		
Variance at farm level	0.99 (0.86–1.17)		0.99 (0.85–1.16)	
Variance at cow level	1.03 (0.94–1.14)		1.03 (0.94–1.14)	

[1]The final conformation score is assessed as potential explanatory factor, and the limb conformation score is assessed as potential explanatory factor.

[2]BS = Brown Swiss, Rhaetian Grey, and Original Brown Swiss; HF = breed group comprising Holstein-Friesian; SF/MB = breed group comprising Swiss Fleckvieh and Montbéliarde.

DISCUSSION

In this study, parity, breed, and herd size were found to be associated with a higher degree than conformation traits. The association between limb conformation and claw health was low but discernible and worthy of consideration.

Association Between Conformation Scores and Claw Health

Studies by Chapinal et al. (2013), van der Linde et al. (2010), and van der Waaij et al. (2005) have demonstrated only low to moderate associations between specific conformation traits and the occurrence of claw disorders. Consequently, the approach of selecting breeding animals based on phenotype scoring is not effective when testing for associations between specific traits and specific claw lesions. The h^2 of certain claw lesions (Chapinal et al., 2013) still makes this selection approach appealing, as it is practical, and the scoring is well-established. The study by Nuss et al. (2020) was the first to begin searching for a reason for this low association. In the intended logic of conformation scoring, the relevance of the hind limb position lies in its determination of load distribution on the limbs. Nuss et al. (2020), however, found the influence of hind limb position to be only minor, which, in turn, explains why the association is inadequate. Our approach using SF and SL, encompassing all traits, respectively all limb traits, has a chance to capture associations between conformation and claw health that may not be linked to a single trait but with the overall limb conformation.

The models assessing lesion occurrence for CPI and MI aligned with the trend of increased odds for lesion occurrence in lower rated cows with small effect sizes. This suggests that poor claw and limb conformation is indeed associated with the occurrence of claw lesions in general, and mechanical-metabolic lesions specifically. The small effect sizes, however, are consistent with the multifactorial nature of claw health (Katsoulos and Christodoulopoulos, 2009) and suggest limited practical implication. The considerable overlap in the CI of

Table 7. Results of multilevel mixed ordered logistic regression models for the severity of 8,968 digital dermatitis lesions in Swiss cows participating in a nationwide project to improve claw health, 2020 to 2023[1]

Item[2]	Potential explanatory factor: Score final		Potential explanatory factor: Score limbs	
	Odds ratio (95% CI)	*P*	Odds ratio (95% CI)	*P*
Breed group				
HF	Referent		Referent	
BS	1.42 (1.12–1.79)	0.003	1.42 (1.12–1.78)	0.003
SF/MB	0.98 (0.80–1.18)	0.799	0.97 (0.81–1.18)	0.791
Parity				
1–2	Referent		Referent	
3–4	0.66 (0.59–0.73)	<0.001	0.66 (0.59–0.73)	<0.001
5–6	0.64 (0.55–0.74)	<0.001	0.64 (0.55–0.75)	<0.001
7+	0.61 (0.49–0.76)	<0.001	0.62 (0.49–0.77)	<0.001
Herd size				
Small	Referent		Referent	
Large	1.21 (0.94–1.56)		1.21 (0.94–1.56)	
Claw trimming frequency				
Low	Referent		Referent	
High	0.92 (0.71–1.20)	0.551	0.92 (0.71–1.20)	0.554
Score final				
1	Referent			
2	0.78 (0.46–1.33)	0.367		
3	0.77 (0.45–1.33)	0.350		
4	0.85 (0.48–1.50)	0.564		
Score limbs				
1	Referent			
2	1.29 (0.98–1.70)	0.068		
3	1.23 (0.93–1.63)	0.154		
4	1.36 (0.98–1.90)	0.065		
5	1.11 (0.69–1.79)	0.671		
Variance at farm level	1.17 (0.93–1.47)		1.19 (0.95–1.49)	
Variance at cow level	0.43 (0.31–0.59)		0.43 (0.31–0.59)	

[1]The final conformation score is assessed as potential explanatory factor, and the limb conformation score is assessed as potential explanatory factor.

[2]BS = Brown Swiss, Rhaetian Grey, and Original Brown Swiss; HF = breed group comprising Holstein-Friesian; SF/MB = breed group comprising Swiss Fleckvieh and Montbéliarde.

SL and SF further reduces the strength of evidence for a true difference in their associations with lesion occurrence. The models for the severities of CPI (CPI_ord) reveal increased odds for higher lesion severity for cows with lower rated limb conformation. Other factors that might influence lesion severity likely include aspects of housing and lameness management, such as timely and proper lesion treatment. The small effect sizes and the possibility of zero effect suggests that the severity of mechanical-metabolic lesions is not associated with SL, which might indicate that the aforementioned factors are especially powerful when it comes to the management of mechanical-metabolic lesions and outweigh the marginal effect of limb phenotype. For the association of SF with lesion severity in general, the small effect sizes and the possibility of zero effect suggest no practical meaning. The effect sizes for the association of SF with the severity of mechanical-metabolic lesions are more notable but still zero effect remains possible. The final score does not reflect the association with SL, likely as it is overlaid by information about other anatomical traits.

Regarding DD, the association of SL and SF with disease occurrence or severity is characterized by small effect sizes with the possibility of zero effect present in all cases. There are various risk factors for DD, including housing, parity, breed, immune response, and, reflecting the diseases infectious nature, external and internal biosecurity (Weber et al., 2023; Fürmann et al., 2024). Good anatomical structure of the claws and limbs does not decrease the odds for DD. Conversely, poor anatomical structure does not increase susceptibility to DD. The severity degrees representing the stages of the cyclical disease dynamics are not associated with conformation, underlining the importance of disease management and treatment.

In summary, it can be concluded that some significant associations of limb conformation and claw health are detectable in the analysis of our study cohort. The critical analysis of specificity and sensitivity, however, contra-

Table 8. Results of multilevel mixed ordered logistic regression models for the severity of 13,289 mechanical-metabolic claw lesions in Swiss cows participating in a nationwide project to improve claw health, 2020 to 2023[1]

	Potential explanatory factor: Score final		Potential explanatory factor: Score limbs	
Item[2]	Odds ratio (95% CI)	*P*	Odds ratio (95% CI)	*P*
Breed group				
HF	Referent		Referent	
BS	1.01 (0.85–1.20)	0.928	1.03 (0.87–1.22)	0.732
SF/MB	0.84 (0.71–1.00)	0.051	0.84 (0.71–1.00)	0.051
Parity				
1–2	Referent		Referent	
3–4	1.85 (1.64–2.08)	<0.001	1.85 (1.65–2.08)	<0.001
5–6	2.79 (2.44–3.19)	<0.001	2.81 (2.46–3.21)	<0.001
7+	3.04 (2.61–3.54)	<0.001	3.06 (2.63–3.56)	<0.001
Herd size				
Small	Referent		Referent	
Large	0.96 (0.81–1.13)	0.622	0.96 (0.81–1.13)	0.601
Claw trimming frequency				
Low	Referent		Referent	
High	0.88 (0.73–1.06)	0.168	0.88 (0.74–1.06)	0.183
Score final				
1	Referent			
2	1.35 (0.95–1.92)	0.098		
3	1.30 (0.90–1.87)	0.157		
4	1.41 (0.93–2.15)	0.106		
Score limbs				
1	Referent			
2	1.04 (0.82–1.32)	0.755		
3	1.08 (0.84–1.39)	0.531		
4	1.33 (0.99–1.81)	0.062		
5	1.28 (0.78–2.08)	0.327		
Variance at farm level	0.70 (0.56–0.87)		0.70 (0.56–0.87)	
Variance at cow level	1.04 (0.87–1.25)		1.04 (0.87–1.24)	

[1]The final conformation score is assessed as potential explanatory factor, and the limb conformation score is assessed as potential explanatory factor.

[2]BS = Brown Swiss, Rhaetian Grey, and Original Brown Swiss; HF = breed group comprising Holstein-Friesian; SF/MB = breed group comprising Swiss Fleckvieh and Montbéliarde.

dicts the applicability of these results as a generalizable predicting method.

Association Between Parity and Claw Health

The increasing odds for CPI and MI and the decreasing odds for DD with increasing age align with previous studies (Somers et al., 2005; Holzhauer et al., 2006; Häggman and Juga, 2015). Regarding CPI and MI, the result reflects the physical stress of lactation, cumulative tissue damage, and the time spent under challenging housing conditions (Fiore et al., 2019). Also, the age-related thinning of the digital fat cushion as well as the sinking of the pedal bone have been linked to the development of claw horn disruption lesions (Häggman and Juga, 2015).

To understand the association of age with DDI, the 3 different cow types must be considered, differing in their immune response dynamics to treponemes (Gomez et al., 2014; Schöpke et al., 2015). The lower DD occurrence in higher parities can be explained by the development of immunity (cow type II; Somers et al., 2005). It should be noted that the mechanism of immunity and the extent to which it can develop are not yet fully understood. Likewise, this association reflects the need for culling the repeatedly affected cows (cow type III; Somers et al., 2005), which is one of the recommended measures to lower the infective pressure within the herd. Zero effect can only be excluded for this tendency after the fourth lactation. This is likely attributable to the time that passes until (repetitive) reactivation of latent infections occurs, immunity can develop, and the farmer makes corresponding culling decisions. Additionally, the contribution of increasing heel height in older cows (Palmer and O'Connell, 2015) and the physical and metabolic stress imposed on young cows by their transition into dairy production (Somers et al., 2005) are discussed.

Association Between Breed and Claw Health

As expected, breed-specific susceptibility was demonstrated. Previous studies have consistently shown the high susceptibility of HF cows to DD (Holzhauer et al., 2006; Palmer and O'Connell, 2015). Conversely, the BS breed group exhibited the lowest odds for DD occurrence and for claw lesions in general, aligning with the results of Kofler et al. (2024). This may be attributed to their robust constitution and possibly also their high genetic diversity (Kosińska-Selbi et al., 2020). Holzhauer et al. (2006) reported a lower risk of DD for Meuse-Rhine-Issel cows, another dual-purpose breed, compared with HF cows. However, it remains unclear whether belonging to a dual-purpose breed confers a protective effect, or if the difference is solely attributable to the high susceptibility in HF cows. Interestingly, the disease severity for DD was higher in BS than in HF cows, possibly due to the management structure of the respective farms being less prepared for timely detection and treatment of DD lesions.

Association Between the Herd Size and Claw Health

The elevated odds for DD and claw lesions in general in larger herds can be attributed to the infectious nature of DD and some of the disorders included in CPI, a finding that is consistent with previous studies (Wells et al., 1999; Katsoulos and Christodoulopoulos, 2009). The effect of herd size can be primarily attributed to the higher infectious pressure within larger populations (Wells et al., 1999). Larger herds are frequently housed in freestall systems, a housing system that has been identified as a risk factor for DD (Weber et al., 2023). However, this relationship can also be contextualized within social factors and resource access for individual cows. Social stress and hierarchy influence food and water intake, as well as the time spent lying down. This, in turn, affects the (claw) health of individual cows (Bruijnis et al., 2012). In addition, the detection of subclinical lesions may be more challenging in larger herds. Late detection could contribute to the higher odds of more severe lesions. The effect of herd size on mechanical-metabolic lesions can be excluded. For these lesions, the risk factors associated with flooring, such as uneven, abrasive, or slippery surfaces, loose elements, and sharp edges, are highly influential (Haufe et al., 2012). Nutritional factors also substantially influence horn quality and claw health by affecting the claw horn formation. Appropriate supply of nutrients, for example, vitamins, minerals, and trace elements, is crucial for high-quality horn production. Nutritional mismanagement leads to increasing susceptibility to environmental damage and potentially results in claw disease and lameness (Tomlinson et al., 2004).

Association Between the Claw Trimming Frequency and Claw Health

The recommended frequency of regular claw trimming is biannual or higher (Katsoulos and Christodoulopoulos, 2009). This practice serves multiple purposes. It removes loose horn material, corrects overgrowth, and allows for the early detection and treatment of subclinical lesions (Fiore et al., 2019). In the present study, higher frequency of claw trimming was associated with increased occurrence of DD. This finding agrees with a previously reported decreased incidence of infective disorders with a lower claw trimming frequency (Häggman and Juga, 2015). Whereas claw trimming tools and equipment have been identified as vectors for disease transmission (Wells et al., 1999), the observed association could also be explained by a higher chance of detection of lesions. Conversely, a higher incidence of DD may also require more frequent trimming interventions. Given the nature of the data, it is not possible to definitively determine the direction of causality for the association between claw trimming frequency and DD occurrence.

Variance on Farm Level Versus on Cow Level

The interfarm variance can be attributed to multiple factors, primarily the infectious nature of numerous claw disorders, with particular emphasis on the presence or absence of DD in each herd. This explains that the variance on farm was higher than on cow level in the models assessing lesion occurrence for CPI and DDI. Additionally, housing systems, various aspects of cow comfort, flooring types, and farm-level factors, such as biosecurity, hygiene, and feeding strategy, contribute to this variance.

The intercow variance reflects the cow-specific characteristics within a herd, encompassing factors such as age and parity, breed, variations in immune status, genetics, and overall health condition. Due to the high relevance of age, the variance is higher at cow than at farm level for the lesion occurrence of MI. The variance for all ordered outcomes was also higher at cow than at farm level, likely because lesion severity depends on the time of infection, time of lesion detection, and the treatment regimen.

Methodological Strengths and Limitations

The methodological precautions minimized interobserver bias and ensured a high level of consistency of the claw health data recording. Similarly, the conformation recording is based on well-defined measuring methods and is subject to continuous monitoring. The entire dataset was thus as uniform and consistent as feasible given the practical limitations of data recording. A potential limitation of the dataset quality is the varying amount of data available for each cow. However, this concern is likely alleviated by the large sample size.

The dataset does not include treatments performed by farmers or veterinarians. Treatments administered by farmers typically address low-severity lesions, whereas veterinarians tend to treat high-severity cases. This may have resulted in an incomplete picture of the clinical status of the study population depending on the lameness management protocol on different farms. The choice of a multilevel model might mitigate this somewhat as interfarm variability is considered. Also, it cannot be ruled out that farmers whose herds have particularly poor claw health are more likely to decline to disclose data for scientific evaluation, resulting in potential selection bias. The definition of the 14-d threshold for follow-up treatment is based on the standard practice in Switzerland of bandage change in weekly intervals. Some claw disorders remain detectable for longer periods and might be counted more than 1 time with this approach. Therefore, the definition represents a compromise between capturing follow-up treatments and distinguishing new disorders for analytical purposes.

CONCLUSIONS

The intended use of conformation scoring as a predictor for subsequent claw health cannot be supported by our results. In some cases, we did detect associations between limb conformation and claw health, but the effect sizes are limited. Consequently, conformation scoring of the limbs can be considered a supplementary tool in approaching claw health, but the score does not serve as a reliable predictor for the anticipated claw health. Claw health is influenced by numerous factors at both herd and individual cow levels. In this study, parity, breed, and herd size were found to be associated with a higher degree than conformation traits. Future research is needed to weight the different determinants, identify risk factors, and aim to develop effective strategies for the improvement of claw health and associated animal welfare. Given that conformation trait scoring is used as a tool for selection of breeding animals, additional research should investigate the h^2 of specific anatomical traits and of the susceptibility for claw disorders. This would help to estimate the extent to which the association between physical conformation and claw health is valid for future generations.

NOTES

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Nonstandard abbreviations used: BS = Brown Swiss, Rhaetian Grey, and Original Brown Swiss; CPI = claw pathology index; CPI_bin, DDI_bin, and MI_bin = binary outcome variables; CPI_ord, DDI_ord, MI_ord = severity degrees; DD = digital dermatitis; DDI = DD index; HF = Holstein-Friesian; LBE = “Lineare Beschreibung und Einstufung”; max = maximum; MI = mechanical index; min = minimum; ROC = receiver operating characteristic curve; SF/MB = Swiss Fleckvieh and Montbéliarde; SF = score final; SL = score limbs.

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SUPPLEMENTARY MATERIALS

Table S1: Distribution of claw health indices across different parities in 21,145 Swiss cows participating in a nationwide project to improve claw health, 2020-2023. Table corresponds to Figure 1 A-C.
[CPI = Claw Pathology Index; DDI = Digital Dermatitis Index; MI = Mechanical Index]

Severity	Parity	CPI (%)	DDI (%)	MI (%)
0	1-2	43.06	82.95	85.75
	3-4	33.67	82.53	75.64
	5-6	28.47	85.99	63.96
	7+	23.01	90.34	51.59
1	1-2	36.01	1.98	10.01
	3-4	39.18	3.38	14.54
	5-6	39.66	2.64	18.73
	7+	41.64	1.86	25.09
2	1-2	12.56	6.04	3.42
	3-4	17.01	6.04	7.73
	5-6	19.72	5.18	13.23
	7+	22.80	3.67	17.23
3	1-2	8.37	9.03	0.82
	3-4	10.14	8.05	2.10
	5-6	12.15	6.19	4.07
	7+	12.55	4.13	6.09

Table S2: Distribution of claw health indices across different breed groups in 21,145 Swiss cows participating in a nationwide project to improve claw health, 2020-2023. Table corresponds to Figure 1 D-F.
[CPI = Claw Pathology Index; DDI = Digital Dermatitis Index, MI = Mechanical Index; HF = breed group comprising Holstein Friesian; BS = breed group comprising Brown Swiss, (Rhaetian) Grey and Original Brown Swiss; SF/MB = breed group comprising Swiss Fleckvieh and Montbéliarde]

Severity	Breed group	CPI (%)	DDI (%)	MI (%)
0	HF	30.97	76.24	76.08
	BS	43.14	92.46	77.19
	SF/MB	34.31	87.54	73.62
1	HF	37.00	4.14	14.16
	BS	38.45	0.51	13.36
	SF/MB	40.99	2.40	16.11
2	HF	18.96	8.09	7.64
	BS	12.05	3.01	7.18
	SF/MB	16.37	4.69	8.03
3	HF	13.07	11.53	2.11
	BS	6.36	4.03	2.26
	SF/MB	8.33	5.37	2.24

Table S3: Distribution of claw health indices across the different categories of the final conformation score of all traits assessed through 'linear conformation scoring'* in 21,145 Swiss cows participating in a nationwide project to improve claw health, 2020-2023. Table corresponds to Figure 1 G-I.
* In Switzerland, linear conformation scoring and classification, called 'Lineare Beschreibung und Einstufung' (LBE), is performed by LINEAR AG for most breeds (https://linearsa.ch/de/) and for Brown Swiss and related breeds by the Braunvieh breeding association (https://homepage.braunvieh.ch/lbe/) to prospectively assess future health and productivity of dairy cows.
[CPI = Claw Pathology Index; DDI = Digital Dermatitis Index; MI = Mechanical Index; SF = score final categorical: final, overall grade per cow, points sorted into score categories]

Severity	SF	CPI (%)	DDI (%)	MI (%)
0	1	32.09	76.51	74.30
	2	33.05	81.27	75.23
	3	38.19	86.13	77.10
	4	42.80	91.25	72.44
1	1	35.21	4.10	14.84
	2	39.01	3.01	14.94
	3	37.76	2.12	13.40
	4	36.69	0.94	17.31
2	1	18.68	7.29	8.19
	2	16.94	6.68	7.69
	3	15.23	5.00	7.35
	4	12.79	2.73	7.34
3	1	14.02	12.10	2.67
	2	11.00	9.05	2.15
	3	8.83	6.75	2.15
	4	7.71	5.08	2.92

Table S4: Distribution of claw health indices across the different categories of the limb's conformation score assessed through 'linear conformation scoring'* in 21,145 Swiss cows participating in a nationwide project to improve claw health, 2020-2023. Table corresponds to Figure 1 J-L.
* Refer to Table S3.
[CPI = Claw Pathology Index; DDI = Digital Dermatitis Index; MI = Mechanical Index; SL = score limbs categorical: score for the subsection 'limbs', points sorted into score categories; LBE = 'Lineare Beschreibung und Einstufung': conformation trait scoring]

Severity	SF	CPI (%)	DDI (%)	MI (%)
0	1	27.84	76.06	72.50
	2	31.89	79.97	74.10
	3	33.87	81.73	74.82
	4	37.23	85.38	77.04
	5	43.87	88.92	78.87
1	1	36.16	4.75	15.28
	2	37.29	3.38	14.35
	3	38.19	3.04	14.95
	4	38.27	2.16	13.70
	5	36.91	1.69	12.66
2	1	19.35	7.30	8.49
	2	18.58	6.37	8.83
	3	16.88	6.44	7.70
	4	15.42	5.28	7.27
	5	12.70	4.20	6.67
3	1	16.64	11.88	3.74
	2	12.24	10.28	2.71
	3	11.07	8.79	2.43
	4	9.08	7.18	1.99
	5	6.53	5.20	1.79

Table S5: Comparative performance of full and restricted regression models assessing the occurrence and severity of claw lesions in in 21,145 Swiss cows participating in a nationwide project to improve claw health, 2020-2023. [CPI_bin = CPI binary: lesion occurrence CPI; DDI_bin = DDI binary: disease occurrence DDI; MI_bin = MI binary: lesion occurrence MI; CPI_ord = CPI categorical: lesion severity CPI; DDI_ord = DDI categorical: disease severity; MI_ord = MI categorical: lesion severity MI; SF = score final categorical: final, overall grade per cow assessed through 'linear conformation scoring', points sorted into score categories; SL = score limbs categorical: score for the subsection 'limbs' assessed through 'linear conformation scoring', points sorted into score categories]

Outcome	Main explanatory variable (parity, breed, herd size and claw trimming frequency were forced into all models)	Log likelihood restricted model	Log likelihood full model	LR test*	Wald test**
CPI_bin	SF	-35021.176	-28178.118	$p < 0.001$	$p < 0.001$
CPI_bin	SL	-35011.856	-28169.777	$p < 0.001$	$p < 0.001$
DD_bin	SF	-22529.078	-19425.567	$p < 0.001$	$p < 0.001$
DD_bin	SL	-22527.799	-19426.232	$p < 0.001$	$p < 0.001$
MI_bin	SF	-28824.491	-25793.771	$p < 0.001$	$p < 0.001$
MI_bin	SL	-28809.679	-25786.841	$p < 0.001$	$p < 0.001$
CPI_ord	SF	-33065.902	-30604.573	$p < 0.001$	$p < 0.001$
CPI_ord	SL	-33056.086	-30601.282	$p < 0.001$	$p < 0.001$
DD_ord	SF	-8967.8095	-8317.7889	$p < 0.001$	$p < 0.001$
DD_ord	SL	-8969.8072	-8316.0848	$p < 0.001$	$p < 0.001$
MI_ord	SF	-12556.217	-12007.916	$p < 0.001$	$p < 0.001$
MI_orde	SL	-12552.089	-12006.369	$p < 0.001$	$p < 0.001$

* Indicates whether random effects improve model fit.
**Indicates whether at least one of the fixed-effect explanatory variables is significantly associated with the outcome.

Figure S1: Receiver operating characteristic curve (ROC-curve) for the association between the occurrence of lesions of the digit and the limb conformation score shown in a multilevel mixed logistic regression model for the occurrence of lesions of the digit in 21,145 Swiss cows participating in a nationwide project to improve claw health, 2020-2023.

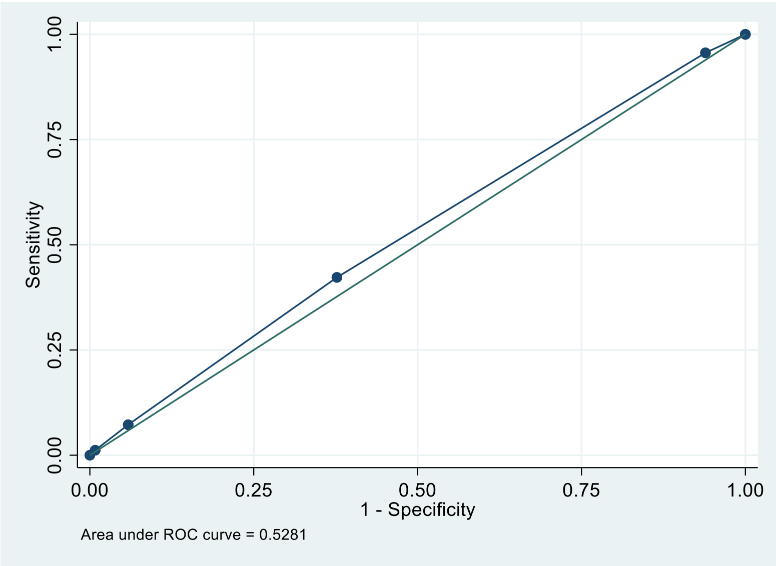


Table S6: Confusion matrix for the association between the occurrence of lesions of the digit and the limb conformation score shown in a multilevel mixed logistic regression model for the occurrence of lesions of the digit in 21,145 Swiss cows participating in a nationwide project to improve claw health, 2020-2023.

Outcome: lesion occurrence (0 = healthy, 1 = sick)				
		predicted		
		0	1	Total
actual	0	13,712	6,372	20,084
	1	3,976	31,693	35,669
	Total	17,688	38,065	55,753

Figure S2: Receiver operating characteristic curve (ROC-curve) for the association between the occurrence of mechanical-metabolic claw lesions and the limb conformation score shown in a multilevel mixed logistic regression model for the occurrence of mechanical-metabolic claw lesions of the digit in 21,145 Swiss cows participating in a nationwide project to improve claw health, 2020-2023.

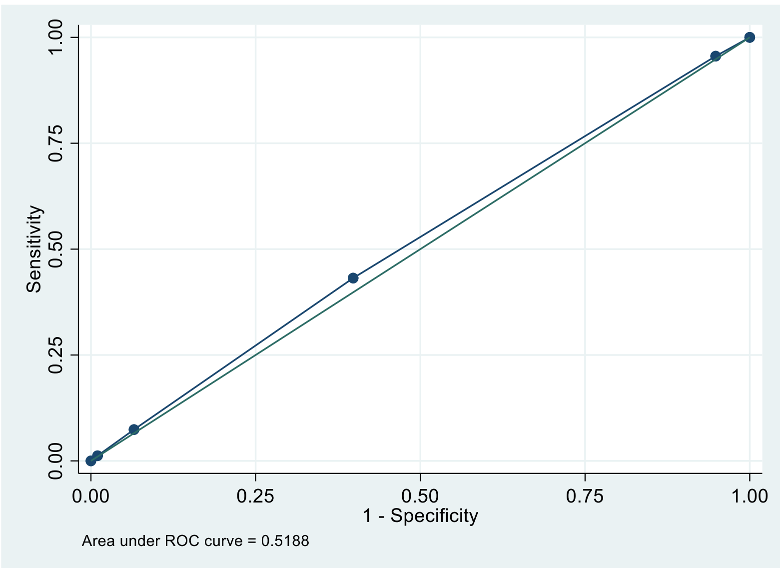
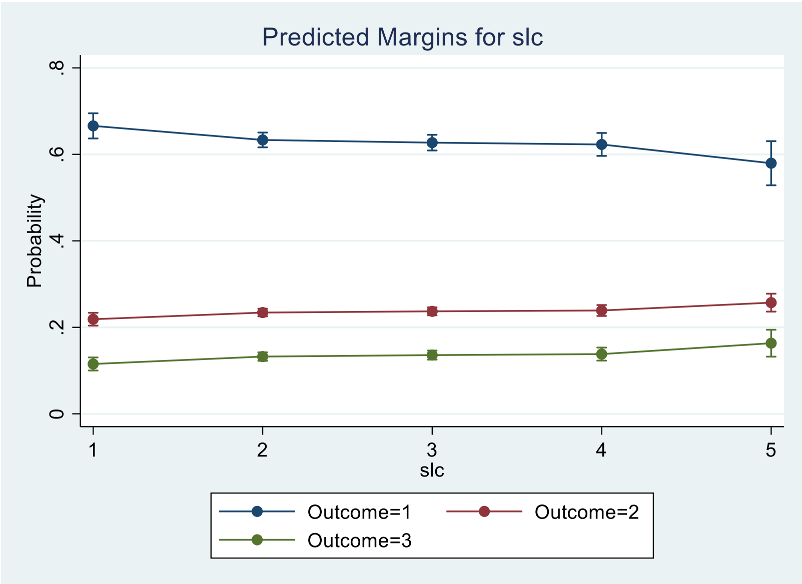


Table S7: Confusion matrix for the association between the occurrence of mechanical-metabolic claw lesions and the limb conformation score shown in a multilevel mixed logistic regression model for the occurrence of mechanical-metabolic claw lesions in 21,145 Swiss cows participating in a nationwide project to improve claw health, 2020-2023.

Outcome: lesion occurrence (0 = healthy, 1 = sick)				
		predicted		
		0	1	Total
actual	0	41,021	1,443	42,464
	1	7,136	6,153	13,289
	Total	48,157	7,596	55,753

Figure S3: Margin plot for the association between the severity of lesions of the digit and the limb conformation score shown in a multilevel mixed logistic regression model for the severity of 35,669 claw lesions in Swiss cows participating in a nationwide project to improve claw health, 2020-2023.



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