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Influence of artificial vs. mother-bonded rearing on sucking behaviour, health and weight gain in calves

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ABSTRACT

In artificial rearing, calves are often fed via an automatic milk feeder and have no opportunity to perform natural sucking behaviour. The majority of these calves show abnormal oral behaviours (e.g. cross-sucking). Furthermore, diseases are also a main problem in artificial rearing of calves, and weight gain prior and after weaning is often suboptimal. The aim of this study was to investigate sucking behaviour, health and weight gain in calves that were reared artificially or with unrestricted or restricted contact to their mother, respectively. Two groups of calves suckled by their mothers (unrestricted contact, $n = 14$; twice daily for 15 min before milking, $n = 15$) were compared to two control groups that were both fed via an automatic milk feeder (six times daily, $n = 14$; twice daily, $n = 14$). The calves of the four treatment groups were kept in the same barn and cows were milked twice daily. To analyse sucking behaviour, the calves were observed three times (at ages of 4, 10 and 15 weeks). All calves were weaned at 13 weeks of age. The health state of each animal was assessed daily and veterinary treatments were counted until weaning. The animals were weighed weekly until 3 weeks after weaning. For statistical analyses, linear mixed-effects models were used. Only one mother-fed calf (twice suckled) performed cross-sucking, while 13 of 14 calves in both automatic fed treatments performed cross-sucking ($p < .001$). The health state of both mother-fed groups was poorer ($p = 0.046$, caused mostly by diarrhoea), but the number of animals that had to be treated by a veterinarian did not differ. During the milk feeding period, weight gain was better in mother-fed calves ($p < .001$). After weaning, the weight gain of all four treatment groups was diminished. This effect was stronger in mother-fed calves than in automatic fed calves ($p < .001$). The higher weight gain in mother-fed calves before weaning can be explained by the large milk amounts the calves received. Mother-bonded rearing prevented the development of cross-sucking, even when calves only met their mothers twice daily for 15 min each. Thus, we assume that calves can deal with housing conditions common in artificial rearing when contact with the mother is possible, even if this contact is very limited. We conclude that artificial milk feeders are not able to satisfy sucking motivation completely. Altogether, we reason that permanent and restricted contact with the mother has great behavioural advantages.

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1. Introduction

In the artificial rearing of dairy cattle, calves are usually separated from their mother shortly after birth and further social contact with the mother is usually prevented. Growing up without contact with the mother has severe consequences for young animals (e.g. Harlow and Harlow, 1962). Sucking behaviour is one the most important behaviours in the reproductive process of mammals, as it results in the transfer of milk from mother to the young during suckling (Oftedal, 1999). To perform natural sucking behaviour, calves require contact with the mother (or a foster cow). In artificial rearing, calves are usually fed via bucket or automatic milk feeders and have no opportunity to perform natural sucking behaviours, even if an artificial teat is provided. The majority of artificially reared calves develop abnormal oral behaviours like cross-sucking (e.g. Lidfors, 1993; Keil and Langhans, 2001; Roth et al., 2008). It is known that abnormal oral behaviours are rarely observed in naturally suckled calves (Sato and Kuroda, 1993).

The main aim of this study was to test the effect of unrestricted vs. restricted vs. no contact with the mother on the development of cross-sucking in calves kept under the same housing conditions. It is known that relations with conspecifics are important for young calves (Phillips, 2002). Under natural conditions, the bonding between cow and calf develops soon after birth and usually persists for at least 1 year (Veissier et al., 1990). Besides nutritional benefits, the mother provides the calf with protection and, therefore, has a much larger role in the calf's life than just "milk provider". Much effort has been directed toward reducing cross-sucking (e.g. Haley et al., 1998; Jung and Lidfors, 2001; Jensen, 2003), but none of the efforts has been able to eliminate cross-sucking. We focused on the development of cross-sucking in calves kept under the same rearing conditions except one group ingested their milk artificially and the other did so via udder. We assume that an artificial milk feeder does not provide the needed stimuli to the calves to satisfy sucking behaviour. Therefore, we hypothesise that calves with unrestricted contact to their mother, compared to calves fed by an automatic milk feeder, are less likely to develop abnormal oral behaviours in terms of cross-sucking.

In addition to abnormal oral behaviours, diseases are a main problem in artificial calf rearing. The milk feeding period is very critical in relation to disease problems (Curtis et al., 1988a; Svensson et al., 2003). Calves at this age are most at risk for respiratory diseases and diarrhoea (e.g. Radostits, 2001; Svensson et al., 2003; Lundborg et al., 2005). A benefit of being suckled by the mother has been shown for short-term contact (5 days after birth, Rajala and Castrén, 1995) and for long-term contact (12 weeks, Boonbrahm et al., 2004). Therefore, we hypothesised that calves that have contact with their mothers are less susceptible to diseases.

Weight gain is a valuable parameter that reflects physiological development. It has often been seen in farming practice that weight gain is reduced after the end of milk provision (e.g. Kirchgessner, 2004; Khan et al., 2007). We assumed that calves in contact with their mothers gain more weight.

Aims of the study were to test the effect of unrestricted vs. restricted vs. no contact with the mother on cross-sucking, health state and weight gain in calves kept under the same housing conditions.

2. Materials, animals and methods

2.1. Animals and housing

The experiment was carried out from August 2006 to August 2007 at the Institute of Organic Farming (Federal Research Institute for Rural Areas, Forestry and Fisheries) in Trenthorst, Germany. Fifty-seven calves (25 Holstein Friesian, two cross-breeds, and 32 German Red Pied dual purpose, one cross-breed) were evenly distributed among four treatment groups according to the mother's lactation number and season. The treatment groups are described in detail below. The two breeds were kept separately in two identical stables in the same building. The two pens for the calves were equipped with a lying (deep litter, 16 m^2) and an activity area (rubber-coated and concrete floor, 46 m^2). The pens were open on one side, but the animals had no access to a pasture. The groups were formed dynamically, and group size did not exceed 13 and 17 calves for the Holstein Friesian and Red Pied dual purpose breeds, respectively. Hay and water were available ad libitum. Each of the two pens was equipped with a computer controlled milk feeder (Stand alone 2000, FA Förster-Technik GmbH, Engen, Germany) and a concentrate feeder (FA Förster-Technik GmbH, Engen, Germany) to which all calves had free access at all times. A chip in the neckband allowed each calf to be identified. The feeding computer automatically recorded the daily concentrate and milk consumption of the calves individually.

2.2. Treatment groups

Two treatment groups were suckled by their mothers ($M > 2$: unrestricted contact, $n = 14$; $M = 2$: contact twice daily for 15 min before milking, $n = 15$). In addition, two control groups were fed a similar number of whole milk meals via an automatic milk feeder, but without contact to the cows ($A = 2$: twice daily, $n = 14$; $A > 2$ six times daily, $n = 14$, see Table 1). The feeding frequency in groups $A > 2$ and $A = 2$ was chosen to mimic the potentially different sucking frequency in $M > 2$ and $M = 2$. All calves were born at the institute. They were kept for 5 days after birth in calving pens with (groups $M > 2$ and $M = 2$) or without (groups $A > 2$ and $A = 2$) their mother. Six days postpartum, calves were brought into the calf area ($M = 2$, $A > 2$, $A = 2$) or the cow area ($M > 2$). Each calf received colostrum no later than 4 h after birth. All cows were milked twice daily. Regarding the form of milk ingestion and number of meals, the treatment groups were characterised as follows:

- Group $M > 2$: Calves were fed by their mothers. They had unrestricted contact to the calf area as well as to the cow area (except during milking) to meet their mothers until weaning at 91 days of age. *A* chip in the neckband provided access to the cow area via a selection gate. Only $M > 2$-calves had access to the cow area.

Table 1
Treatment groups: characteristics, sex, breed, birth weight, and number of animals per treatment group.

Group name	Milk source	Frequency of milk meals	Sex		Breed		Birth weight[a] ± S.E.M.[b]
			♀	♂	Holstein Friesian	Red Pied dual purpose	
$M > 2$	Mother	Approx. 6	8	6	6	8	46.3 ± 5.3
$M = 2$	Mother	2	10	5	7	8	45.9 ± 5.3
$A > 2$	Automatic milk feeder	Approx. 6 (4.9 ± 0.2)	7	7	6	8	43.7 ± 4.2
$A = 2$	Automatic milk feeder	2 (2.3 ± 0.2)	7	7	6	8	45.0 ± 4.8

[a] Treatment groups and sexes did not differ in birth weight (model G, see the statistic's section).
[b] Standard error of mean.

- Group $M = 2$: Calves were fed by their mothers. Calves had restricted contact to their mothers and were fed for 15 min twice daily before milking until weaning at 91 days of age. To suckle their calves, cows were brought to the calves' activity area. In order to allow for undisturbed sucking, during these 15 min, only $M = 2$-calves had access to this area.
- Group $A > 2$: Calves were fed 8 L of whole milk by an automatic milk feeder approximately six times per day (actual frequency of milk intake 4.9 ± 0.2, portion size: 1.0–2.0 L). After 11 weeks, milk was gradually reduced to 3 L per day until weaning at 91 days of age. Milk allowance started at the earliest at 03:00 and lasted approximately until 20:00.
- Group $A = 2$: Like $A > 2$, calves were fed 8 L of whole milk by an automatic milk feeder, but only two times per day (actual frequency of milk intake 2.3 ± 0.2, portion size: 4 L). After 11 weeks, milk was gradually reduced to 3 L per day until weaning at 91 days of age. Milk allowance started at the earliest at 05:00 and lasted approximately until 20:00.

The concentrate amounts provided were the same for all calves (gradual increase from 0.1 kg to 2 kg per day during the first 6 weeks, then constantly 2 kg per day until weaning). All calves were weaned and relocated at 91 days of age, which agrees with the guidelines for organic farming in the EU. The feeding schedule after weaning was the same for all calves (water and silage ad libitum plus approximately 1.5 kg concentrate per day per animal).

2.3. Behavioural observations

Each calf was observed three times for 4 h per day on two consecutive days using direct ($M > 2$, from 1.30–3.30 p.m. and 5–7 p.m.) and video observations ($M = 2$, $A > 2$ and $A = 2$, 3–7 p.m.). Observations before weaning were defined such that at least one milk ingestion of each calf could be observed. Therefore, observations were done during most active time. For $M > 2$-calves, observations were interrupted during milking because these calves had no access to their mothers for 2.5 h. Observations were carried out at 4, 10 and 15 weeks of age. We recorded sucking on the udder (mother or alien cow), the milk feeder (artificial teat was only available when the calf obtained milk), another calf (cross-sucking), and the equipment in the pen (never observed).

We noted the start and end of each sucking bout. The time and duration of each visit to the milk feeder were automatically recorded by the computer. To assess the amount of consumed milk of $M = 2$- and $M > 2$-calves, the milk yield of cows of $A > 2$- and $A = 2$-calves and of $M > 2$- and $M = 2$-calves were compared (Schneider et al., 2007). Due to technical problems, the sample size is smaller for the first and second observation than the total sample size of 57 calves, as indicated in Table 1 (first observation $n = 45$, second observation $n = 52$). For behavioural observations and analysis, the software Interact (version 7.4.2.1) was used.

2.4. Health state

The health state of each calf was evaluated daily by trained caretakers according to a scoring list (Roth et al., 2009) from week two until weaning at 13 weeks of age. The general condition, state of eyes, nose, ears and navel, incidence of cough, and dirtiness caused by faeces were evaluated. Points from 0 to 2 were assigned such that higher scores corresponded to a poorer health state. Each animal's points were summed (health score) and all veterinary treatments of infectious disease were recorded for each calf.

2.5. Calculation of weight gain and solid food intake

Calves were weighed at birth and then weekly until 3 weeks after weaning (16 weeks of age). The daily weight gain of each animal was calculated and averaged monthly. The feeding computer recorded the number of visits to the concentrate feeder and the amounts of concentrate consumed for each calf individually.

2.6. Statistical analysis

Generalised linear mixed-effects models were used to analyse the influence of the frequency of milk intake and the form of milk ingestion on sucking behaviour (models A–B), health state (models C–D) and weight gain (models E–I). The applied covariance structure was a general positive-definite matrix. In all models, the frequency of milk meals (twice daily vs. six times daily), the form of milk ingestion (mother vs. milk feeder), its two-way interaction, breed and sex were used as explanatory variables. Where indicated, a time factor (respective age on observation date) and its interactions with the frequency and form of milk ingestion were included as explanatory variables. Starting from the full model, we used a stepwise backward method to find an appropriate final model. The 5% significance level of the partial F statistic was applied as a threshold for exclusion of explanatory variables from the model. We examined the assumptions of normally distributed errors and homoscedasticity graphically, with the use of the Normal plot (residual quantiles versus quantiles of a normal distribution), the Tukey–Anscombe plot (residuals versus estimates), and plots of the residuals vs. all explanatory variables. All calculations were done using R (version 2.6.1, R Development Core Team, 2007).

2.6.1. Sucking behaviour (models A–B)

Because a normal distribution of errors could not be achieved, the number of animals showing cross-sucking (model A) was dichotomised (exhibiting cross-sucking during observation yes/no) and a logistic model was applied. The observation dates (4, 10 and 15 weeks of age) were additionally included as explanatory variables in the model. Interactions could not be considered because these led to overfit and numeric problems. The random effect of the calf was included to consider repeated measurements.

For duration of milk intake (model B), the random effect of the calf was also included to consider repeated measurements. Analysis of duration of cross-sucking and number of sucking bouts (cross-sucking and milk intake separately) is descriptive.

2.6.2. Health state (models C–D)

To analyse health state, health score (model C) served as a response variable. Furthermore, veterinary treatments (model D) were used as dichotomous response variable (treated yes/no).

2.6.3. Weight gain (models E–I) and solid food intake

For the analysis of weight gain (model E), the month (first, second, third before weaning) and the interaction with frequency and form of milk ingestion were included in the model. The random effect of the calf was included to consider repeated measurements. Since weight gain before and after weaning did not develop linearly, a separate model analysing weight gain in month four (model F) was calculated. To analyse absolute weight, three models were examined: birth weight (model G), weight at weaning (model H) and weight 3 weeks after weaning (model I). Solid food intake data is descriptive.

3. Results

3.1. Sucking behaviour

3.1.1. Cross-sucking (model A)

In total, 13 of 14 $A > 2$-calves and 13 of 14 $A = 2$-calves showed cross-sucking. Only one $M = 2$-calf (the same individual in each observation) and none of the $M > 2$-calves were observed cross-sucking (Fig. 1). At 4 and 10 weeks of age, 8 and 12 $A > 2$-calves and 8 and 13 $A = 2$-calves performed cross-sucking, respectively. After weaning, 1 $A > 2$-calf and 4 $A = 2$-calves showed cross-sucking. The form of milk ingestion (mother vs. milk feeder, $t_{55} = -6.45$, $p < .0001$) and time of observation (10 weeks vs. 4 weeks, $t_{94} = 5.07$, $p < .0001$; 15 weeks vs. 4 weeks, $t_{94} = -8.01$, $p < .0001$) had a significant influence on cross-sucking. Sucking of the pen itself was never observed.

3.1.2. Duration of milk intake (model B)

The total duration of milk intake was twice as long for mother-fed calves (Table 2) than for calves fed by the milk feeder. This behaviour remained constant with increasing age in $M > 2$- and $M = 2$-calves, but decreased in $A > 2$- and $A = 2$-calves (form of milk ingestion × age at observation $F_{1,44} = 5.15$, $p = 0.0283$). The duration of milk intake was similar in $M > 2$- and $M = 2$-calves, and the duration of milk intake was also similar in $A > 2$- and $A = 2$-calves. Table 2 shows duration and frequency of cross-sucking and milk intake in all treatment groups.

3.2. Health state

Analysis of total health score (model C) revealed a poorer health state for $M > 2$- and $M = 2$-calves compared

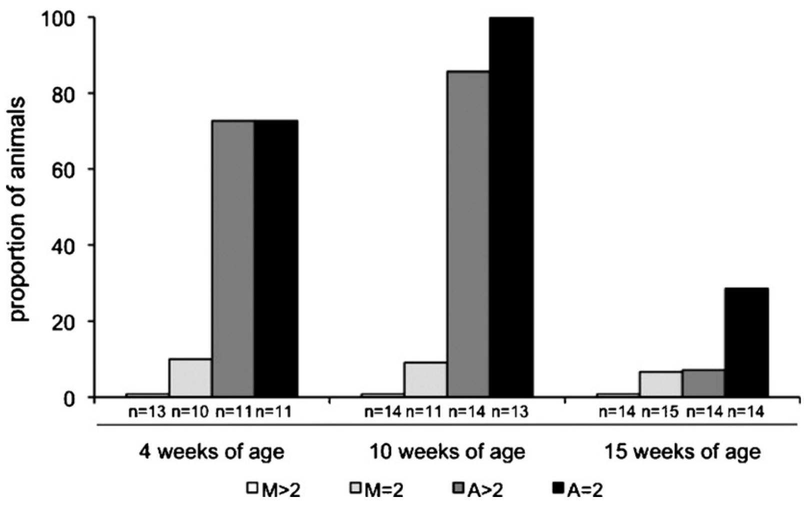

Fig. 1. Proportion of $M > 2$-calves (unrestricted contact to their mother), $M = 2$-calves (fed twice daily by their mother), $A > 2$-calves (fed several times daily by an automatic milk feeder) and $A = 2$-calves (fed twice daily by an automatic milk feeder) performing cross-sucking during observations at 4, 10 and 15 weeks of age.

Table 2
Mean duration of cross-sucking and milk intake (min per 4 h observation) and mean number of sucking bouts (per 4 h observation) of $M > 2$-calves (fed several times daily by their mother), $M = 2$-calves (fed twice daily by their mother), $A > 2$-calves (fed several times daily by an automatic milk feeder) and $A = 2$-calves (fed twice daily by an automatic milk feeder) at 4, 10 and 15 weeks of age.

	Age (weeks)	$M > 2$ Mean ± S.E.M.[a]	$M = 2$ Mean ± S.E.M.[a]	$A > 2$ Mean ± S.E.M.[a]	$A = 2$ Mean ± S.E.M.[a]
Duration of cross-sucking (min/4 h)	4	0.00 ± 0.0	0.10 ± 0.1	3.24 ± 1.4	2.04 ± 0.7
	10	0.00 ± 0.0	0.08 ± 0.1	1.64 ± 0.4	4.74 ± 1.8
	15	0.00 ± 0.0	0.02 ± 0.0	0.02 ± 0.0	1.16 ± 0.9
Frequency of cross-sucking (per 4 h)	4	0.00 ± 0.0	0.10 ± 0.1	1.59 ± 0.4	2.64 ± 1.0
	10	0.00 ± 0.0	0.05 ± 0.0	2.43 ± 0.6	3.85 ± 0.8
	15	0.00 ± 0.0	0.03 ± 0.0	0.04 ± 0.0	0.35 ± 0.2
Duration of milk intake (min/4 h)	4	12.51 ± 1.6	12.58 ± 0.7	6.12 ± 0.9	5.37 ± 0.5
	10	13.18 ± 1.8	12.82 ± 0.6	5.17 ± 1.0	4.58 ± 0.6
Frequency of milk intake (per 4 h)	4	1.88 ± 0.3	1.60 ± 0.2	1.64 ± 0.1	1.11 ± 0.1
	10	1.68 ± 0.3	1.36 ± 0.7	1.29 ± 0.1	1.04 ± 0.1

[a] Standard error of mean.

to $A > 2$- and $A = 2$-calves ($F_{1,51} = 4.19$, $p = 0.0458$). The main proportion (68.1%) of health scores in $M > 2$- and $M = 2$-calves originated from diarrhoea. The number of animals treated by a veterinarian (model D) did not differ among the groups. The majority of treatments were for diarrhoea (56.3%) or respiratory diseases (22.9%). In total, 47.4% of all calves were treated by a veterinarian at least once (range 1–4). The mean health scores and the numbers of animals treated are listed in Table 3.

3.3. Weight gain and solid food intake

3.3.1. Weight gain and absolute weight

Weight gain differed substantially between $M > 2$- and $M = 2$-calves and $A > 2$- and $A = 2$-calves. During the milk feeding period, $M > 2$- and $M = 2$-calves gained considerably more weight (model E, Fig. 2) than $A > 2$- and $A = 2$-calves ($F_{1,54} = 60.24$, $p < .0001$). The weight gain of all calves increased from birth until weaning ($F_{2,111} = 35.94$, $p < .0001$). As expected, male calves gained more weight before weaning than female calves ($F_{1,54} = 11.10$, $p = 0.0016$). Weight gain after weaning (model F, Fig. 2) showed a different pattern in that $M > 2$- and $M = 2$-calves gained less than $A > 2$- and $A = 2$-calves ($F_{1,53} = 59.45$, $p < .0001$) and calves that had been fed several times per day during the milk feeding period gained more than calves that had been fed only twice a day ($F_{1,53} = 4.24$, $p = 0.0444$).

Absolute weight at weaning amounted to 146.0 (±5.6), 138.9 (±5.6), 113.3 (±2.6), and 117.0 (±1.7) for $M > 2$-, $M = 2$-, $A > 2$-, and $A = 2$-calves, respectively, and was higher (model H) for $M > 2$- and $M = 2$-calves than for $A > 2$- and $A = 2$-calves ($F_{1,54} = 50.12$, $p < .0001$). Male calves weighed more than female calves ($F_{1,54} = 9.39$, $p = 0.0034$). $A = 2$- and $A > 2$-calves did not recover their absolute weight until 3 weeks after weaning: absolute weight amounted to 162.3 (±5.8), 153.4 (±5.6), 138.1 (±2.7), and 138.4 (±2.3) for $M > 2$-, $M = 2$-, $A > 2$-, and $A = 2$-calves, respectively, and was higher (model I) for $M > 2$- and $M = 2$-calves than for $A > 2$- and $A = 2$-calves ($F_{1,54} = 25.07$, $p < .0001$). Again, male calves weighed more than female calves ($F_{1,54} = 9.30$, $p = 0.0035$).

3.3.2. Solid food intake

Amounts of food taken in differed substantially between mother-fed calves and calves fed by the automatic feeder. From birth until weaning, total concentrate intake of $M > 2$- and $M = 2$-calves averaged 1.73 kg (±0.51) and 3.75 kg (±0.63), respectively, whereas $A > 2$- and $A = 2$-calves consumed 21.28 kg (±2.26) and 21.74 kg (±3.25).

4. Discussion

Calves that were allowed to perform natural sucking behaviour did not develop cross-sucking, regardless of the duration of contact with the mother (restricted or unrestricted), except for one calf with restricted contact. The number of animals treated by a veterinarian was similar irrespective of the frequency and form of milk ingestion. Also, calves having contact with the mother gained more weight before weaning, but less after weaning than calves fed by the automatic teat feeder.

4.1. Sucking behaviour

In this experiment only sucking on the mother fully prevented cross-sucking, except for one calf, whereas

Table 3
Mean health score and number of treated animals (±S.E.M.) of $M > 2$-calves (fed several times daily by their mother), $M = 2$-calves (fed twice daily by their mother), $A > 2$-calves (fed several times daily by an automatic milk feeder) and $A = 2$-calves (fed twice daily by an automatic milk feeder) from 1 week after birth until weaning at 13 weeks.

	$M > 2$ ($n = 14$)	$M = 2$ ($n = 15$)	$A > 2$ ($n = 14$)	$A = 2$ ($n = 14$)
Mean health score	31.27 ± 5.01	35.93 ± 4.52	26.58 ± 3.84	23.14 ±3.50
Mean health score (diarrhoea only)	21.38 ± 12.54	24.39 ± 17.33	20.27 ± 9.26	14.39 ± 9.49
Number of animals treated by a veterinarian	7	7	7	6

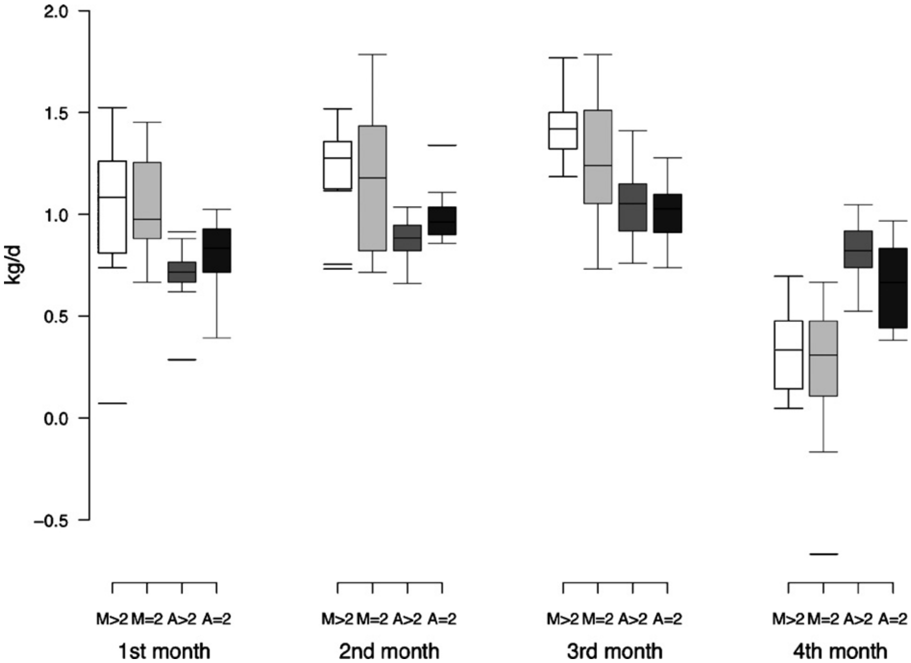

Fig. 2. Daily weight gain (kg/d, median with first and third quartiles) during the first 4 months of age in $M > 2$-calves (fed several times daily by their mother), $M = 2$-calves (fed twice daily by their mother), $A > 2$-calves (fed several times daily by an automatic milk feeder) and $A = 2$-calves (fed twice daily by an automatic milk feeder).

almost all calves (92%) fed by the automatic milk feeder developed cross-sucking. Even calves that were allowed to meet their mother only for two times 15 min per day did not exhibit cross-sucking (again, except for one calf). This supports our hypothesis that milk intake via an artificial teat does not fully satisfy the calves' motivation to perform sucking behaviour.

This high proportion of cross-sucking $A > 2$- and $A = 2$-calves may be enforced by fact that the automatic milk feeder did not provide a dry teat (i.e. the possibility to suck a teat when no milk was available). However, other studies where the milk feeder was equipped with a dry teat also found a remarkable proportion of cross-sucking calves (e.g. Jensen, 2004: 51%; Roth et al., 2007: 85.4%; Roth et al., 2008: 85.2%). Furthermore, it is known that an enriched environment (e.g. access to a barnyard) may reduce the occurrence of cross-sucking (Keil et al., 2000). Therefore, we expected a slightly lower proportion of cross-sucking calves in this study, because the calves were provided a high space allowance (deep litter, 16 m^2) with access to an activity area (46 m^2) that is comparable to a barnyard.

Notably, the duration of milk intake was prolonged for mother-fed calves. Prolonged milk intake has been suggested to reduce non-nutritive sucking or cross-sucking in several studies (Aurich and Weber, 1994; Haley et al., 1998; Jung and Lidfors, 2001), but none of these studies could eliminate cross-sucking totally. In a previous study, we found that a weaning method that aimed to cover the nutritional needs of each calf reduced the number of animals performing cross-sucking, but could not completely eliminate cross-sucking, either (Roth et al., 2008). Additionally, further studies describe a variety of methods to reduce cross-sucking (e.g. feeding stall with a self-enclosing mechanism: Weber and Wechsler, 2001; teat vs. bucket feeding: Jensen and Budde, 2006). Although much effort has been directed at optimising artificial rearing, none of the previously described methods was able to eliminate cross-sucking in calves that had no access to their mother or a foster cow. Furthermore, it has been shown that restricted suckled calves released more oxytocin compared to bucket fed calves (with or without contact to the mother, Lupoli et al., 2001). It is assumed that oxytocin has "anti-stress" effects, such as decreased blood pressure and lower cortisol levels (Uvnäs-Moberg et al., 2001). Lupoli et al. (2001) found that higher oxytocin levels in response to suckling were followed by a late decrease in cortisol after suckling in calves. The release of cholecystokinin and insulin was found to be higher in calves that were allowed to perform non-nutritive sucking after milk ingestion (de Passillé et al., 1993). In rats and humans, it has been shown that suckling induces a calming effect on the newborn (Blass, 1994). However, this calming effect has not (yet) been proved for calves.

All these findings indicate that during sucking, several physiological processes are activated, which we believe may be insufficiently triggered by automatic feeding systems. It is unlikely that today's automatic feeding systems are able to satisfy the calf's behavioural requirements of sucking. The fact that $M = 2$-calves did not develop cross-sucking leads us to the conclusion that calves can cope with rearing conditions common in artificial rearing when they are suckled by the mother, even if this contact to the mother is very limited.

4.2. Health state

Almost half of all animals (47%) needed a treatment by a veterinarian at least once. Even though it is rather high, this rate is comparable to those reported in other studies (Rajala and Castrén, 1995: 66%; Quigley et al., 2006: 48.7–72.5%; Svensson and Jensen, 2007: 78%; Roth et al., 2009: 49%). As reported in other studies, the main medical issues resulted from diarrhoea and respiratory diseases (Svensson et al., 2003; Boonbrahm et al., 2004; Lundborg et al., 2005; Svensson and Liberg, 2006).

Contrary to our hypothesis, the health state of $M = 2$- and $M > 2$-calves was not better than health state of $A = 2$- and $A > 2$-calves. This can be explained by the enormous milk amounts the calves consumed, which caused a high incidence of diarrhoea. However, these cases of diarrhoea were not infectious as suggested by the fact that same number of animals were treated in all groups. However, we do not know the extent of negative impact of diarrhoea on the animals' well-being and whether this high incidence of diarrhoea could lead to long-term damage in the animal. Because all calves were kept in the same barn, calves of all treatment groups fell ill similarly frequently. Furthermore, the careful administration of colostrum after birth assured the same immune protection for all calves. It is known that the health state is mainly affected by husbandry, management and feeding practices (Curtis et al., 1988b; Radostits, 2001; Svensson et al., 2003). We conclude that health state could not be improved by permanent or restricted contact to the mother.

4.3. Weight gain and solid food intake

The large differences in weight gain before and after weaning were caused by the unequal milk and concentrate intakes depending on the treatment. Mother-fed calves gained significantly more weight during the milk feeding period, supporting the findings of de Passillé et al. (2008) and Flower and Weary (2001). We assume that during the milk feeding period, $M = 2$- and $M > 2$-calves consumed considerably more milk than $A = 2$- and $A > 2$-calves, although we did not measure milk consumption of mother-fed calves directly. Milk amounts of multiparous cows of *A*-calves and *M*-cows amounted in average about 29 and 14 L milk per day, respectively, with no differences between $M = 2$- and $M > 2$-cows (Schneider et al., 2007). Thus, the difference of the amounts milked in the parlour amounted to approximately 15 L per day per cow. We have to assume that the *M*-calves consumed the main proportion of this "missing" amount of milk. Of course, the large amounts of milk led to markedly higher weight gain in mother-fed calves during the milk feeding period. Weight gain of mother-fed calves was similar to or higher than that of ad libitum artificially fed calves (e.g. Appleby et al., 2001; Jasper and Weary, 2002; von Keyserlingk et al., 2006; Borderas et al., 2007), unrestricted suckled calves of comparable breeds (e.g. Schiessler et al., 2002), veal calves (e.g. Cozzi et al., 2002, but these animals were older), and was even higher than weight gain of beef calves (e.g. Grings et al., 2008) and foster calves (e.g. Rosecrans and Hohenboken, 1982). The weight gain of $M = 2$-calves was higher than previously reported for calves suckled twice daily (e.g. Boonbrahm et al., 2004; de Passillé et al., 2008; Fröberg et al., 2008). Whereas calves in other studies were suckled after milking, calves in this study were suckled immediately before milking. By this, they drank more milk per meal than in artificial feeding regimes where a meal consists of approximately 1–4 L milk. Nevertheless, in all treatment groups, and not only in the mother-fed calves, weight gain before weaning was considerably higher than the recommended weight gain of 750 g/d (Kirchgessner, 2004). After weaning, weight gain was clearly reduced in all treatment groups, but much more for mother-fed calves.

Calves fed by the milk feeder consumed more concentrate during the milk feeding period than mother-fed calves. It is well known that a high milk intake is associated with a low concentrate intake (Jasper and Weary, 2002; Hepola, 2003; Borderas et al., 2007) and that rumen development is positively influenced by concentrate intake (Tamate et al., 1962; Lesmeister and Heinrichs, 2004; Roth et al., 2009). We thus assume that calves fed by the milk feeder had better rumen development and were therefore more likely after weaning to be able to cover their energy demands with solid food only. The higher concentrate consumption and the better weight gain of $A > 2$- and $A = 2$-calves after weaning might be an effect that has been enforced by the gradual weaning we applied to these calves during the last 2 weeks of the milk feeding period. Further studies are required to develop methods to gradually wean mother-fed calves in order to initiate their rumen development.

4.4. Influence of restricted vs. unrestricted contact to the mother

To our surprise, $M = 2$- and $M > 2$-calves did not differ in any of the measured parameters. We expected that the influence of living in a group of adults and having unrestricted contact with the mother on $M > 2$-calves would be notable. However, it seems that two daily 15 min cow–calf encounters is enough to satisfy the calves' requirements for bonding to the cow.

5. Conclusion

We conclude that today's artificial milk feeders are unlikely to satisfy sucking motivation completely. Calves having contact with their mother are able to cope with housing conditions common in artificial rearing even if this contact is very limited. Altogether, we reason that permanent or restricted contact with the mother has great behavioural advantages. However, the high incidence of diarrhoea is unfavourable.

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