Systematic Clinical Examinations for Identification of Latent Udder Health Types in Danish Dairy Herds

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ABSTRACT

A cross-sectional study was conducted to explore the applicability of systematic clinical examinations of udders as an additional tool for the evaluation of udder health status on dairy farms. During 2000, each of the 16 dairy farms was visited 5 times; 20 cows per farm were chosen at random at each visit for clinical udder examination immediately after milking. The clinical examination included both pathological and morphological variables. One examination per cow was included in the analysis ($n = 707$ cows). Principal component analysis (PCA) was performed in 3 steps. First, 19 variables characterizing udder and teats were analyzed (PCA 1). Second, the variables parity and stage of lactation were included (PCA 2). Finally, somatic cell count (SCC) and milk yield (PCA 3) were included. The PCA resulted in 4 components that explained 30% of the variation of the data: 1) small udder, 2) distressed udder, 3) mastitis udder, and 4) soiled udder. Variables with high positive correlation to the “small udder” were small udder shape, short teats, and first parity. Impaired teat surface, hard udder texture, and a long udder shape were related to the “distressed udder.” The “mastitis udder” was characterized by the clinical variables asymmetry between front quarters, asymmetry between hind quarters, knotty tissue, and acute clinical mastitis. Reduced milk yield and high SCC were related to the “mastitis udder,” whereas low SCC was related to the “small udder.” The “soiled udder” was related to early lactation. Including this information in the assessment of udder health may be of substantial value for data analysis in farms with suspected under-reporting of clinical mastitis.

(**Key words:** udder health, principal component analysis, clinical investigation, udder characteristics)

Abbreviation key: ECM = energy-corrected milk, MLOGSCC = mean of log-transformed SCC, MRES-MILK = mean residual of observed-expected milk yield, PCA = principal component analysis.

INTRODUCTION

Udder health is characterized by many different terms, such as reported cases of clinical mastitis, SCC on quarter or cow level, and occurrence of pathogens isolated from infected quarters (IDF, 1997). Field studies quantifying the occurrence of treated cases of mastitis may be biased because of factors related to farm management. For example, the farmer's threshold relevant to when treatment should be initiated or the veterinarian should be consulted influences the incidence rate of farmer-reported cases of clinical mastitis. A farmer's decision to treat a cow for mastitis may be determined by factors such as 1) the seriousness of symptoms, 2) characteristics of the cow, 3) infection level of the herd, and 4) preference of alternative treatments (Vaarst et al., 2002). How these factors are weighted differs from farmer to farmer. One effect is the under-reporting of mastitis in many farms; strong evidence for under-reporting of clinical mastitis has been identified in national cattle databases (Bartlett et al., 2001). Farm management can also influence test day SCC if cows with clinical or chronic mastitis are excluded from milk recordings. Quarter milk samples tested for SCC and mastitis pathogens are regarded as the most precise practice in evaluating udder health (Hamann, 2003). However, because pathogens such as *Staphylococcus aureus* are shed intermittently with milk (Sears et al., 1990), a very costly frequent quarter sampling is needed.

Received August 8, 2003.

Accepted December 19, 2003.

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Consequently, the development of more practical, precise, and cheaper methods to assess udder health on farms is needed. Systematic clinical examination of udder and teat characteristics is relatively inexpensive and may provide valuable information. Collection of such data is quite feasible, especially in herds already applying a herd health management system including other clinical recordings, e.g., body condition scoring or other paraclinical data (Markusfeld et al., 1997, Enevoldsen et al., 2000). In such herds, the marginal costs related to systematic udder examinations are low.

The overall objective of the present study was to evaluate the applicability of systematic clinical udder assessments of individual cows as a supplement to SCC and udder treatment records. The specific objectives of the study were 1) to identify types of udders of cows by using biologically meaningful combinations of systematic clinical assessments of individual cows during cross-sectional examinations and 2) to estimate the relationship between udder traits and milk yield, as a production parameter, and SCC, as a marker of inflammation.

To identify the major udder types, principal component analysis (PCA) was used to reduce the number of observed variables to a limited number of artificial variables, the "principal components."

MATERIALS AND METHODS

The Herds

Sixteen dairy farms from Southern Jutland in Denmark were selected as a convenience sample from herds enrolled in the "Kongesø Projekt" (Andersen et al., 2000). The farms were selected to represent a broad spectrum of Danish milk production units and management levels and have previously been described (Vaarst et al., 2002). The farms were visited 5 times from January to December 2000. Table 1 gives an overview of herd characteristics.

Clinical Examinations

Two veterinarians and 2 experienced and specially trained research technicians performed the clinical examinations. After the first visits to each farm, the results were discussed to increase inter- and intra-observer agreement, and the recording sheet was adjusted. The research technicians performed the clinical examinations during the subsequent farm visits. The cows were examined within 2 h after milking. During every herd visit, 20 cows were chosen at random for clinical examination from the milking herd on that day. The clinical examination was conducted based on the method described in Rosenberger (1979) and further

developed by Houe et al. (2002). In addition to udder and teat characteristics, the degree of soiling with manure of thigh, udder, and teats was recorded (Table 2). All quarters of a cow were examined. If the degree of a condition differed between quarters within a cow, the most critical condition was recorded (e.g., if poor skin quality was observed on one teat, this was the recorded result from this cow).

A total of 1578 records of 1018 cows were collected. The number of examinations per cow ranged from 1 to 5. Because of the adjustments that were made in the recording scheme after the first farm visit, records of the first farm visit were omitted from further analysis.

Statistical Analysis

Principal component analysis was performed using the factor procedure of SAS (Proc factor, SAS, 1999). The number of components to retain was determined by evaluating the eigenvalue-one criterion, the scree test, the proportion of variance accounted for, and the interpretability criteria (Hatcher, 1994). Because each observed variable contributes one unit of variance to the total variance in the data set, a component displaying eigenvalues >1 accounts for a greater amount of variance than one variable alone and is worthy to be retained. The scree test displayed 4 components with the largest eigenvalues before a visible 'break.' Further, a component was regarded as important and kept for further analysis if at least 3 variables had high loadings on that component and shared the same conceptual meaning. A factor loading greater than ± 0.35 was considered important.

A loading represents the correlation of a given variable with the underlying factor. Loadings range from -1 to +1. Principal component analysis attempts to identify a minimum number of components explaining the majority of the variation in the original data. The first component extracted in a PCA accounts for a maximal amount of total variance in the observed variables (Hatcher, 1994). Typically, the second component will be correlated with some of the observed variables that did not display strong correlations with the first component. Further, the second component is not correlated with the first component. The successive components identified explain progressively smaller portions of the total sample variance. Linear combinations of observed variables are formed. In contrast to common factor analysis, in PCA, no assumptions about the underlying common parts (communalities) and unique parts of the variables are made (Rummel, 1970).

Because ordinary PCA does not account for the effect of the individual cow, only the last observation per cow was included in the analysis ($n = 707$). Therefore, only

Table 1. Herd characteristics of 16 dairy herds selected for examination of udder health.

Herd ID	Breed ¹	Cow years	Housing system ^{2,3}	ECM ⁴ (305 d)	Calculated bulk milk SCC	Cows/mo. with chronic elevated SCC	Cows included in analysis
				(kg)		(%)	(no.)
1	HF	51	Tied	7087	320	20.2	34
2	HF	56	Tied	7940	478	24.6	35
3	HF	66	Loose (DL)	7120	452	26.8	41
4	HF	74	Tied	7144	209	4.1	41
5	Jersey	72	Tied	7683	354	7.2	44
6	HF	74	Tied	9306	199	6.3	41
7	HF/RDM	95	Loose (SF)	7803	144	3.4	51
8	HF	113	Tied	8532	353	17.1	46
9	HF	102	Loose (SF)	8518	226	7.7	35
10	HF	70	Tied	7673	278	12.4	45
11	HF	57	Tied	7447	331	4.7	50
12	HF	190	Loose (SF)	7803	353	10.1	36
13	HF	63	Tied	8177	253	5.1	39
14	RDM	51	Tied	7845	196	5.4	37
15	HF	131	Loose (SF)	7125	215	16.0	48
16	HF	119	Loose (SF)	5911	418	14.0	57

¹HF = Holstein Friesian; RDM = Red Danish Milking Breed.

²Loose (DL) = loose housing with deep litter system; loose (SF) = loose housing with slatted floor and boxes with bedding.

³Calculated on cow level and based on monthly milk records on milk yield, milk composition, and SCC. Observed minus expected values of log₁₀ (milk × SCC) adjusted for breed and parity.

⁴ECM = Energy-corrected milk.

clinical examinations conducted by the 2 technicians were analyzed. Principal component analysis was carried out with categorical and continuous variables (Table 2). Udder shape, teat shape, parity, and stage of lactation were treated as dummy variables with normal udder and teat shape, second parity, and middle part of lactation as reference level. In cases of these dichotomous variables, the loadings on a factor were interpreted as the probability of its presence (positive loading) or absence (negative loading), given that the factor exists (Rummel, 1970).

Three different PCA were performed. First (PCA 1), only clinical variables were included in the analysis to simulate the situation of the practitioner on farm with no further information about the cows. Second (PCA 2), the variables parity and stage of lactation were added as dichotomous variables. Third (PCA 3), milk yield and previous SCC were added. The non-orthogonal promax rotation with a power of 3 was used to enhance the interpretability of the factors.

Milk Yield

Milk yield from each test day of all cows in the herds during 1999 that had at least 9 DIM was transformed to energy-corrected milk (ECM) using the following formula (Anonymous, 2002):

$$\text{ECM} = \text{milk (kg)} \times (383 \times \text{fat (\%)} + 242 \times \text{protein (\%)} + 783.2)/3140. \quad [1]$$

When analyzing ECM from test day records to model the lactation curve, the change in slope was expected to occur around 60 d after calving (Enevoldsen et al., 2000). A standard lactation milk curve of the current lactation was estimated for each cow using a piecewise linear regression model (Proc mixed; SAS, 2000) as described by Enevoldsen et al. (2000). The peak of the lactation curve was set to d 60 after calving. It was the intercept of the model and was set to 0 (DIM 60):

$$\text{DIM 60} = (\text{DIM} - 60)/245. \quad [2]$$

The second variable (DIMB60) was defined, which has the value 1 if DIM is below 60, otherwise 0. This variable models the slope from calving until 60 DIM:

$$\text{DIMB60} = \text{DIM 60}(\text{DIM} < 60). \quad [3]$$

The model accounted for the effect of parity and stage of lactation and was

$$Y_{ijk} = \mu + \text{parity}_i + \text{DIM 60}(\text{parity})_j + \text{DIMB60}(\text{parity})_k + \varepsilon_{ijk} \quad [4]$$

where

$$Y_{ijk} = \text{estimated ECM}, \\ \mu = \text{expected mean at 60 DIM among third parity cows},$$

Table 2. Clinical and morphological variables and their definitions selected for inclusion in principal component analysis (n = 707 cows). Definitions were based on Rosenberger (1979) and Houe et al. (2002). All quarters of a cow were examined, and in cases of different findings, the quarter with the worst condition was recorded.

Variable	Scale	Additional guidelines
Asymmetry between hind quarters/ asymmetry between front quarters	1 = slight (just noticeable), 3 = pronounced, 5 = complete atrophy of one quarter	Visual inspection just after milking
Clinical mastitis	Signs: redness, swelling, pain, warmth, hardness of udder tissue	Visual and palpation
Udder edema	1 = slight, 2 = large area of the udder, 3 = most of the udder	Palpation, especially on under part of udder
Knotty tissue	Present: yes or no	Distinct nodule or general nodulous tissue can be palpated
Udder tissue condition	1 = soft; fingers easily palpate deep in the gland; 3 = firm, fingers palpate 3 to 5 cm into the tissue, but general firm tissue; 5 = hard, fingers cannot palpate into udder tissue	Palpation of normal hind quarters (no signs of atrophy or mastitis)
Udder shape ¹	1 = normal; 2 = small; 3 = long abdominal; 4 = backward bulging; all four teats between hind legs, 5 = slanting; 6 = deep; 7 = deep and slanting	Visual inspection from side and back
Teat shape ¹	1 = normal, 2 = short (<5 cm), 3 = conical, 4 = fleshy, 5 = other	Visual inspection
Teat wound	Present: yes or no	Inspection
Scar tissue in teat canal	Present: yes or no	Palpation
Skin quality of teats	1 = smooth like silk, 2 = smooth, 3 = intact and moderately smooth, 4 = rough, 5 = very rough	Palpation
Warts on teats	Warts >2 mm present, <8 on all teats, or ≥8	Palpation and inspection
Warts on top of teats	Present: yes or no	If wart is at orifice or can disturb milk flow
Wounds on warts	Present: yes or no	Inspection with light
Teat end callosity ¹	1 = slight, 3 = immediate visible, 5 = extreme	Inspection approximately 1 min after milking
Soiling on teats/udder	1 = slight, 2 = marked, 3 = very thick layer of manure	Inspection after milking

¹Clinicians were supplied with pictures.

parity_i = fixed effect of parity (i = 1, 2, and 3+),

DIM 60(parity)_j = fixed effect of DIM within parity, and

DIMB60(parity)_k = fixed effect of 'before or after d 60' within parity.

The intercept is an estimate of the peak milk production at d 60 after calving and was 32.4 kg for cows in the third parity group (Table 3). The estimate of DIM 60(parity) is the estimated difference in milk production between exactly 60 DIM and 305 DIM within the different parity groups. Cows in first lactation had the lowest difference of -4.1 kg ECM between DIM 60 and DIM 305, indicating the highest persistency. The estimated difference in milk yield between the day of calving and

60 DIM in second parity cows was not significant, indicating a falling line from calving until d 305 instead of a peak at 60 DIM, which is common in models of milk yield where milk is not adjusted to ECM.

The normally distributed residuals of the model represent the parity-specific deviation of the expected milk yield from the measured milk at any point during lactation according to the lactation curve of all cows in a specific parity. The mean residual milk yield of the complete lactation (observed—expected) for each cow was used as a continuous variable, **MRESMILK**, in the PCA 3. It characterizes the cow as yielding higher, lower, or as expected in comparison with all cows in that parity across herds. The mean residuals of the cows included in the PCA ranged from -15.0 to 16.1 kg ECM below or above the expected ECM; the mean was 0.50 ± 4.3 kg.

Table 3. Parameter estimates with standard error and significance level from the piecewise linear regression model estimating energy-corrected milk (ECM) yield within parity and stage of lactation across herds.

	Estimated ECM	P
Intercept ¹	(kg) 32.40 ± 0.08	<0.001
Parity group		
1	−6.76 ± 0.11	<0.001
2	−1.78 ± 0.12	<0.001
3	0	
Slope of the lactation curve between d 60 and 305 within parity group		
Parity group 1	−4.15 ± 0.15	<0.001
Parity group 2	−9.70 ± 0.18	<0.001
Parity group 3	−12.02 ± 0.15	<0.001
Slope of the lactation curve before d 60 within parity group		
Parity group 1	4.00 ± 1.01	<0.001
Parity group 2	−1.67 ± 1.26	0.170
Parity group 3	2.89 ± 1.00	<0.001

¹Peak milk yield at d 60 in parity group 3.

SCC

The previous SCC was the log-transformed (log₁₀) SCC of all test days of the examined cows from calving until the day of their clinical examination. The mean gives information about the infection status in a cow during lactation and was included as **MLOGSCC** in the third step, PCA 3.

RESULTS

Descriptive statistics of the clinical examination are given in Table 4. Normal udder shape was recorded in 66.4% of cows. Nine percent of cows had small udders, 13.6% had deep udders, and 10.8% of cows had other udder shapes. Ninety-two percent of teats were of normal shape, 3.1% were short, 1.8% were fleshy, and 3.4% had other teat shapes.

In all 3 PCA, 4 components were extracted that explained 27% of the variation in the data. The rotated factor patterns of PCA 1-PCA 3 show the standard regression coefficients (Tables 5, 6, and 7). Principal component analysis 3 was regarded as the “full model” and was used to label the factors with respect to their biological meaning.

The first component seems to characterize the “small udder” in contrast to the deep udder. Variables with the highest positive loadings on the component were first parity, small udder, and short teats. Variables with high negative loadings were parity 3+, deep udder, and MLOGSCC. The second component could best be described as a “distressed udder,” as variables describing an impaired teat surface such as wounds on warts, poor skin quality, and teat wounds were loading high on the component. Further, a long or backward-bulging udder

Table 4. Descriptive statistics of udder and teat characteristics of cows analyzed in the principal component analysis (n = 707 cows).

Variable	Distribution of score values ¹					
	0%	1%	2%	3%	4%	5%
Asymmetry between hind quarters	67.6	19.7	9.8	3.0		
Asymmetry between front quarters	81.1	9.0	5.5	4.4		
Clinical mastitis	99.3	0.7				
Udder oedema	97.2	16	0.9	0.4		
Knotty tissue	97.4	2.6				
Udder hardness		1.3	22.9	68.9	7.1	0
Teat wounds	93.8	6.2				
Scar tissue in teat canal	98.9	1.1				
Skin quality of teats		12.2	73.4	13.9	0.6	
Warts on teats	23.4	49.8	26.8			
Warts on top of teat	77.4	22.6				
Wounds on warts	78.5	21.5				
Teat end callosity	0.4	5.0	27.0	40.0	22.3	5.2
Soiling on teats	92.1	7.4	0.6	0		
Soiling on udder	52.6	38.1	7.9	1.4		

¹Increasing score value with increasing severity of condition.

Table 5. Principal component analysis 1. Correlations (standardized regression coefficient) between udder health parameters and 4 components after oblique rotation (promax rotation, power = 3).

Variable	Component 1 "Distressed udder"	Component 2 "Mastitis udder"	Component 3 "Small udder"	Component 4 "Soiled udder"
Wounds on warts	0.61*	-0.09	0.03	-0.07
Udder hardness	0.58*	0.28	-0.11	-0.06
Skin quality of teat	0.58*	0.04	0.23	0.23
Long udder	0.38*	-0.12	0.01	-0.25
Teat wounds	0.35*	0.09	0	0.10
Fleshy teat	0.33	-0.18	-0.25	0.04
Backwards bulging udder	0.31	-0.13	-0.03	0.01
Other teat shape	0.29	0.13	-0.06	0.03
Asymmetry between hind quarters	0.02	0.61*	0.01	0
Clinical mastitis	0.06	0.54*	0.03	0.02
Asymmetry between front quarters	-0.09	0.42*	-0.03	0.11
Scar tissue in teat canal	0.26	0.38*	0.04	-0.13
Short teats	0.01	0.07	0.70*	0.04
Small udder	-0.06	-0.06	0.66*	-0.04
Teat-end callosity	-0.31	0.04	-0.35*	0.04
Soiled teat	-0.03	0.02	0.20	0.56*
Soiled udder	-0.15	0.11	-0.04	0.56*
Deep udder	0.13	0.05	-0.37*	0.42*
Knotty tissue	0.05	0.23	0.02	0.28
Conical teat	0.08	-0.04	-0.11	0.21
Slanting udder shape	-0.09	0.17	-0.07	0.18
Udder oedema	-0.15	0.34	-0.02	-0.35*
Deep and slanting udder	-0.07	0.26	0.03	-0.36*
Eigenvalue	1.9	1.5	1.4	1.2
Variance explained, %	8.6	7.0	6.4	5.7

*Correlation coefficients >0.35 were regarded as significant.

and fleshy teats were related to the component. The third component was labelled "mastitis udder" because it consisted of variables describing acute alterations (clinical mastitis) and chronic alterations (asymmetry, knotty tissue) of the udder. Cows loading high on the "mastitis udder" had a higher MLOGSCC as well as a lower MRESMILK. The fourth component was labelled "soiled udder." Cows loading high on "soiled udder" had soiled udder and teats and were more likely to be in early lactation than in other stages of lactation.

With the introduction of non-clinical variables in PCA 2 and PCA 3, the biological meaning of the components emerges more clearly. In PCA 1, the component "small udder" starts with high positive loadings (probabilities) of small udder shape and short teats together with high negative loadings of deep udder shape and degree of teat end callosity (PCA 1). The addition of parity in PCA 2 and SCC in PCA 3 explains the "small udder" further as having a higher probability among first parity cows in contrast to cows in second (reference level) or higher parity and in contrast to cows having normal (reference level) or deep udder shape. Furthermore, cows with high loadings on that component had a lower MLOGSCC.

From PCA 1 to PCA 2, the order of the components changed. When only clinical variables were analyzed, the component "distressed udder" explained most of the

variation in data. When the variables parity and stage of lactation were added, the component "distressed udder" moved to the second position, and "small udder" explained most of the variation of the data and remained the first extracted component in PCA 3. From PCA 2 to PCA 3 the components "mastitis udder" and "soiled udder" changed their order and meaning. The oblique rotation revealed a low inter-correlation between the components in general (Table 8). The highest inter-component correlation (-0.17) was found between component 1 "small udder" and component 4 "soiled udder". That is, in general, small udders were slightly less soiled.

DISCUSSION

Component 1, The Small Udder

First parity cows were related to small udders with short teats, whereas deep udders and cows in higher parities were negatively correlated with the component. Udder depth is reported to increase with parity (Seykora and McDaniel, 1985). Deep udders are likely to develop if the strength of the udder attachment decreases with increasing age (Harris et al., 1992). In general, there is a genetic correlation between improvement of milk production and an increase in udder depth

Table 6. Principal component analysis 2. Correlations (standardized regression coefficient) between udder health parameters, parity, and stage of lactation and 4 components after oblique rotation (promax rotation, power = 3).

Variable	Component 1 "Small udder"	Component 2 "Distressed udder"	Component 3 "Mastitis udder"	Component 4 "Soiled udder"
First parity	0.77*	0.01	-0.08	-0.02
Small udder	0.63*	0.06	0.19	0.01
Short teats	0.40*	0.06	0.08	0.16
Conical teats	-0.12	0.05	0	0.06
Deep and slanting udder	-0.21	-0.12	-0.10	0.02
Deep udder	-0.46*	0.05	0.12	0.16
Parity 3+	-0.77*	0.07	0.03	0.05
Wounds on warts	0.10	0.63*	-0.09	-0.04
Skin quality of teat	0.13	0.57*	0	0.24
Udder hardness	-0.17	0.54*	0.11	0.17
Long udder	-0.01	0.40*	-0.13	-0.19
Teat wounds	0.01	0.33	0.16	0.10
Backwards bulging udder	-0.04	0.33	0.06	-0.14
Fleshy teat	-0.16	0.33	0.01	-0.19
Other teat shape	-0.07	0.25	-0.15	0.22
Udder oedema	-0.05	-0.17	-0.01	0.07
Teat-end callosity	-0.07	-0.31	0.24	-0.08
Early lactation	0.02	0.14	0.62*	-0.22
Soiled udder	0.11	-0.15	0.60*	0.18
Soiled teats	0.16	-0.02	0.44*	0.18
End of lactation	0.15	-0.05	-0.57*	0.13
Clinical mastitis	0.02	-0.02	-0.07	0.55*
Asymmetry between hindquarters	-0.01	-0.06	0.10	0.52*
Asymmetry between front quarters	-0.18	-0.19	-0.07	0.44*
Knotty tissue	0.01	0.01	0.07	0.36*
Scar tissue in teat canal	-0.04	0.21	-0.08	0.34
Slanting udder shape	-0.10	-0.12	0.14	0.19
Eigenvalue	2.4	1.8	1.5	1.5
Variance explained, %	9.2	6.9	5.6	5.1

*Correlation coefficients >0.35 were regarded as significant.

(Kelm et al., 2000). The increase in milk-producing capacity requires a higher activity and storage capacity of the secretory cells of the udder (Akers, 2000) and, thus, requires space to expand. An udder with tight attachment caused by strong ligaments is higher, but milk production may be restricted mechanically (Blake and McDaniel, 1978). MRESMILK contributed with a negative loading to the component, but below the threshold of 0.3. Cows with small udders, short teats, and in first parity did not differ in milk yield from other cows in first parity.

The small udder was related to lower SCC. Deeper udders indicate a decrease in teat end to floor distance, which is correlated with higher SCC (Rogers et al., 1991; Faye et al., 1998) and is even related to a higher risk of subclinical (Ronningen and Reitan, 1990) and clinical (Slettbakk et al., 1995) mastitis. In general, cows in higher parities have higher SCC (Laevens et al., 1997; De Haas et al., 2002). However, in cows that are uninfected by mastitis pathogens, SCC is uncorrelated with parity (Laevens et al., 1997). In conclusion, cows with a high loading on the component "small ud-

der" may be less susceptible to mastitis than cows with normal or deep udder shape.

Component 2, The Distressed Udder

In comparison with normal udder shape, long udders and backward-bulging udders were related to harder tissue and an impaired teat surface with rough teat skin and wounds on warts and teats. Rough teat skin (Burmeister et al., 1998) and wounds on skin (Larsen et al., 2000) are a reservoir for *S. aureus*. Even superficial lesions of the teat skin increase the risk of subclinical and clinical mastitis (Agger and Willeberg, 1986). Warts caused by viruses can result in local damage of the natural defense mechanisms of the teat and predispose them for bacterial mastitis (Wellenberg et al., 2002).

Hardness of udder tissue characterizes two different morphological features: the udder parenchyma with aggregations of alveoli (secretory cells) partitioned off into lobules by thin connective tissue septa growing into stronger connective tissue, the second morphologic feature, which builds up the udder attachment with the

Table 7. Principal component analysis 3. Correlations (standardized regression coefficient) between udder health parameters, parity, stage of lactation, expected milk yield, SCC, and 4 components after oblique rotation (promax rotation, power = 3).

Variable	Component 1 "Small udder"	Component 2 "Distressed udder"	Component 3 "Mastitis udder"	Component 4 "Soiled udder"
First parity	0.77*	0.01	-0.07	-0.06
Small udder	0.63*	0.06	0.04	0.19
Short teats	0.39*	0.06	0.19	0.08
Conical teats	-0.12	0.05	-0.09	0.03
Deep and slanting udder	-0.20	-0.11	0	-0.10
Deep udder	-0.46*	0.04	0.13	0.12
Parity 3+	-0.76*	0.08	0.07	0.02
Wounds on warts	0.09	0.63*	-0.11	-0.07
Udder hardness	0.12	0.57*	0.25	0.02
Skin quality of teat	-0.18	0.56*	0.06	0.14
Long udder	-0.04	0.39*	-0.23	-0.13
Backward-bulging udder	0.02	0.34	0.06	0.18
Teat wounds	-0.04	0.33	-0.21	0.07
Fleshy teat	-0.16	0.33	-0.22	0.01
Other teat shape	-0.07	0.24	0.16	-0.13
Udder oedema	-0.06	-0.16	-0.02	0
Teat-end callosity	-0.08	-0.30	-0.14	0.25
Asymmetry between hind quarters	0.01	-0.04	0.46*	0.13
MLOGSCC ¹	-0.35*	0.08	0.45*	-0.01
Asymmetry between front quarters	-0.15	-0.17	0.42*	-0.06
Clinical mastitis	0.04	0	0.42*	-0.03
Knotty tissue	0.02	0.02	0.30	0.09
Scar tissue in teat canal	-0.03	0.22	0.26	-0.05
Slanting udder shape	-0.08	-0.12	0.20	0.14
MRESMILK ²	-0.25	-0.18	-0.48*	0.12
Early lactation	0.03	0.15	0.21	0.61*
Soiled udder	0.10	-0.15	0.18	0.61*
Soiled teats	0.16	-0.03	0.17	0.45*
End of lactation	0.12	-0.07	0.06	-0.54*
Eigenvalues	2.6	1.9	1.5	1.5
Variance explained, %	9.1	6.7	5.6	5.2

*Correlation coefficients >0.35 were regarded as significant.

¹MLOGSCC = mean of log-transformed SCC.

²MRESMILK = mean residual of observed-expected milk yield.

ligaments. The percentage of secretory tissue differs among individual dairy cows and genotypes and is influenced by parity and stage of lactation (Michel, 1994). In freshly calved first parity cows, the percentage of fat tissue is high, and the percentage of secretory tissue is low. During the first lactation, the percentage of secretory tissue increases and replaces the fat tissue, accompanied by increasing udder hardness. In subsequent parities, number and size of alveoli increase further until the fifth or sixth parity. The secretory tissue de-

creases again during the declining phase of lactation and during involution of the secretory tissue. In contrast to information from literature, stage of lactation and parity did not contribute to component 2. One explanation could be an interaction between connective and secretory tissue: udders appearing fleshier after milking have a heavier stroma or connective tissue than udders with a large amount of secretory tissue (Smith, 1959). Furthermore, the hardness of the udder was measured from behind with both hands palpating the

Table 8. Inter-component correlations of principal component analysis 3 after oblique rotation.

	"Small udder"	"Distressed udder"	"Mastitis udder"	"Soiled udder"
"Small udder"	1.00			
"Distressed udder"	-0.10	1.00		
"Mastitis udder"	-0.06	0.10	1.00	
"Soiled udder"	-0.17	0.05	-0.02	1.00

udder close to the ventral abdomen where ligaments and connective tissue were strongest and percentage of secretory tissue was lowest. Cows with a strong ligament and udder capsule may also have had a stronger connective tissue in the parenchyma, leading to a higher degree in hardness than cows with a weaker ligament structure (Akers, 2000). However, previous SCC showed no relationship with high component 2 values on the “distressed udder,” but cows with such “distressed udder” may be at a higher risk for subsequent clinical mastitis because of impaired teat surface.

Component 3, The Mastitis Udder

Because the incidence of truly acute clinical mastitis is of short duration (Smith and Hogan, 1995), we expected to find a low frequency of acute cases in our study. In addition to signs of acute clinical mastitis, knotty tissue and asymmetry of quarters significantly contributed to the “mastitis udder,” component 3.

This component appeared to be a mixture of acute and chronic symptoms of clinical mastitis. Hardness of mastitis quarter and diagnosed clinical mastitis are acute symptoms, whereas asymmetry and knotty tissue are chronic alterations of the udder. Chronic mastitis can lead to atrophy of the affected quarter, resulting in asymmetry as a post-inflammatory state. Mastitis can also develop progressively with increases in fibrous tissue so that the size of the affected quarter increases (Fuchs, 1994). Further, the farmer may have decided to dry off a mastitis quarter, resulting in involution of the affected quarter. Because these chronic alterations were longer-lasting conditions, the observed frequency in the presented investigation is much higher than the frequency of acute mastitis. The clinical variables with high loadings point toward the same result—a clinical (visible) mastitis—and can be used as additional classification of clinical mastitis. Especially in situations where under-reporting is suspected, this component can improve the quality of data because it decreases the number of false-negative non-mastitis cows. A problem when using this component to classify udder health can be that it only tells that there was previous mastitis but tells nothing about the duration or the onset of disease. Conversely, udders once affected by clinical mastitis are more susceptible to recurrent cases of mastitis with acute symptoms (Hogan et al., 1989). When there is no further information about first cases of clinical mastitis available, a distinction between acute clinical mastitis and chronic mastitis with acute episodes is difficult, especially in older cows.

As expected, the variables describing clinical signs of mastitis were related to a higher SCC and a lower milk yield in comparison with other cows in the same

parity. Chronic alterations may have reduced the milk production in the affected quarter. Furthermore, the reduction in milk yield after clinical mastitis seemed to persist during the whole lactation as reported in the literature (Morris, 1973; Bartlett et al., 1991). A systematic screening for cows with high loadings on the component may be beneficial in the assessment of udder health status and in the development of a treatment strategy in the herd.

Component 4, The Soiled Udder

The soiled udder was related to early lactation and is consistent with Ward et al. (2002), who found higher counts of *Escherichia coli* and *Staphylococcus uberis* in beds of early lactation cows and a higher degree of soiling in early lactation cows. No other clinical or production variable contributed to the “soiled udder” when stage of lactation was added to the analysis. This result is in contrast to the results of a factor analysis performed by Bruun (2003), where days after calving showed no relation with degree of soiling. Contamination via manure reflects hygiene in the barn (Cook, 2002) and because degree of soiling was measured immediately after milking, hygiene practices before the milking process had an influence on the degree of soiling. These management practices affected the cows independently from their udder and teat morphology, milk production, or previous SCC.

General Discussion

Differences in the clinical examinations performed by 2 different persons might have induced a bias. Houe et al. (2002) have shown that the agreement between clinicians on pathological conditions is high, but there was a higher variation when classifying non-pathological conditions such as udder shape or hardness of udder parenchyma. Because our data recording sheets supplied the 2 clinicians with detailed descriptions and figures on specific conditions, we expect the variation between clinicians to be low. Further, the last observation of each cow was chosen to minimize bias caused by a “learning effect” of the examiners during the project.

When developing and interpreting PCA, the researcher should find biologically meaningful descriptions for the extracted components. The order of the components changed with the introduction of non-clinical variables in PCA 2 and PCA 3. Components “soiled udder” and “mastitis udder” reversed in PCA 2 and PCA 3. But, the amount of variation explained by each component was similar; a change in the order of the components was not an interpretational problem. The

clinical variables with the highest loadings on a component kept their high loading and their position within a component throughout the model-building process. The stability of these variables is evidence for a meaningful pattern that was not produced by chance. When non-clinical variables were included in the analysis, the focus changed within the component “small udder,” and age became the most important variable related to the size of the udder. In contrast, the component “distressed udder” consisted only of clinical variables that were not related to age, stage of lactation, milk production, or previous SCC. Therefore the “distressed udder” remains invariant from PCA 1 to PCA 3. The factor “mastitis udder” is a combination of clinical variables, previous SCC, and milk yield. However, each part of the combination adds up to the whole component, indicating that each part is of the same importance in its contribution to the “mastitis udder.” The fourth component, “soiled udder,” is determined only by those clinical variables describing soiling of teats and udder and stage of lactation. The presence of a low inter-component correlation with the “small udder” indicates that there is only a weak relationship between udder size and soiling.

Factor analysis was used in 2 other studies on clinical udder examinations in Denmark. Houe et al. (2002) extracted 3 factors with common factor analysis including clinical variables only: the mastitis udder, the long udder, and the high udder. Variables loading high on the mastitis udder were asymmetric front or hind quarters and dry quarters. Similar to our results, but by using the mastitis factor as a variable in a general linear model, Houe et al. (2002) showed that an increase in factor score was correlated with a decrease in lactation milk yield (305-d energy-corrected milk). As in our study, Bruun (2003) extracted 4 factors, but used common factor analysis with maximized variance. The author labelled the first factor “chronic changes,” which was similar to our component “mastitis udder.” In contrast to our results, no acute signs of mastitis contributed to the factor and no relationship with milk yield were found. The researcher used the milk yield recorded immediately before clinical examination, whereas the present study worked with a milk model to classify cows as high, average, or low yielders within their parity.

Comparable with Bruun et al. (2003), the total amount of variance explained was around 27%, which indicates that several variables have high degrees of uniqueness. That is, they provide important information on their own. Further, the data structure may not have been optimal; Bruun (2003) rescaled ordinal variables with the method of optimal scaling to improve linearity. When rescaled variables are analyzed, the interpretation is more difficult with regard to the origi-

nal categories. In the present study, dummy variables were used, e.g., for parity and stage of lactation, when non-linearity was suspected. Regardless of this somewhat different approach, extracted factors or components were similar in both studies when the correlation to the factor (component) was strong. In addition to a different method within factor analysis and treatment of variables, differences may also be caused by the choice of variables that were included in the analysis. Introduction of new variables with important contribution to a factor (component) may shift the focus or enhance the interpretability of a factor (component) as seen in the component “small udder.” Variables related to factor “udder shape” (Bruun, 2003) and to the component “small udder” of the present study were identical, which is further evidence that the PCA produced a biologically meaningful pattern and contributes to the understanding of udder health.

Welfare and health assessment protocols, including animal-based measurements, become an issue of increasing importance in health management and quality programs in several countries (Noordhuizen and Metz, 2003; Whay et al., 2003). Increasing herd sizes increase the demand for systematic, effective, and economic tools in udder health management. Inclusion of animal-based measurements could be beneficial in advisory services to understand the udder health situation on the farm and to specify udder health risks. The extracted udder types can be implemented in decision support systems on udder health in dairy farms. The presence of cows with “distressed udder” indicates impaired teat and udder condition and could be used to evaluate the effectiveness of hygienic measures or the necessity of measures in the milking parlor. The “soiled udder” could be used as an indicator of hygiene in the barn. Classifying cows according to the “small udder” can support decision making when selecting cows for mastitis prevention on the herd level. The prevalence of cows with a “mastitis udder” provides information about the number of clinically affected cows and the severity of clinical signs, which is of prognostic value. When results from clinical examination are compared with farm records, management practices, such as blinding of mastitis quarters, will be revealed, and the quality of farm records can be evaluated. Further investigations are necessary to test the applicability and the effect of animal-based measurements in udder health monitoring.

CONCLUSIONS

The stepwise approach in 3 models by using PCA shows that the clinical variables form a consistent pattern that was not changed by adding more traditional

variables such as milk yield and SCC. This stability in udder type patterns provides solid evidence that clinical udder examinations can be a reliable tool in veterinary research and practice. The extracted components provide information on udder health status in addition to SCC and milk yield. Both the practitioner and the scientist conducting a field study can benefit from performing systematic clinical udder examinations, especially when under-reporting of mastitis cases is expected.

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