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J. Dairy Sci. TBC
https://doi.org/10.3168/jds.2024-25124
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Factors associated with the evolution of digit health in Swiss dairy herds in a nationwide digit health program

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ABSTRACT

The purpose of this study was to investigate the evolution of digit health (DH) on Swiss dairy farms participating in a nationwide DH program and to identify risk factors associated with poor DH. Specially trained claw trimmers recorded disorders of the digits (DOD) electronically during routine trimmings between January 2020 and June 2023.

The first part of the study was a non-randomized controlled implementation study, comparing the evolution of DH in 75 herds that received professional on-farm risk assessments as well as veterinary advice with 49 herds that did not. Overall DH improved over time in both groups, with no difference between the groups. Differences emerged when implementation rates of measures after on-farm risk assessment were considered: DH of farms implementing >50% of recommended measures improved significantly more compared with farms implementing £ 50%. Also, farms where cows predominantly suffered from infectious-related lesions improved significantly compared with farms where cows suffered predominantly from mechanical-metabolic-related lesions.

The second part of the study consisted of a retrospective observational risk factor analysis with a larger population (498 farms). Here, greater improvement of DH on a farm over the study period was associated with a higher Farm-Claw-Score (FCS; index for decreased DH) at the beginning of the study and longer duration of participation in the DH program. Moreover, less improvement of DH was associated with freestalls, with "valley area" farm sites and with herds with Holstein Friesian cows as predominant breed.

Our results suggest that, if implemented appropriately, measures issued by DH experts may improve DH. Furthermore, voluntary participation in a DH program in combination with routine electronic recording of DH data by claw trimmers seem to raise farmers' motivation to improve DH. Our results are useful for farmers and veterinarians as well as for establishing DH programs in other countries.

Key words: cattle, digit health, farm claw score, risk assessment

INTRODUCTION

The worldwide prevalence of disorders of the digits (DOD) and the frequency of resulting lameness represents an important and often underestimated health aspect in dairy cattle (Leach et al., 2010a; b; Šárová et al., 2011; Alvergnas et al., 2019). In Switzerland, for example, at least one DOD has been reported to be present in more than 3-quarters of cows participating in a digit health (DH) program (Jury et al., 2021). Specific economic implications of DOD include, for example, reduced milk yield and impaired fertility due to reduced feed intake of affected cattle and early culling (Booth et al., 2004; Charfeddine and Pérez-Cabal, 2017). Cha et al. (2010), calculated the economic impact of different DOD, with the average cost of a cow with a sole ulcer being 216.07 (US, $). And although only DOD known as alarm lesions are associated with pain and subsequent lameness (Kofler, 2021), the detrimental effects of all DOD on cattle welfare (Whay and Shearer, 2017), are beyond controversy.

Long-term DH improvement and a reduction in DOD prevalence are urgently needed. Electronic documentation of routinely collected DH data allows for effective surveillance of DOD in dairy cattle, which is why software applications have been launched in several countries to assess the current DH status of a herd (e.g., Klaue in Germany, Klauenmanager in Austria or Digiklauw in

Received May 5, 2024.
Accepted December 4, 2024.
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The list of standard abbreviations for JDS is available at adsa.org/jds-abbreviations-24. Nonstandard abbreviations are available in the Notes.

the Netherlands) (Kofler, 2013a). The 3 main functions of these similarly structured software applications are the electronic documentation of DH data, the tracking of DH development, and the recording of therapies performed. Additionally, some countries including Austria (Kofler et al., 2022), Germany (Lindena and Hess, 2022), Sweden (Sandgren et al., 2009) and Denmark (Nielsen, 2018), have extended their DH and animal welfare monitoring programs by comparing individual farms using a benchmarking system to increase awareness and enhance farmers' motivation (Sumner et al., 2020). In Switzerland, the DH monitoring and benchmarking project "Healthy claws - the foundation for the future" was launched by the Swiss Federal Office for Agriculture in 2019 (Huber et al., 2021; Jury et al., 2021; Strauss et al., 2021; Bayer et al., 2023; Fürmann et al., 2024). Extensive data collection across Switzerland provides a foundation for systematic analysis to enhance veterinary consulting and treatment plans. DOD in dairy farms arise from complex factors, with some contributors likely unknown. Addressing these gaps requires research into unidentified factors and subsequent targeted consulting by veterinarians. Similar data sets have successfully supported calf health programs (Lava et al., 2016a; b; Becker et al., 2020).

The aims of the present study, consisting of parts A and B, were (A1) to assess the evolution of DH in herds in which professional on-farm risk assessments were conducted and veterinary advice was given, and to compare it to that in herds without on-farm risk assessments and veterinary advice; (A2) to examine whether the percentage of implemented measures was associated with the evolution of DH; and (A3) to explore whether the evolution of DH of a herd was associated with the predominant DOD category of the respective herd. The aim of part B of the study was to investigate herd-level risk factors for DH. We hypothesized regarding DH, (A1) that farms receiving professional advice would significantly outperform those that did not; (A2) that DH would more significantly improve on farms implementing a higher percentage of recommended measures than on farms implementing lower percentages; and (A3) that farms experiencing mainly infectious DOD would improve significantly more than farms with non-infectious DOD. The hypothesis for part B of the study was that risk factors that are significantly associated with the evolution of DH on herd-level can be identified.

MATERIALS AND METHODS

Ethical approval was granted by the competent authority of the Canton of Bern, Switzerland (approval number: BE 2022–12–21), and written informed consent was obtained from all participating farmers for the use of anonymized production and health data for research purposes and publication.

Data Collection

DOD data were collected between January 01, 2020 and June 30, 2023. The professional claw trimmers participating in the DH program were required to have a valid license and successfully completed an advanced training (Strauss et al., 2021). The latter introduced claw trimmers in DOD assessment using the classifications of the ICAR Claw Health Atlas (Egger-Danner et al., 2020c) and its appendices (Egger-Danner et al., 2020a; 2020b). A total of 44 claw trimmers who achieved sufficient agreement (κ-values ≥0.6) with the instructing veterinary specialists during a final assessment were recruited for the study. They were subsequently offered annual continuing education courses covering current topics such as DOD allocation, claw trimming techniques, and recommendations for therapeutical and biosafety measures during claw trimming (Strauss et al., 2021; Weber et al., 2023).

DH data had been recorded electronically using the software application KLAUE (dsp-Agrosoft GmbH, Ketzin/Havel, Germany) on a tablet PC (Pokini Tab FS 12; EXTRA Computer GmbH, Giengen-Sachsenhausen, Germany) since the beginning of the DH program in 2019. The KLAUE app stores definitions and illustrations of DOD with corresponding severity degrees based on the ICAR Claw Health Atlas and its appendices (Supplementary Table 1). DOD documentation guidelines and the advanced training for claw trimmers ensured standardized data recording on-site. Additionally, a digital questionnaire in KLAUE addressing questions about certain farm characteristics (e.g., production type, housing type, floor type or type of cubicles) was completed by the claw trimmers during the initial trimming session of each herd. The recorded data was exported to a central storage platform programmed and managed by Qualitas AG, the competence center for informatics and quantitative genetics for Swiss breeding organizations. Participating claw trimmers received an expense allowance of $0.34 per each complete data set submitted (DH data of all 4 feet) for routinely trimmed cattle.

The following data was extracted from the central storage platform: claw trimming data and supplementary information for the risk factor analysis on (i) digit health scores, (ii) housing conditions, (iii) herd size, (iv) predominant breed, (v) mean number of trimmed animals, (vi) mean age of trimmed animals, and (vii) current implementation status of recommended measures (if applicable). Information on RAUS program participation (i.e., a government-funded voluntary program for improved animal welfare, assuring that cows are granted regular outdoor access [Federal Office for Agriculture, 2023]) was obtained from the national livestock register. Geographical zones referring to the topographic location of the farm (divided into valley area (including valley zone and hill zone) as well as mountain area (including mountain zones I - IV)) and milk yield data (reported for each cow as mean kg per day for the entire observation period) were provided by breeding organizations. If records were missing, complementary information was obtained by phone conversation with the farmers. To generate data sets representing the general DH status of enrolled herds, only data from routine trimmings (meaning ^{3} 80% of the cattle ≥24 mo of age of a herd trimmed during the respective trimming event or within +/− 7 d) were considered (Charfeddine et al., 2016; Solano et al., 2016). Correspondingly, data collected during therapeutic trimming visits or visits for the follow-up treatment of DOD were excluded.

Definitions and Calculations of Digit Health Scores

Trimming data was imported from the KLAUE app, and the Farm-Claw-Score (FCS) was calculated according to Kofler et. al. (2023) with some minor adaptations in the geometric severity scores, as shown in Supplementary Table 1. The geometric severity scores are an assessment method to account for the greater clinical relevance of more severe DOD (Greenough and Vermunt, 1991). The sum of the geometric severity scores of all claws of a cow results in the Cow-Claw-Score (CCS). In contrast to Kofler et al. (2013), instead of the median CCS, the arithmetic mean of all CCSs was used. Therefore, the sum of all CCSs divided by the number of documented cows then provides the FCS of a herd. All DOD described in the ICAR Claw Health Atlas (Egger-Danner et al., 2020c) and its appendices (Egger-Danner et al., 2020b; a) as listed in Supplementary Table 1 were considered for the calculation of the FCS. (Kofler, 2013b)

In addition to the FCS, 2 separate DH sub-scores were calculated exclusively in the context of the DH program, i.e., the Mechanical-Metabolic-Farm-Claw-Score (MMFCS) and the Digital-Dermatitis-Farm-Claw-Score (DDFCS). These DH sub-scores were calculated using the same prerequisites as mentioned above and in the same manner as the FCS, except for the limited number of disorders considered: For the MMFCS, these were double sole (DS), white line fissure/abscess (WLF/WLA), sole hemorrhage diffused form/circumscribed form (SHD/SHC), sole-/, bulb-/, toe ulcer (SU/BU/TU), toe necrosis (TN), concave dorsal wall (CD), axial horn fissure (HFA), horizontal horn fissure (HFH), vertical horn fissure (HFV) and thin sole (TS). For the DDFCS, these were all stages of digital dermatitis (M1, M2, M3, M4, M4.1) and all DD-associated claw horn lesions (DD-associated heel horn erosion (DD-HHE), DD-associated bulb ulcer (DD-BU), DD-associated horn fissure horizontal (DD-HFH), DD-associated horn fissure axial (DD-HFA), DD-associated horn fissure dorsal (DD-HFD), DD-associated interdigital hyperplasia (DD-IH), DD-associated sole ulcer (DD-SU), DD-associated toe ulcer (DD-TU), DD-associated white-line-abscess (DD-WLA), DD-associated toe necrosis (DD-TN)).

Farms were subsequently attributed to one of 4 complexes (differentiation was a modification of existing categorizations from the literature (e.g., Greenough, 2007; Van der Spek et al., 2013; Huxley, 2019)). For this purpose, the aforementioned sub-scores were used to determine the main disease complex of each farm at the beginning of the study, i.e., (i) individual-animal-determined and/or claw-trimming-related, (ii) mechanical-metabolic-related, (iii) infectious-related, or (iv) mixed. Table 1 displays the 4 different main disease complexes with corresponding definitions.

Evaluation of the on-Farm Evolution of Digit Health

A relative over-time progression was used to determine the evolution of DH on each farm. To calculate the relative progression of a farm, relations between FCS-1, as initial value, and every subsequent available FCS were calculated separately. FCS-1 refers to the score from the first routine trimming performed during the study. Subsequent FCSs were assigned ascending numbers (FCS-2, FCS-3, …, FCS-*i*). The same numbering principle was used for the MMFCS and DDFCS. FCSs from at least 2 routine trimmings were required per farm to calculate at least one relation. This means that if FCSs from 4 routine trimmings were available, 3 corresponding relations were calculated (FCS-2/FCS-1; FCS-3/FCS-1; FCS-4/FCS-1). Values below 1.0 indicate an improvement, whereas values above 1.0 indicate a deterioration of DH on a farm. Farms were visited 2 to *i* times. Mean duration of participation of each individual farm was calculated using the mean of intervals (days) between first and subsequent data collection events.

Study Structure

The study was divided into 2 parts (A and B) to address our hypotheses. Two subpopulations were created: The subpopulation of Part A contained farms which received professional veterinary on-farm risk assessments, individual advice and supervision (case farms), and corresponding control farms (selection process will be described in the section "Selection, Stratification and Frequency Matching of Control Farms"); the subpopulation of Part B contained all farms in the DH program fulfilling the criteria as described in "data collection."

Table 1. Part A3: Definitions of four main disease complexes; based on two digit health sub-scores, farms were attributed to complexes according to the main underlying causes of the most prevalent disorders of the digits

Main disease complex	Definition
Individual-animal-determined and/or claw-trimming-related	MMFCS[1]-1 + DDFCS[2]-1 £ 40% of FCS[3]-1[4]
Mechanical-metabolic-related	MMFCS-1 > 50% of FCS-1
Infectious-related	DDFCS-1 > 50% of FCS-1
Mixed	MMFCS-1 + DDFCS-1 > 40% of FCS-1 but MMFCS-1 < 50% and DDFCS-1 < 50% of FCS-1

[1]Mechanical-Metabolic-Farm-Claw-Score.

[2]Digital-Dermatitis-Farm-Claw-Score.

[3]Farm-Claw-Score.

[4]Numbering: 1 refers to the score deriving from the first routine trimming of the respective farm considered in the study. Subsequent FCSs are then assigned ascending numbers (FCS-2, FCS-3, …, FCS-*i*). The same numbering applies to the MMFCS and DDFCS.

Part A – Evaluation of Farms Participating in the Digit Health Program

Part A was designed as a non-randomized controlled implementation study that addressed 3 main questions. Part A1 investigated whether the relative over-time progression of FCSs from case farms was significantly different from that of control farms. In part A2, the association between the percentage of measures implemented on-farm and the relative over-time progression of the FCSs was examined. Part A3 assessed whether the main disease complex present at the beginning of the study was associated with the relative over-time progression of a case farms' FCSs. For A2 and A3, only case farms were considered.

Case farms were selected through a screening process. To this end, all DH data from routine trimmings on farms in the DH program was evaluated on a monthly basis, and farms were ranked using their latest FCS. A free voluntary on-farm risk assessment was offered to the farms with an FCS exceeding the 90th percentile of the participating farms. Additionally, farms that voluntarily contacted the team with a request for an assessment were visited, even if their FCS did not exceed the 90th percentile, to ensure that all participating farms could benefit from the services offered by the DH program.

Farm visits were conducted based on previously published protocols (Alberta Milk, 2016; van Huyssteen et al., 2020) as on-farm risk assessments. Data relating to the farm in general (i.e., production type, housing type, standard labor units), the management (i.e., feeding regimen, milking routines, preventive measures), the housing conditions (i.e., flooring properties, type and dimensions of cubicles), and individual animals (i.e., cleanliness, body condition score, lameness, claw conformation) were collected. Suitable measures to improve DH were identified and communicated to each farmer in a written report after every visit. The implementation of the recommended measures was either checked by the claw trimmer during the subsequent routine trimming or by the herd veterinarian in charge via a follow-up visit one year after the initial visit. The implementation status of the recommended measures had not yet been checked on all farms by the end of the study period; farms with unknown implementation status of measures were excluded from the corresponding analyses.

Selection, Stratification and Frequency Matching of Control Farms. Potential control farms were defined as farms voluntarily participating in the DH project that had not been visited by the team and thus no on-farm risk assessment had been performed.

To match suitable control farms to case farms, we opted to create 3 distinct strata within the group of case farms. Stratum 1 consisted of all case farms with an FCS-1 ≤ 30.0, Stratum 2 consisted of all case farms with an FCS-1 > 30.0 to ≤45.0, and Stratum 3 contained all case farms with an FCS-1 > 45.0.

Following the stratification of the case farms, a frequency matching of the control farms was performed according to Gail (2014) and Diehl et al. (2021). The aim was to create control strata whose mean FCS-1 did not differ substantially from the corresponding case strata. As described earlier the FCS-1 refers to the score deriving from the first study-relevant routine trimming. Our matching criteria for FCS-1 of control farms were that (i) FCS-1 must lie in the same stratum as that of the matched case farm (stratum 1: FCS-1 ≤ 30.0, stratum 2: FCS-1 > 30.0 to ≤45.0 or stratum 3: FCS-1 > 45) and (ii) the data underlying FCS-1 must have been collected during a routine trimming performed in the same 6-mo period of the same year as that of the respective case farm. The second criterion was chosen mainly to account for the different climatic conditions within and among years, which may favor different DOD.

Data Management and Statistical Analyses

A1 - Comparison of the relative over-time progression of FCSs in case and control farms No suitable control farms could be identified for stratum 3, as all farms with an FCS-1 exceeding 45 had undergone on-farm risk assessment. For adequate comparability, only the relations of stratum 1 and stratum 2 of case farms and control farms were included in this analysis.

A2 - Comparison of the relative over-time progression of FCSs in case farms with ≤ 50% versus > 50% of recommended measures implemented All 3 strata of case farms were included, as on-farm risk assessments were conducted and measures recommended in all case farms. Case farms were divided into 2 groups: Group 1 farms implemented ≤50%, and group 2 farms implemented >50% of the recommended measures. The execution of the recommended measures was either checked by the claw trimmers during the subsequent routine trimming or by the responsible herd veterinarian during a follow-up visit. Information on the current implementation status was then transmitted either by the KLAUE software or by e-mail. The latest implementation status was used for the analyses.

Comparison of the relative over-time progression of FCSs from case farms depending on the main disease complex present at the entrance in the study (A3) For this analysis, all case farms were assigned to a group according to the definitions in Table 1.

For descriptive statistical calculations and production of figures NCSS (https://www.ncss.com/) was used. Analytical statistical calculation were performed using lme4 package of R Studio (R Core Team, 2018, Vienna, Austria; https://www.r-project.org/). Strata were not considered in the statistical analyses, because the stratification was used only for the selection of appropriate control farms. For each analysis, an appropriate model was selected to answer the specific question. Concerning Part A of the study (A1-A3), univariable linear mixed models were used, with the values of the relative progression being the outcome. As stated earlier the relative progression of a farm was calculated, by creating the relations between FCS-1, as initial value, and every subsequent available FCS separately. To address for unequal potential of improvement of farms starting at different levels of DH (farms with high FCS-1 vs. farms with low FCS-1) the relative progression rather than the absolute was chosen in all analyses.

To account for hierarchically structured data, a random effect for farm was included in each model. The level of significance for the models was set at $P \leq 0.05$. For A1, the explanatory variable offered to the model was adherence to group (case or control). For A2, it was implementation of measures (≤50% vs. > 50%). For A3, it was the type of main disease complex.

Part B – Risk Factor Analysis

Part B of the study consisted of a retrospective observational risk factor analysis to identify factors at herd-level associated with the evolution of DH. Unlike for Part A of the study, a modified data set was used for Part B. The largest possible subpopulation was selected to investigate associations of potential predictors with the relative progression of a farm's FCS. All general inclusion criteria mentioned for Part A also applied to this part of the study. Only data from dairy herds with complete milk records were used. Thus, farms that did not belong to a breeding association and those that kept the Eringer breed (meat breed) were excluded. The detailed 4-step farm selection process is illustrated in Supplementary Figure 1. Twelve potential predictors were predefined, and their descriptions are shown in Supplementary Table 2.

Data Management and Statistical Analyses. The relations of FCSs for each farm were calculated as described above. If the FCS-1 of a farm was 0.0, the subsequent FCS with a positive value was defined as the starting point since the farms should only be evaluated prospectively after the time point when a DH problem occurred. Relations with a value above 10 (i.e., 10-fold deterioration between consecutive data collection events) were treated as outliers to fulfil model assumptions and were therefore excluded from the analysis. A total of 12 relations originating from 7 farms were excluded to do them being erroneous (either entry errors or data from follow-up visits not qualifying as study visits). For descriptive statistical calculations and production of figures NCSS (https://www.ncss.com/) was used. Analytical statistical calculation were performed using lme4 package of R Studio (R Core Team, 2018, Vienna, Austria; https://www.r-project.org/). Categorical variables were described by frequency distributions. Farms were visited 2 to *i* times. Mean duration of participation of each individual farm was calculated as the mean of intervals (days) between first (FCS-1) and subsequent data collection events (FCS-*i*). The outcome was defined as the relative progression of the FCSs. To achieve normal distribution of the data, several transformations were tested (cubic, square root, and logarithmic), of which logarithmic transformation of the values of relative change resulted in the best fit. Normality distribution was checked visually and confirmed by using the Kolmogorov-Smirnov test for normality. For modeling, we accounted for the hierarchical structure of the data using random effects for claw trimming and farm. Outcome of interest was numerical, and each explanatory variable was analyzed in a linear mixed model. Only variables showing P-values <0.2 and revealing no collinearity were included for further analysis. Potential correlations were checked using mean square

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contingency coefficient phi (cutoff phi = 0.6). A linear mixed model was built in a stepwise backward elimination procedure. Subsequently, homogeneity of variance and normality of the residuals were observed. Model results were presented in estimates with the respective 95% confidence interval (95% CI). The level of significance for the models was set at $P \leq 0.05$.

RESULTS

Overall, data from 926 Swiss farms were available for scientific evaluations. A total of 145 farms in the DH program were visited by the team.

Part A

Of the 145 farms visited, 75 met all required inclusion criteria and were selected as case farms. When stratifying case farms, 11 were assigned to stratum 1, 41 to stratum 2 and 23 to stratum 3. A total of 49 control farms were identified. Of those, 11 were assigned to stratum 1 and 38 to stratum 2. A descriptive representation of all FCSs and associated relations for the 75 case farms and the 49 control farms is shown in Table 2.

Herd Characteristics. The characteristics of the case-control farms are shown in Table 3. Of the 124 farms included, the majority of cows were kept in freestalls (n = 60; 80.0% case farms, respectively, n = 34; 69.4% control farms). Sixty-eight (90.7%) case farms and 43 (87.8%) control farms were members of a breeding organization. Holstein Friesian was the predominant breed in both groups, but the dominance in the case farms (n = 59; 78.7%) was markedly more pronounced than in the control farms (n = 22; 44.9%). The median herd size in Switzerland was 35 cattle (Identitas AG, 2023). Large farms with more than 60 cattle were overrepresented in case farms (n = 39; 52.2%) and control farms (n = 20; 40.8%). Claws were routinely trimmed once a year on 17 farms, twice on 82 farms and 3 times on 25 farms.

Comparison of the relative over-time progression of FCSs in case and control farms (A1). The evolution of DH in strata 1 and 2 of the case farms (n = 52) was compared with the one of the control farms of the corresponding strata (n = 49). We observed no significant difference (estimate: 0.04, SE = 0.06, $P = 0.45$) in the relative over-time progression of case versus control farms. Nevertheless, a general tendency for improvement of the relative over-time progression of the FCSs is visible for both case and control farms, as all relations below 1.0 indicate an improvement (see Figure 1).

Comparison of the relative over-time progression of FCSs in case farms with ≤50% versus >50% of recommended measures implemented (A2). Of the 75 case farms, 14 were excluded from this analysis as the implementation status of recommended measures was unknown at the end of the study period. The relative improvement of FCSs was significantly higher (estimate: −0.15, SE: 0.07, $P = 0.03$) in the group of farms that implemented >50% of the recommended measures (n = 25) compared with those that implemented ≤50% (n = 36). Effect size was medium (0.28).

Comparison of the relative over-time progression of FCSs from case farms depending on the main disease complex present at the entrance in the study (A3). Eight farms were attributed to the group with a mechanical-metabolic main disease complex, 47 farms to the infectious-related main disease complex, and 20 farms to the mixed disease complex. None of the case farms were assigned to the group "Individual-animal-determined and/or claw-trimming-related main disease complex." The relative over-time progression of the case farms was significantly associated with herds suffering from the main disease complex 'infectious-related' (reference; mechanical-metabolic-related, estimate 0.23, SE = 0.1, $P = 0.02$; mixed −0.12, SE = 0.1, $P = 0.07$).

Part B

A total of 498 dairy farms participating in the DH program (53.7%) were analyzed, providing 1772 FCSs. A descriptive representation of all FCSs and associated relations for the farms included in Part B are presented in Table 4. In 2 of the 498 farms, the FCS-1 was 0.0, thus the following FCS >0 was considered as starting point. Relations from 7 farms were excluded because they had been identified as outliers.

In the univariable analysis, 5 of the 12 variables examined proved to be significant at $P \leq 0.05$ for an association with the relative over-time progression of the FCSs over the mean interval from FCS-1 to FCS-i (Table 5).

Results of the final linear mixed models are presented in Table 6. In the multivariable model, 4 of the investigated variables were significantly associated with the outcome. By each interval, the value of FCS-1 was higher, a relative improvement in the FCSs of 2% (95%-CI: 2% - 1%) was achieved over the mean interval from FCS-1 to FCS-i. Concerning the duration of participation in the DH health program, for each 365-d interval, the farms' FCSs relatively improved by 14% (95%-CI: 17% - 10%). Both, farms with freestall systems and farms with tiestall systems showed a decrease of the FCS over time. Farms with freestall systems showed a decrease of FCSs that was 19% (95%-CI: 6% - 32%) lower compared with farms with tiestalls. Farms in the valley area showed a decrease of FCSs that was 25% (95%-CI: 11% - 40%) lower compared with farms located in the mountain area. In comparison with farms keeping other breeds, farms with predominantly Holstein Friesian cows showed a

Table 2. Part A: Descriptive representation of 300 Farm-Claw-Scores (FCS) and 225 associated relations for the 75 case farms (3 strata) and of 181 FCS and 132 associated relations for the 49 control farms (2 strata) included in Part A of the study

FCS[1]	n[2]	Mean	Median	Min-max	SD[3]	Relation[4]	n	Mean	Median	Min-max	SD
Case Farms (n = 75)											
1	75	42.5	38.3	17.9 – 128.6	16.3						
2	75	31.2	27.6	4.5 – 102.1	16.7	1	75	0.74	0.74	0.15 – 1.82	0.33
3	59	30.7	28.3	8 – 65.8	13.9	2	59	0.72	0.66	0.28 – 1.59	0.29
4	42	26.5	22.5	4.3 – 72.9	14.8	3	42	0.60	0.55	0.12 – 1.44	0.29
5	25	28.7	22.8	10.4 – 78.2	17.9	4	25	0.60	0.49	0.18 – 1.18	0.29
6	17	29.5	22.5	11.9 – 47.2	13.2	5	17	0.60	0.50	0.23 – 1.93	0.40
7	6	30.0	26.25	11.8 – 58.4	17.0	6	6	0.73	0.67	0.35 – 1.39	0.38
8	1	55.1	55.1	55.1		7	1	1.31	1.31	1.31	
Control Farms (n = 49)											
1	49	32.9	31.8	20.1 - 44	5.8						
2	49	24.0	21.4	7.7 – 63.7	11.0	1	49	0.74	0.69	0.25 – 2.10	0.36
3	42	18.5	16.3	0 – 82.4	14.1	2	42	0.57	0.49	0.00 – 2.29	0.41
4	19	19.4	16	4.7 – 65.6	13.0	3	19	0.56	0.49	0.13 – 1.49	0.32
5	13	17.8	12.7	0 - 40	12.8	4	13	0.52	0.41	0.00 – 1.16	0.34
6	7	15.9	14.3	4.9 – 22.8	6.5	5	7	0.49	0.47	0.17 – 0.67	0.20
7	2	15.35	15.35	13.9 – 16.8	2.1	6	2	0.53	0.53	0.44 – 0.62	0.12

[1]Farm-Claw-Score.

[2]Total number of available values.

[3]Standard deviation.

[4]To calculate the relative progression of a farm, relations between FCS-1, as initial value, and every subsequent available FCS were calculated separately.

12% (95%-CI: −1% - 26%) lower decrease of FCSs (*P* = 0.06).

DISCUSSION

To the best of our knowledge, this is the first study dealing with the long-term follow-up of farms participating in a DH program and tracking the evolution of their DH. The timing of the current study was intentional, as the nationwide DH program was running in its fifth and penultimate year. At this point, data from a large number of dairy farms was available (Kofler et al., 2022).

The most important findings from Part A of the study are that herds suffering from DOD related to the infectious disease complex improved substantially compared with herds suffering from mechanical-metabolic-related DOD, and that measures issued by DH experts have the potential to lead to improvement of DH if they are implemented appropriately. On the other hand, in Part B of the study, 5 potential predictors at herd level were identified. Greater relative improvement of DH over the study period was associated with a (i) higher FCS-1 and (ii) longer duration of participation in the DH program. Less relative improvement of DH over the study period was associated with (iii) freestalls, (iv) the location of farms in the “valley area” and herds with (v) Holstein Friesian cows as predominant breed.

Calculations of Digit Health Scores

For the calculation of CCS and the corresponding FCS, our modified approach based on Kofler et al. (2013) had the advantage of reducing the risk of underestimating affected farms and, therefore, neglecting cows with high CCS. Both, using the mean and median are valid approaches for statistical analysis, but their application depends on the specific goals of the study. Using the mean to calculate the FCS prevents farms with a small proportion of cows exhibiting severe DOD from being misclassified as healthy. While calculating the mean may shift the FCS slightly compared with the median, this distortion applies consistently across affected farms. Given the increasing societal emphasis on high welfare standards and antimicrobial-free farming in Switzerland, our use of the mean instead of the median supports more targeted interventions for farms with severe DOD.

Part A

Comparison of the relative over-time progression of FCSs in case and control farms (A1). Contrary to expectations, this study did not find a significant difference of DH evolution between case farms with on-farm risk assessment and respective individual advice given after supervision compared with control farms without risk assessment and advice given. In both groups, a general trend toward improved DH over time was observed. This result may be explained by the fact that voluntary participation in the DH program by itself is sufficient stimulus

Table 3. Characteristics of 75 case and 49 control farms included the analyses (A1-A3) of Part A of the study

Herd characteristic	Farms (n/N; %)[1]	
	Case	Control
On-farm risk assessment[2]	75/75; 100	0/49; 0
Measures recommended[2]	75/75; 100	0/49; 0
Breeding association		
Swissherdbook	47/75; 62.7	14/49; 28.6
Braunvieh Switzerland	11/75; 14.7	19/49; 38.8
Holstein Switzerland	10/75; 13.3	10/49; 20.4
Non-herdbook	7/75; 9.3	6/49; 12.2
Farm size[3]		
≤30	8/75; 10.7	13/49; 26.5
>30 up to 60	28/75; 37.3	16/49; 32.7
>60	39/75; 52.2	20/49; 40.8
Housing system		
Tiestall	15/75; 20.2	15/49; 30.6
Freestall	60/75; 80.0	34/49; 69.4
Routine trimming[4] frequency per year		
n = 1	9/75; 12.0	8/49; 16.3
n = 2	54/75; 72.0	28/49; 57.1
n = 3	12/75; 16.0	13/49; 26.5
Predominant breed		
Holstein Friesian	59/75; 78.7	22/49; 44.9
Brown[5]	8/75; 10.7	15/49; 30.6
Swiss Fleckvieh	6/75; 8.0	8/49; 16.3
Other[6]	2/75; 2.7	4/49; 8.2
Farm-Claw-Score (FCS)		
FCS-1		
FCS-1 ≤ 30	11/75; 14.7	11/49; 22.5
FCS-1 > 30 and ≤45	41/75; 54.7	38/49; 77.6
FCS-1 > 45	23/75; 30.7	0/49;0[7]
Total available FCSs[8]		
n =	300	181
Median (Q1 – Q3)	30.9 (20.95–42.35)	22.1 (14.2–31.1)
Min - max	4.3–128.6	0–82.4

[1]Applies only to categorical variables.

[2]On-farm risk assessment and recommendations were only performed on case farms.

[3]Mean farm size at trimming dates (all animals of the bovine species on the farm).

[4]Herd trim: ≥ 80% of cows trimmed.

[5]Comprises both Original Braunvieh and Swiss Brown.

[6]Includes crossbreeds and purebreds.

[7]No control farms available, all farms with high FCS were visited.

[8]Metric variable.

Q1 = 25th percentile; Q3 = 75th percentile.

to raise farmers' awareness of DH. A complementary explanation is that the claw trimmers who performed regular trimmings on the participating farms passed on their expertise to the farmers, regardless of whether the farm belonged to the case or control group. This explanation would further support the findings of Ellis-Iversen et al. (2010) and Bruijnis et al. (2013) who reported that farmers were more likely to implement recommended changes when motivated by a trusted advisor, e.g., the farm veterinarian or the claw trimmer, rather than by the government (veterinarians of this governmental DH program). Furthermore, all participating farms benefited from the advantages of electronic documentation of DOD. This enabled farmers to continuously monitor DH on their own farms, to compare it to that on other participating farms (benchmarking), and thus to identify DOD at an early stage.

Comparison of the relative over-time progression of FCSs in case farms with ≤50% versus > 50% of recommended measures implemented (A2). Another important finding of the study was that farms implementing more than half of the recommended measures showed significantly greater improvement over time. It can, therefore, be assumed that measures proposed by the DH experts, if properly implemented, did have the desired effect on DH. Since only 25 of the 61 case farms implemented more than half of the recommended measures, the question arises as to why the other 36 farms did not do so. Specific given farm characteristics may favor successful implementation of suggested measures. Therefore,

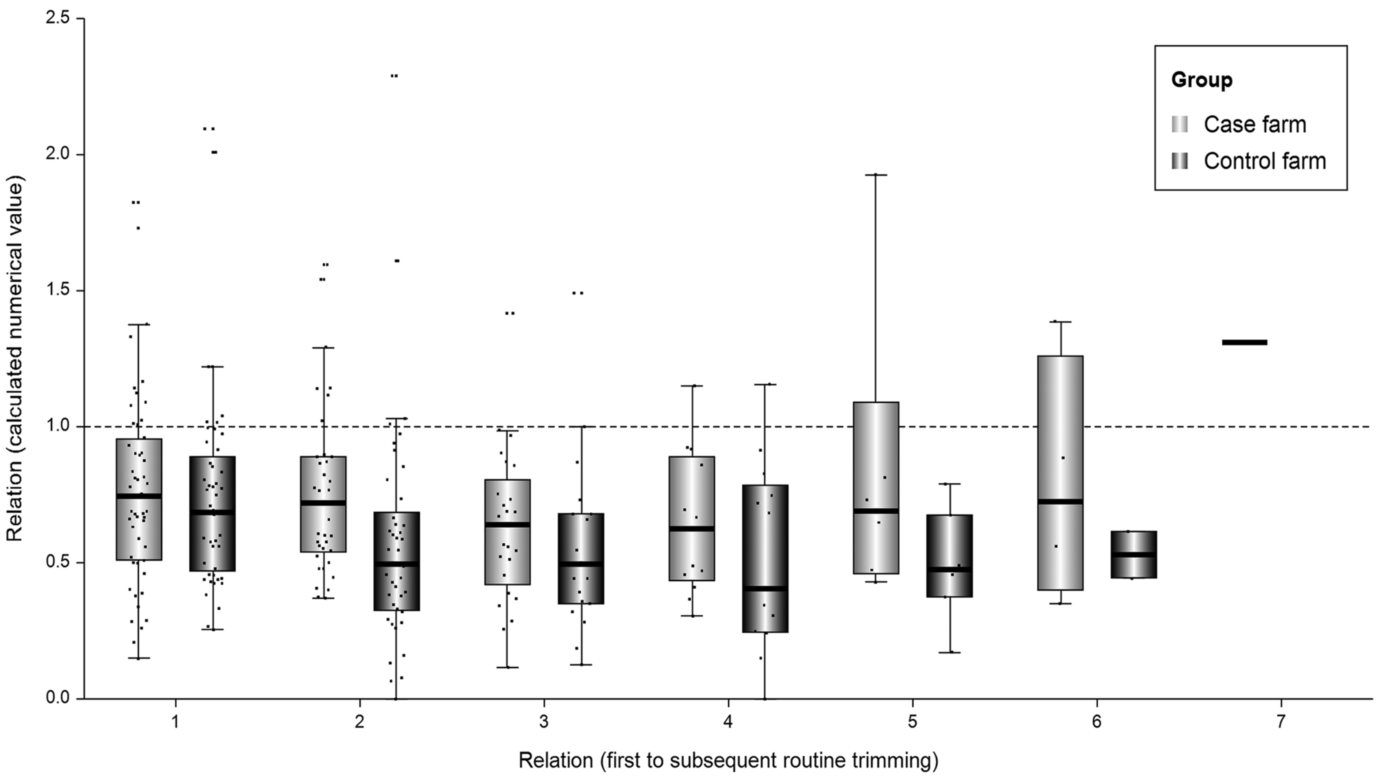

Figure 1. Box and dot plots illustrating the relative over-time progression of digit health of 52 case farms and 49 control farms participating in a nationwide digit health program.

the list of suggestions for measures had been discussed with the farmer, and only measures deemed feasible by the farmer to be implemented were listed. Nevertheless, farmers' compliance and awareness of the importance of sanitation of painful and economically relevant DOD must be given in first place. It must certainly also be taken into account that in farms that implemented fewer measures, reasons such as fewer well-trained staff or less time per staff member resulted in non-implementation of measures. An unstructured query revealed that financial or time-related factors were the main causes (data not shown), independently of the expected effect.

The relatively poor implementation rates in some case farms may also reflect the defensive attitude of farmers toward veterinarians employed by the government. Farmers in general disagree with measures that, in their

Table 4. Part B: Descriptive representation of 1772 Farm-Claw-Scores (FCS) and 1274 associated relations for the 498 farms included in Part B of the study

FCS[1]	n[2]	Mean	Median	Min-max	SD[3]	Relation[4]	n	Mean	Median	Min-max	SD
1	498	17.6	14.4	0.1 – 77.6	13.7						
2	496	14.8	11.3	0 – 67.9	12.1	1	496	1.08	0.82		1.06
3	357	14.8	11.3	0 – 63.7	12.3	2	357	0.94	0.70		0.89
4	222	14.6	12.1	0 – 65.6	11.1	3	222	0.95	0.72		0.93
5	115	15.4	12.5	0 - 75	12.7	4	115	0.85	0.66		0.88
6	58	16.9	15.6	0.6 – 47.2	11.0	5	58	0.73	0.60		0.60
7	19	19.5	17.3	6 – 58.4	13.6	6	19	0.92	0.57		0.97
8	6	20.4	9.8	3 – 55.1	21.7	7	6	0.68	0.60		0.53
9	1	4.4	4.4	4.4		8	1	0.32	0.32	0.32	
10	1	4.1	4.1	4.1		9	1	0.29	0.29	0.29	

[1]Farm-Claw-Score.

[2]Total number of available values.

[3]Standard deviation.

[4]To calculate the relative progression of a farm, relations between FCS-1, as initial value, and every subsequent available FCS were calculated separately.

Table 5. Part B – Risk factor analysis: Summary of predictors screened by univariable analyses for their association with the evolution of digit health

Variable		*P*-value
Farm-Claw-Score-1[1]		<0.001
Median (Q1-Q3)	14.4 (7.2–23.85)	
Min-max	0 – 77.6	
Digital-Dermatitis-Farm-Claw-Score-1[1]		0.045
Median (Q1-Q3)	2.2 (0–9.3)	
Min-max	0 – 52.9	
Mean duration of participation in the digit health program[1, 2]		<0.001
Median (Q1-Q3)	470 (361–579)	
Min-max	296–668	
Mean Milk yield per cow and day[1]		0.282
Median (Q1-Q3)	24.6 (21.8–27.2)	
Min-max	13.1 – 35.5	
Farm size[1]		0.089
Median (Q1-Q3)	46.3 (33.1–65.5)	
Min-max	8 - 251	
Mean Age (years)[1]		0.806
Median (Q1-Q3)	5.09 (4.94–5.24)	
Min-max	4.12 – 6.63	
	Farms (n/N[3]; %)	
Label RAUS		0.478
No	35/498; 7.0	
Yes	464/498; 93.2	
Housing System		0.002
Tiestall	225/498; 45.2	
Freestall	274/498; 55.0	
Geographical Zone		0.002
Mountain area (zone I–IV)	188/498; 37.8	
Valley area (valley zone + hill zone)	311/498; 62.4	
Predominant breed		0.090
Other	296/498; 59.4	
Holstein Friesian[4]	203/498; 40.8	
Claw trimming frequency per year		0.155
≤1	68/498; 13.7	
>1 to <2	180/498; 36.1	
2	136/498; 27.3	
>2	115/498; 23.1	
Main disease complex[5]		0.944
Individual-animal-determined and/or claw-trimming-related	114/498; 22.9	
Mechanical-metabolic-related	150/498; 30.1	
Infectious-related	130/498; 26.1	
Mixed	105/498; 21.1	

Q1 = 25th percentile; Q3 = 75th percentile; RAUS = regular access to outdoor areas.

[1]Metric variable.

[2]Farms were visited two to *i* times. Mean durations of participation were calculated as follows: mean of intervals (days) between first and respective subsequent data collection events. For modeling, hierarchical structure of claw trimming to farms was accounted for, using random effects.

[3]n = Proportion of farms to which the scheme applies; n = total number of farms.

[4]Animals of both Holstein Friesian and Red Holstein breeds included.

[5]Classification according to description in *Definitions and Calculations of Digit Health Scores*.

Table 6. Part B – Risk factor analysis: Results of final linear mixed models of predictors associated with the evolution of digit health in 498 Swiss dairy farms participating in a digit health program

Variable	Estimate (95% CI[2])	P-value
Farm-Claw-Score-1[1] (Interval = 1.0)	0.98 (0.98- 0.99)	<0.001
Duration of participation in the digit health program[1] (Interval = 365 d)	0.86 (0.83–0.90)	<0.001
Housing System: Freestall (Ref: Tiestall)	1.19 (1.06–1.32)	0.002
Geographical Zone: Valley area (Ref: Mountain area)	1.25 (1.11–1.40)	<0.001
Predominant Breed: Holstein Friesian (Ref: other)	1.12 (0.99–1.26)	0.063

[1]Metric variable.

[2]95% confidence interval.

opinion, do not make sense, but their attitude toward measures are considerably influenced by the person proposing them (Moya et al. (2021). Similar studies (Wassink et al., 2010; Bruijnis et al., 2013) provide more reasons for the moderate intention of farmers to improve DH, such as (i) satisfaction with the current situation, (ii) mismatch between measures proposed and actual farm management, (iii) fear that additional costs would incur and work routines would have to be changed, but also (iv) farmers' belief that they have already done plenty and that more action would not result in enough improvement in DH to justify the investment of time, money or labor. In addition to farmers' defensiveness, veterinarians and farmers often differ in terms of problem perceptions in relation to DH. For example, farmers seem to underestimate the extent of lameness and its impact on the productivity of their cows (Leach et al., 2010a), reducing the perceived need for intervention. In addition, participation in our DH program and compliance with the recommended measures was voluntary and there was no economic incentive to implement measures. Last but not least, we assume that some measures were initially implemented but neglected or abandoned over time, an effect that has also been described for the implementation of biosecurity measures against bovine paratuberculosis (Klopfstein et al., 2021).

Comparison of the relative over-time progression of FCSs from case farms depending on the main disease complex present at the entrance in the study (A3). According to our hypothesis, the main disease complex present at the beginning of the study was significantly associated with the evolution of DH. This is plausible since measures to control mechanically induced DOD tend to be very time-consuming and cost intensive (e.g., structural improvements leading to better cow traffic, avoidance of dead ends and narrow passages forcing sharp turns, elimination of slippery or abrasive floors and rough surfaces (Weaver et al., 2018)).

Part B

Farm-Claw-Score-1. One key finding was that farms with higher FCS-1 have a greater potential for improvement over time. The magnitude of the predictor was considerable. For example, if the FCS was 20% higher, this would be associated with a 40% relative improvement. This result was expected and may be explained by the fact that on farms struggling with many DOD, even minor adjustments in management result in substantial success, while only more extensive measures lead to further improvements on well-managed farms. Furthermore, the first obvious successes can help motivate the farmer to make further adjustments and thus gradually improve. However, this result also indicates that the transfer of knowledge, whether through claw trimmers or through team members visiting individual farms, seems to have worked well, so that even farms which initially disadvantageous DH were able to improve over time.

Duration of participation in the digit health program. Another important finding of the current study was that the longer a farm was involved in the DH program and, as a consequence, the longer its DH data was recorded electronically, the more favorably its DH developed. The relative improvement by 14% per year of enrollment across all farms is promising, pointing out that making farmers aware of health issues may be associated with improved DH. To ensure that achievements made during the DH program can be sustained long-term, the herd-level risk assessment protocol for mechanical-metabolic-related DOD and resulting lameness (Vetsuisse-Faculty, 2022) is now publicly available.

Housing system. The ratio of tiestalls to freestalls represented in this analysis roughly reflects the overall distribution of housing systems in Switzerland (Federal Statistical Office, 2023). Compared with farms with tiestalls, farms with freestalls showed significantly less improvement of DH over time. Regarding infectious DOD, this finding is in line with Weber et al. (2023) who found that pathogen transmission may be lower in cows kept in tiestalls because they tend to have better lower leg hygiene (Ostojić-Andrić et al., 2011), are usually tied to the same spot, and because there tend to be fewer animals in tiestalls than in freestalls. With respect to mechanical DOD, confinement in one spot and resulting restriction of movement may also limit the impact of shear forces, explaining, for example, why WLF/WLA appears to be less common in tiestalls (Sogstad et al., 2005; Cramer et al., 2008; Solano et al., 2016; Fürmann et al., 2024). Last but not least, much of the work is still done by hand in traditional tiestalls, making the implementation of management measures easier than in modern, highly automated freestalls. Although being a predictor for relative improvement of DH of high magnitude, transitioning from freestalls to tiestalls is very impractical and may entail welfare issues typical for that housing system.

Geographical zone. One unanticipated finding was that farms located in mountainous areas were able to improve DH significantly more efficiently than farms located in valley areas. Data from the Federal Statistical Office's Farm structure census for 2022 show that farms in valley areas are generally larger than farms in mountainous areas. Despite the professionalization hypothesis (Lindena and Hess, 2022), which suggests that larger farms are generally more professionalized at management level, larger farms often employ unqualified workers (Spiller et al., 2015) and tend to have fewer staff per animal (Robbins et al., 2016). We assume that on smaller farms, where the farm manager takes care of the animals himor herself, animal observation capacity is less likely to be overstrained. This contrasts with employees on large farms whose workday is over when working time has elapsed and not necessarily when all the work is done. These circumstances could lead to a negative impact on the provision of individualized animal care on larger farms and may explain our result. These circumstances could lead to a negative impact on the provision of individualized animal care on larger farms. The magnitude of our finding underlines, that social factors may play an important role for the success of health programs.

Predominant breed. Our results show indications that herds with predominantly Holstein Friesian cows improve considerably (by 12%) less efficiently over time than herds with other breeds, regardless of the efforts undertaken. When planning DH sanitation programs, this finding is of importance and may help adjust timelines depending on the predominant breed of a farm. According to Becker et al. (2014) one possible explanation for the impact of breed are differing angles of the dorsal claw wall. Holstein Friesian cows tend to have more pointed angles, resulting in lower heights of the bulb and, as a consequence, more contact surface with slurry. As a matter of fact, prior studies have suggested a genetic correlation of good feet and leg conformation with characteristics of DH (Onyiro et al., 2008; van der Linde et al., 2010). Alternatively, our result may also be explained by the higher milk yields of Holstein Friesian cows (Barker et al., 2010), although we did not observe a significant association between the progression of DH over time and higher milk yields. Our hypothesis is that larger and heavier udders of high yielding Holstein Friesian cows may result in more weight on hind claws, which in turn might influence DH, but comparative gait analyses with mobile pressure sensor systems are not yet available.

Representativeness

Compared with other studies using electronic trimming records (such as Capion et al., 2021), the amount of data exported to the central storage platform is smaller. However, this is due to the fact that our claw trimmers only submitted data to the central database from farms with a valid written consent. Thus, the results presented here may not be fully representative of the entire population of Swiss dairy herds and must be interpreted bearing this restriction in mind.

Similarly to Capion et al. (2021), there was considerable variation between claw trimmers in our study in terms of how accurately and how frequently they used the electronic recording tool. This may be because most claw trimmers in Switzerland work on a part-time basis (Strauss et al., 2021) and an individual claw trimmer's capacity is therefore limited. Further, claw trimmers' relatively high average age (e.g., 43% aged over 50 and only 17% under 30 in Strauss et al. (2021)) may explain variation and reluctance toward the electronic recording of DOD, particularly because it involves additional time for each animal. Reluctance might decrease if data recording was considered valuable/necessary and priced accordingly.

To maximize the benefit from electronic recordings in the future, it will be necessary to further increase claw trimmers' motivation to work with the existing software applications so that a constantly growing proportion of claw trimmings will be recorded, and data from them will permanently be accessible. However, it has already been described that some DOD were under-recorded (Fjeldaas et al., 2006; Capion et al., 2021) and further studies on the recording behavior of claw trimmers are needed.

CONCLUSIONS

This is the first study dealing with the long-term follow-up of farms participating in a nationwide DH program, tracking the evolution of their DH and identifying herd-level risk factors influencing its evolution over time. Our results suggest that measures issued by DH experts have the potential to lead to improvement of DH if they are implemented appropriately. Furthermore, participation in a DH program in combination with electronical recording of DH data seem to be sufficient stimuli to raise farmers' awareness, which, in turn, leads to improvement of DH. Therefore, existing national DH programs form the basis for improving DH in cattle and should serve as a role model for other countries with similar ambitions. In the future, it would certainly be beneficial for other countries to launch similar programs and to draw the necessary attention to the important issue of DH.

ACKNOWLEDGMENTS

This study was mainly funded by the Swiss Federal Office of Agriculture (project # 51) and co-funded by various sponsors (Association of Swiss Cattle Breeders, Zollikofen, Switzerland; Braunvieh Switzerland, Zug, Switzerland; Fondation Sur-la-Croix, Basel, Switzerland; Gesellschaft Schweizer Tierärztinnen und Tierärzte, Bern, Switzerland; Gummiwerk KRAIBURG Elastik GmbH & Co. KG, Waldkraiburg, Germany; Holstein Switzerland, Posieux, Switzerland; Krieger AG, Bösingen, Switzerland, Beef Cattle Switzerland, Ruswil, Switzerland; Swiss Farmers' Union, Brugg, Switzerland; Schweizer Klauenpflegervereinigung, St. Imier, Switzerland; Schweizer Milchproduzenten, Bern, Switzerland; Schweizerische Vereinigung für Wiederkäuergesundheit, St. Antoni, Switzerland; Swissgenetics; Swissherdbook, Zollikofen, Switzerland; UFA AG, Herzogenbuchsee, Switzerland; Vereinigung Schweizerischer Futtermittelfabrikanten, Zollikofen, Switzerland; Vetsuisse Faculty, University of Bern, Bern, Switzerland) as part of the project "Healthy claws - the foundation for the future."

We thank all farmers for their willingness to participate in the program and for granting us access to their facilities. Special thanks go to claw trimmers and organizations. Special thanks are also due to Prof. Dr. Gertraud Schüpbach and the Veterinary Public Health Institute of the Vetsuisse Faculty of the University of Bern for their statistical advice.

The authors confirm that there are no conflicts of interest.

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