Journal of Dairy Research (2005) **72** 296–302. © *Proprietors of Journal of Dairy Research 2005*
doi:10.1017/S0022029905000920 *Printed in the United Kingdom*

Ultrasonographic measurement of the bovine teat: breed differences, and the significance of the measurements for udder health

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Received 22 June 2004 and accepted for publication 5 November 2004

The objective was to measure teat canal length and diameter, teat diameter and teat wall thickness by ultrasonographic scanning in order to determine the differences in bovine breeds, and to study the influence of teat canal length and diameter on the occurrence of mastitis. A total of 269 lactating dairy cows of four different breeds (Brown Swiss, Simmental, Simmental crossbred with Red Pied, and Holstein-Friesians) from seven Upper Austrian dairy farms were examined. Average teat canal length of Brown Swiss animals was shortest (15·7 mm) followed by Holstein-Friesians (17·2 mm) and Simmental (18·3 mm). These differences in teat canal length were highly significant ($P \leqslant 0 \cdot 001$). There was no significant difference in teat canal length between pure-bred and crossbred Simmentals. Differences of teat canal diameter between breeds were significant ($P \leqslant 0 \cdot 05$). Brown Swiss animals had the largest diameters (2·0 mm) and Holstein-Friesians the smallest (1·7 mm). Differences in teat diameter between Brown Swiss, Holstein-Friesian and Simmental were also significant. No differences were found between the pure-bred and crossbred Simmental cows. The narrowest teats were in Holstein-Friesians and the widest in Simmental. Holstein-Friesians also exhibited the thinnest teat walls while the Simmental had the thickest ones. Teat canal length and diameter were correlated with udder health. Teat canals of healthy udders tended to be longer (17·4 mm) and narrower (1·8 mm) than teat canals of infected udders (15·8 mm, 2·1 mm; $P \leqslant 0 \cdot 001$). A logistic regression model showed significant effects of teat canal length, teat canal diameter and lactation number on udder health.

Keywords: Sonography, cow, teat canal, mastitis.

Udder health is important in modern dairy farming and is the basis for economical and hygienic milk production. Mastitis causes a loss in milk production, changes of milk components and raw milk quality, increased costs for treatment, early culling of dairy cows and other important economic losses (Wendt et al. 1994; Kossaibati, 2000). The bovine teat including the natural defence mechanism against udder pathogens provided by the teat canal, is important in preventing udder infections (Seykora & McDaniel, 1985; Hamann & Østerås, 1994).

The influence of teat canal structures on udder health has been examined by various authors using different methods for measurement of teat canal length and/or diameter. McDonald (1975) adopted radiographic techniques, Grindal et al. (1991) and Lacy-Hulbert & Hillerton (1995) used special sterile cannulae and Hamana et al. (1994), Scherzer (1992) and Seyfried (1992) ultrasonographic scanning.

Recently ultrasonographic scanning has attained increased importance in veterinary medicine. In bovine medicine, this diagnostic tool is mainly used for gynaecological examinations but routinely also for exploration of the abdomen, urinary tract, lungs, umbilicus, heart, tumours and for orthopaedic purposes (Braun, 1997). Udder and teat scanning is generally performed for diagnosis of milk flow disturbances but also is increasingly used for examination and measurement of different anatomical structures

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(Franz et al. 2001; Neijenhuis et al. 2001; Khol, 2003). The first ultrasonographic examinations of bovine teat were carried out by Caruolo & Mochrie (1967) as an A-mode and a frequency of 1 MHz. Cartee et al. (1986) tested B-mode (real-time mode) ultrasonography to diagnose milk flow disturbances. Later, teats were scanned using 3·5 and 5·0 MHz (Jenninger, 1989; Stocker et al. 1989; Will et al. 1990; Saratsis & Grunert, 1993; Seeh et al. 1996). Reasonable quality of pictures especially for the examination of anatomical structures could be obtained by means of 8·5 MHz linear array (Franz et al. 2001).

In the sonographic image, the teat wall appears as a threefold layered structure. The teat skin appears as a 1–2 mm thin, bright, echoic line and is followed by the muscular/connective tissue layer containing blood vessels showing a thicker, homogeneous, less echoic layer with inclusion of anechoic cavities. The internal boundary as mucous membrane appears as a thin bright line (Braun, 1997; Hospes & Seeh, 1999; Franz et al. 2001). Physiological teat canal sonograms are presented as a thin, white, hyperechoic line circumscribed on each side by parallel hypo- to anechoic bands. Franz et al. (2001) compared these sonographical findings with histological preparations. They found that stratum corneum with keratin causes the hyperechoic middle line, and the stratum granulosum the surrounding less echoic lines.

The aim of the present study was to measure different parameters of the teat and teat canal using ultrasonographic scanning. Furthermore, the findings were compared for different bovine breeds and lactation numbers, and the influence of the measured teat canal structures on udder health was evaluated.

Materials and Methods

Preliminary study

Preliminary examinations were carried out to test the repeatability of the method. For this study, 280 teats of healthy quarters were scanned and independently measured by two people and the results were statistically evaluated.

Cows

A total of 269 lactating cows from seven dairy farms were selected and 87 Brown Swiss, 83 pure-bred Simmental, 31 Simmental crossed with Red Pied and 68 Holstein-Friesians were examined. Cows in their first lactation numbered 86; 72 were in their second, 46 in their third and 65 in their fourth or higher lactations. Annual average milk yield in Brown Swiss was up to 9000 kg; in Simmental, 9000 kg; and in crossed Simmental and Holstein-Friesians, 10 000 kg. Cows were housed in free-stall barns and milked twice a day in a milking parlour. In all of the farms examined, some milking hygiene procedures, as described by Glawischnig et al. (1971), Kleinschroth (1991) and Spohr & Schulze-Wartenhorst (1991), were significantly reduced to cleaning teats using a water-wet or a dry paper before milking. Neither was a premilking cup used nor the teats disinfected after milking. For this investigation only cows that received no antibiotic treatment at all during lactation were included.

Ultrasonographic scanning and measurement

Teats were scanned in B-mode using a portable instrument (SONOACE 600V, KRETZ-Technik, Zipf, Austria) equipped with an 8·5 MHz/60 mm linear array transducer. For documentation of the data obtained, a black and white thermoprinter (SONY Inc., Tokyo, Japan) was used and pictures printed on UPP-110S Type I Paper (SONY Inc., Tokyo, Japan). To prevent deformation of the teat and to ensure complete presentation of the tip of the teat, the teat was dipped in a water-filled plastic cup and a contact gel AQUASONIC 100 (Parker Labs, Fairfield NJ, USA) used. All teats of a cow were scanned before routine milking. Teats were examined by vertical planes and the probe was positioned equally at all times during the experimental period. When characteristic structures of the teat and teat canal as described by Franz et al. (2001) appeared, and the picture showed a satisfactory quality, it was printed out. Measurements of the teats were carried out using a slide caliper (HM Helu-2, Fa. Müllner) on the printed images. The teat was presented smaller on the printed picture; values were converted with the appropriate multiplier to get the actual measurements. The following structures of the teat were measured: teat canal length (Furstenberg's rosette was included; tcl), teat canal diameter (middle of the canal; tcd), teat diameter on the level of Furstenberg's rosette (td 1), teat diameter 1·5 cm proximal of Furstenberg's rosette (td 2) and teat wall thickness 1·5 cm proximal of Furstenberg's rosette (twt) (Fig. 1).

Udder Health

Udder health was assessed by clinical examination of the udder; a California Mastitis Test was performed and milk samples taken for bacteriological examinations as described by Baumgartner (2002). Milk samples were collected on the day of ultrasonographic examination, cell count determined by means of Fossomatic and bacteriologically examined. Healthy quarters of the udder were free of clinical symptoms due to mastitis, cell count in milk showed a maximum level of 100 000 per ml (Hamann, 1996) and no udder pathogens were found.

Statistical Analyses

Statistical analyses were carried out using SPSS for Windows (Version 12.0). Duplicate scans of the same teat were carried out by two people to test the repeatability of teat scanning and measurement of the various parameters. A Pearson correlation was used to evaluate significant

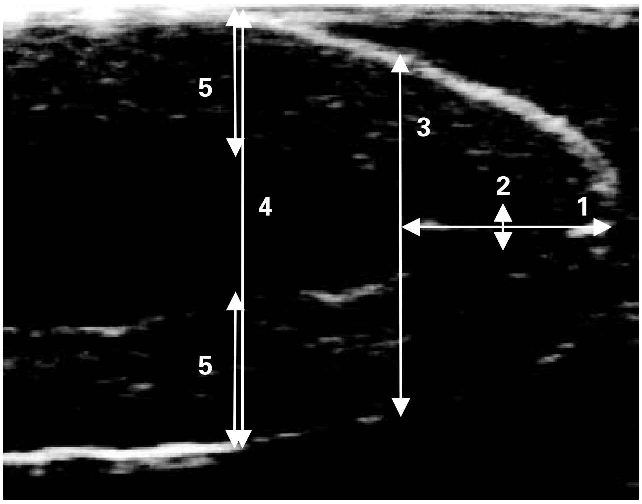

Fig. 1. Measurements on a vertical ultrasonographic scan of the bovine teat: teat canal length (1), teat canal diameter (2), teat diameter at the level of the Furstenberg's rosette (3), teat diameter 1·5 cm proximal of the Furstenberg's rosette (4) and teat wall thickness 1·5 cm proximal of the Furstenberg's rosette (5).

differences between the parameters tested. For examination of two dependent samples such as correlation between teat canal measurements and udder health a Paired Wilcoxon-Test was used; for evaluation of independent samples (differences of measured parameters in-between breeds, lactation number) a Mann-Whitney-U-Test and Kruskal-Wallis-Test was used. Significant differences were considered as $P\leqslant 5\%$ ($P\leqslant 0{\cdot}05$) and highly significant differences as $P\leqslant 0{\cdot}001$.

For discussing the possible effects of the variable factors on udder health, a logistic regression model was chosen. The estimate B for the coefficient and its SE, the Wald statistic, the degrees of freedom and the resulting significance value are listed in Table 5. If the last value is <0·05 the parameter can be regarded as significantly different from zero. Exp(B) is the exponential form of the parameter estimate. The 95% confidence interval for Exp(B) is also listed. If it contains the value 1, the parameter is not significant. The parameter estimates (B) quantify the effect of a variable or a factor category on the logit of being positive and therefore on the probability of being positive. Negative parameter values imply a decreasing effect on being positive. Lactation number is coded as a categorical variable with 1, 2, 3 and ⩾4, where the last one is taken as reference.

Results

Preliminary study

The repeatability of ultrasonographic scanning of teat canal length and diameter, teat diameter and teat wall thickness was highly significant ($P\leqslant 0{\cdot}001$). Pearson correlation coefficient for teat canal length was 0·949 and for teat canal diameter 0·816. Teat diameter at the level of the Furstenberg's rosette and 1·5 cm proximal of the Furstenberg's rosette showed a correlation of 0·954 and 0·915 respectively. The value for teat wall thickness was 0·756.

Table 1. Measurements of teat parameters (mm) of 1068 teats

	n	Mean	SE	Median	Minimum	Maximum
Teat canal length	1068	17·0	2·8	17·2	8·6	24·0
Teat canal diameter	1068	1·9	0·4	1·8	1·0	3·3
Teat diameter 1	1068	23·9	2·4	23·9	16·9	33·9
Teat diameter 2	786	27·7	2·8	27·6	20·1	37·4
Teat wall thickness	710	7·7	2·0	7·6	3·1	14·5

Teat Measurement

In total, 1068 teats of 269 cows were measured. Eight teats could not be evaluated because the cows showed injuries affecting teat parameters or they were off lactation. In some teats, a measurement of the teat diameter and teat wall thickness 1·5 cm proximal of the Furstenberg's rosette was not possible. Results of the measurements of all the teat parameters examined are shown in Table 1. Measured parameters were not significantly different ($P>0{\cdot}05$) between front and rear teats.

Measurements of healthy teats of the breeds tested are presented in Table 2. Teat canal length differed significantly between all pure breeds. Between pure and crossbred Simmental no significant differences could be detected. Teat canal diameter differed among the breeds examined. In addition to teat canal length, the teat diameter at the level of Furstenberg's rosette showed significant differences between pure breeds, but not between pure and crossbred Simmental. Teat diameter 1·5 cm proximal of the Furstenberg's rosette varied significantly between all breeds. A difference in teat wall thickness between Brown Swiss and Holstein Friesian could not be detected, but in contrast values differed between these two breeds and Simmental as well as between pure and crossbred Simmental.

Measured teat parameters not only showed differences between breeds but also in animals with different lactation numbers (Table 3).

Mastitis was evident in 145 of 269 cows examined and a total of 267 of the examined quarters were affected. Front quarters were infected in 52% of cases and rear quarters in 48%. Of the infected cows, 41% suffered from clinical mastitis including increased cell counts and clinical signs of inflammation, 46% showed subclinical mastitis including elevated cell counts and 13% latent mastitis. As predominant pathogens *Staphylococcus aureus* (74%), followed by coagulase-negative staphylococci (12%), *Streptococcus* spp. (7%), Lancefield group C, D, G (6%)

Table 2. Measurements of teat and teat canal parameters (mm) of healthy teats of different bovine breeds

	Brown Swiss			Simmental			Simmental × Red Pied			Holstein Friesian		
	n	Mean	Median	*n*	Mean	Median	*n*	Mean	Median	*n*	Mean	Median
tcl†	221	15·7	$15{\cdot}9^{F,Fx,HF}$	283	18·3	$18{\cdot}6^{B,HF}$	102	18·6	$18{\cdot}6^{B,HF}$	195	17·2	$17{\cdot}2^{B,F,Fx}$
tcd	221	2·0	$2{\cdot}0^{F,Fx,HF}$	283	1·8	$1{\cdot}8^{B,Fx,HF}$	102	1·9	$1{\cdot}9^{B,F,HF}$	195	1·7	$1{\cdot}6^{B,F,Fx}$
td1	221	23·3	$23{\cdot}3^{F,Fx,HF}$	283	25·2	$25{\cdot}0^{B,HF}$	102	25·0	$25{\cdot}0^{B,HF}$	195	22·4	$22{\cdot}4^{B,F,Fx}$
td2	192	27·8	$27{\cdot}7^{Fx,HF}$	196	28·3	$28{\cdot}2^{Fx,HF}$	67	29·1	$28{\cdot}7^{B,F,HF}$	119	25·9	$25{\cdot}9^{B,F,Fx}$
wt	189	7·2	$7{\cdot}1^{F,Fx}$	154	9·0	$8{\cdot}8^{B,Fx,HF}$	59	8·1	$7{\cdot}9^{B,F,HF}$	113	7·2	$7{\cdot}0^{F,Fx}$

† tcl, teat canal length, Furstenburg's rosette included; tcd, teat canal diameter, middle of canal; td1, teat diameter at level of Furstenberg's rosette; td2, teat diameter 1·5 cm proximal of Furstenburg's rosette; twt, teat wall thickness 1·5 cm proximal of Furstenburg's rosette
[B] Difference is significant compared with Brown Swiss
[F] Difference is significant compared with Simmental
[Fx] Difference is significant compared with Simmental × Red Pied
[HF] Difference is significant compared with Holstein Friesian

Table 3. Measurements of teat and teat canal parameters (mm) of healthy teats from cows with different lactation numbers

	Lactation number											
	1			2			3			⩾4		
	n	Mean	Median	*n*	Mean	Median	*n*	Mean	Median	*n*	Mean	Median
tcl†	285	16·7	16·9	233	17·3	17·7*	125	17·5	17·4	158	18·4	18·5*
tcd	285	1·8	1·8	233	1·8	1·8	125	1·8	1·7	158	1·9	1·8*
td 1	285	23·2	23·3	233	23·8	23·5*	125	24·6	24·4*	158	25·2	25·2*
td 2	193	26·9	27·0	163	27·7	27·4*	99	28·1	27·8	119	28·7	28·6*
twt	169	7·9	7·8	148	7·4	7·1*	89	7·9	7·8	109	8·2	8·0

† For key to abbreviations, see Table 2
* significant difference ($P \leqslant 0{\cdot}05$)

streptococci were found, and to a lesser extent (1%) *Arcanobacterium pyogenes*, *Escherichia coli* or yeasts.

Teat canal length and diameter of healthy and infected quarters showed highly significant differences ($P \leqslant 0{\cdot}001$). These differences could also be detected between uninfected and infected quarters within an animal and within cows of one breed or lactation number, as well within a farm (Table 4).

Results of the logistic regression model are consistent concerning the findings mentioned earlier (Table 5). The results confirm that teat canal length, teat canal diameter and lactation number are relevant to udder health status. Teat canal length is a negative parameter estimate because the longer the canal, the lower the risk of being infected by udder pathogens. In contrast, teat canal diameter is a positive parameter estimate. For lactation number, an increasing risk is seen from first to fourth and following lactations as well. For infection rate, no significant differences between 1st and 2nd or between 3rd and ⩾4th lactation were found.

Discussion

Ultrasound examination as reported by Neijenhuis et al. (2001) and Franz et al. (2003) is a very useful tool to measure teat and teat canal structures. The method used in the present study showed a high repeatability in connection with the practical experience of the people involved. Quality of imaging of the teat and its structures was dependent on teat dipping in a water-filled plastic cup to identify exactly the tip of teat (Will et al. 1990; Franz et al. 2003).

Mean values of the parameters are different from those reported earlier (McDonald, 1968a; Grindal et al. 1991; Hamana et al. 1994) especially in the longer teat canal. These outcomes are explained by the use of different kinds of methods and mechanical manipulation of the teats to be examined. Further reasons for the different results are the inclusion of Furstenberg's rosette; time of examination relative to milking time; lactation number; and genetic differences between the breeds examined.

In the present study, no significant differences were found between parameters of front and rear teats, which contrasts with the findings of McDonald (1968a), Hamann (1989) and Hamann & Burvenich (1994) who found differences in teat canal measurements. McDonald (1968a) found slightly smaller and shorter teat canals of front teats and Hamann & Burvenich (1994) found significantly smaller teat canal diameter in front teats. Brown Swiss cows had relatively small teats with the shortest and widest teat canals when compared with the other breeds

https://doi.org/10.1017/S0022029905000920 Published online by Cambridge University Press

Table 4. Comparison of teat canal length and diameter of healthy and infected quarters

			teat canal length, mm		teat canal diameter, mm		Significance for length and diameter
		n	Mean	Median	Mean	Median	
all	healthy	801	17·4	17·5	1·8	1·8	*P*<0·001
	infected	267	15·8	15·9	2·1	2·2	
Brown Swiss	healthy	221	15·7	15·9	2·0	2·0	*P*<0·001
	infected	122	14·9	14·9	2·1	2·0	
Simmental	healthy	282	18·3	18·6	1·8	1·8	*P*<0·001
	infected	48	17·6	17·4	2·0	2·0	
Simmental × Red Pied	healthy	102	18·6	18·6	1·9	1·9	*P*<0·001
	infected	20	16·6	17·2	2·2	2·2	
Holstein Friesian	healthy	192	17·2	17·2	1·7	1·6	*P*<0·001
	infected	77	16·1	15·8	2·2	2·3	
1st lactation	healthy	285	16·7	16·9	1·8	1·8	*P*<0·001
	infected	55	15·3	15·1	2·0	2·0	
2nd lactation	healthy	233	17·3	17·7	1·8	1·8	*P*<0·001
	infected	62	15·8	15·8	2·2	2·3	
3rd lactation	healthy	125	17·4	17·4	1·8	1·7	*P*<0·001
	infected	54	15·6	15·9	2·1	2·1	
⩾4th lactation	healthy	158	18·4	18·5	1·9	1·8	*P*<0·001
	infected	96	16·3	15·5	2·1	2·0	

Table 5. Results of the logistic regression

							95·0% CI for Exp (B)	
	B	SE	Wald	df	Significance	Exp(B)	Lower	Upper
tcl†	−0·221	0·030	54·453	1	0·000	0·802	0·756	0·850
tcd	2·030	0·225	81·417	1	0·000	7·616	4·900	11·838
Lactation			44·966	3	0·000			
1st lactation	−1·319	0·219	36·404	1	0·000	0·268	0·174	0·411
2nd lactation	−1·045	0·217	23·183	1	0·000	0·352	0·230	0·538
3rd lactation	−0·368	0·232	2·519	1	0·113	0·692	0·439	1·090
⩾4th lactation	0·000							
Constant	−0·711	0·702	1·025	1	0·311	0·491		

† tcl, teat canal length; tcd, teat canal diameter

examined. Holstein Friesian cows had the smallest teat diameters and also short and tight teat canals. Teats were thickest, including very long teat canals and mean diameters, in Simmental cows and their crossbreeds. Results for teat diameter and length of teat canal are in accordance with findings of Scherzer (1992) and Seyfried (1992), but without any differences in teat diameter between Simmental and Brown Swiss cows.

In some reports, teat and teat canal measurements varied with lactation number (McDonald, 1968b; Binde & Bakke, 1984; Michel & Rausch, 1988; Hamann & Burvenich, 1994): the higher the lactation number, the longer the teat canal. McDonald (1968b) found an increase of 12·1% of teat canal length from first to fourth lactation. Hamann (1989) stated that lengthening of the teat canal is caused by mechanical exposure of the teat during milking. In the first to third lactation, diameter of the teat canal was not different between the cows tested, but at fourth and following lactation it was enlarged. McDonald (1968b) found a dilatation of teat canal diameter from first to fourth lactation up to 53·1% and Hamann & Burvenich (1994) found an increase in the second and third lactations. The increase of thickness of the teat wall and teat diameter also are caused by mechanical exposure and traumatic effects during milking (Hebel et al. 1979).

Many factors are incriminated in the development of mastitis. Natural defence mechanisms against udder pathogens are the teat and teat connective tissue. The influence of teat canal length and diameter on the occurrence of mastitis by bacterial pathogens has been examined (McDonald, 1975; Grindal et al. 1991; Scherzer, 1992; Seyfried, 1992; Hamana et al. 1994; Lacy-Hulbert & Hillerton, 1995). Grindal et al. (1991) could find no significant influence of teat canal length on new infection

https://doi.org/10.1017/S0022029905000920 Published online by Cambridge University Press

rate of the udder but there was a trend towards a decrease of infection with increased length of teat canal. Similar results were obtained by McDonald (1975) and Hamana et al. (1994) but, additionally, they found significant differences in teat canal diameter between healthy and infected udder quarters. Scherzer (1992) postulated that length of teat canal is not associated with acute mastitis, but that a relatively longer teat canal gives rise to more udder pathogens and may be related to chronic or subclinical mastitis. Seyfried (1992) stated that especially long as well as short teat canals enhance bacterial colonization of the mammary gland. Significant relations between length of teat canal and mastitis caused by *Streptococcus uberis*, but not by *Streptococcus agalactiae*, were reported (Lacy-Hulbert & Hillerton, 1995). Our results for length and diameter of teat canal between healthy and infected quarters, which were highly significant, do not agree with the various reports just mentioned. Differences were confirmed within a breed and for lactation number.

Based on the present results, future breeding strategy should be focused on long and narrow teat canals to improve udder health. As limiting factors in terms of economic considerations of dairy cows, milkability and speed of milking should be considered. Our results show that lactation number and measurements of teat canal are important parameters for udder health status.

The authors thank Prof. Dr Petra Winter and the staff of the milk laboratory at the Department of Farm Animals and Herd Management for supporting this study and are grateful for the assistance of Mag. Maria Pont.

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