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Improved weaning reduces cross-sucking and may improve weight gain in dairy calves

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Abstract

Artificially reared dairy calves are weaned as soon as possible for economic reasons, often without sufficient consideration of individual differences in capability to eat dry food. A particularly critical situation occurs when milk provision is discontinued without knowing whether the calves are able to cover their nutritional requirements with solid food only. Possible consequences are diminished weight gain and abnormal oral behaviour (especially cross-sucking). In this study, a concentrate-intake-dependent weaning method (reduction of milk allowance dependent on an increasing consumption of concentrate ($n = 14$ calves: individually weaned calves)) was compared with a conventional weaning method generally used on Swiss farms (milk provision ended at 11.5 weeks of age irrespective of concentrate intake ($n = 13$ calves: conventionally weaned calves)). The sucking and feeding behaviour of each calf was observed three times for two consecutive days (1 week after grouping, 1 week before and 1 week after the end of milk provision). Each calf was weighed twice weekly. Individually weaned calves reduced cross-sucking occurring independently of milk intake with increasing age, whilst this was not observed in conventionally weaned calves ($P = 0.002$). There was a tendency for weight gain in individually weaned calves to increase steadily, whereas the weight gain of conventionally weaned calves remained constant after milk provision was stopped ($P = 0.069$). These findings indicate that optimised management of weaning bearing the individual animal's development in mind improves production and welfare in dairy calves.

Keywords: Abnormal behaviour; Artificial weaning; Cross-sucking; Dairy calves; Weight performance

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1. Introduction

The newborn calf is not yet capable of digesting solid food, but instead develops into a ruminant during the first few months of life (Kirchgessner, 2004; Garnsworthy, 2005). Under natural conditions, the weaning process of a calf is completed at about 9–11 months of age (Reinhardt and Reinhardt, 1981). In the artificial rearing of dairy cattle, calves are meant to be weaned as soon as possible for mainly economic reasons, e.g. solid food costs less than milk (Garnsworthy, 2005) and the provision of solid food is less labour-intensive than the provision of milk.

Conventional milk feeding plans normally consider the age of the calves as the sole criterion for milk allowance and weaning. When one feeding plan is applied like this to all calves, however, it is scarcely possible to consider individual differences in capability to eat dry food. Moreover, milk allowance for calves in poor health should not be reduced too quickly, as the growth development of calves lessens during illness (Radostits, 2001). Failing to bear in mind individual characteristics means at worst that the calves' ability to cover their nutritional needs with solid food only after milk feeding has stopped cannot be guaranteed. A possible consequence of this is diminished weight gain, which is commonly seen in dairy calves after weaning (Kirchgessner, 2004). Furthermore, it has been shown that an inappropriate feeding management around weaning is likely to enhance cross-sucking in dairy calves, because less adequate ration energy density has been shown to be related to increased cross-sucking frequency (Keil and Langhans, 2001).

Most studies suggest that cross-sucking is mainly elicited by feeding milk, since sucking motivation is elevated for 12–15 min after milk ingestion (e.g. Lidfors, 1993; de Passillé and Rushen, 1997; Margerison et al., 2003). Cross-sucking also occurs in the absence of close temporal association with milk intake, however, as has been found in several studies with prolonged observations after milk consumption. Such cross-sucking bouts accounted for a remarkable proportion of all observed cross-sucking events (e.g. Veissier et al., 1998; Keil and Langhans, 2001; Weber and Wechsler, 2001). Questions thus arise as to why cross-sucking occurs not only after milk intake, but also temporally independently of it, and how cross-sucking can be explained by nutritional deficits. Hunger is known to enhance sucking motivation in calves (de Passillé and Rushen, 1997). This may be especially important when a calf is fed according to an inadequate weaning schedule, where milk is reduced despite the calf's rumen not being capable of sufficiently digesting solid food. We therefore assumed that milk-independent cross-sucking is triggered not only by milk intake, but also by other motivational mechanisms, one of them likely being hunger.

The improved weaning method used in the present study was therefore based on the concept that milk allowance should be reduced in close relation to the individual calf's concentrate intake. This weaning method aims to cover the nutritional needs of each calf at any time during the milk feeding period, and ensures that calves are not weaned from milk until they are able to feed on solid food only. The consideration of the individual animal's potential to become a ruminant should thus reduce the negative consequences of premature weaning, such as diminished weight gain, or cross-sucking occurring independently of milk intake.

The aim of this study was therefore to test the effect of this individual and concentrate-dependent artificial weaning method on performance and cross-sucking occurring independently of milk intake in artificially reared dairy calves.

2. Materials, animals and methods

2.1. Animals and housing

The experiment was carried out from March to June 2004 at Agroscope Reckenholz-Taenikon Research Station ART in Taenikon (Ettenhausen, Switzerland). Twenty-seven dairy calves (23 Swiss Brown, 2 Swiss Brown × Limousin and 2 Red Holstein × Simmental) were assigned to two treatment groups. Calves were matched to pairs according to sex, feeding management (e.g. milk allowance, feeding of concentrate or hay) and husbandry at their farm of origin, and also to weight and age at point of purchase. The two calves of each pair were assigned randomly to treatment to create two comparable groups. One group was conventionally weaned (conventionally weaned calves: 3 female calves and 10 male calves), the other group was individually weaned (individually weaned calves: 3 female calves and 11 male calves). All of the female calves and two of the male calves (one in each group) were born at Agroscope Reckenholz-Taenikon Research Station ART in Taenikon (Ettenhausen, Switzerland), whilst all the other calves (19 male calves) were purchased from 12 Swiss dairy farms.

The average age at grouping was 32 days (range 20–53 days). All calves were kept in an enclosed building in the same pen measuring 36.5 m^2 (1.4 m^2/animal) on deep litter without access to a barnyard or pasture. Hay and water were available ad libitum to all calves. The calves were fed with milk replacer and concentrate by a computer-controlled milk feeder and a concentrate feeder (FA Förster-Technik GmbH, Engen, Germany), to which they had free access at all times. A chip in the neckband allowed each individual calf to be identified. The automatic milk feeder stall was equipped with a self-enclosing mechanism (according to Weber and Wechsler, 2001) that prevented displacements from the milk feeder by other calves. Calves with diseases were treated by a veterinarian. Groups did not differ in terms of frequency of veterinary treatments (10 and 8 cases of respiratory diseases in individually and conventionally weaned calves, respectively).

2.2. Weaning methods

Three experimental periods were defined (Fig. 1), depending on the daily milk allowance. In period 1, 6 L milk per animal and day were provided for both weaning methods. Period 2 was characterised by the reduction of the daily milk allowance. Period 3 started after milk provision was stopped.

2.2.1. Conventional weaning (conventionally weaned calves)

The feeding schedule for the conventionally weaned calves was based on a conventional weaning method common in Switzerland (Fig. 1(a)), starting with 6 L milk daily at the age of 3 weeks, a reduction in milk allowance beginning at 8 weeks, and the end of milk provision at 11.5 weeks (Swiss Federal Research Station for Animal Production, 1999). Conventionally weaned calves had access to concentrate according to their calculated nutritional need, but the individual's concentrate consumption was not used to adjust milk allowance.

2.2.2. Individual and concentrate-dependent weaning (individually weaned calves)

Like conventionally weaned calves, individually weaned calves received 6 L milk daily at the beginning of period 1 (Fig. 1(b)). Thereafter, each individually weaned calf was fed according to its own individual feeding schedule: as soon as an individually weaned calf consumed more than 700 g concentrate per day, the reduction of milk began (start of period 2). When an individually weaned calf consumed more than 2000 g concentrate per day, milk feeding was stopped altogether (start of period 3). At a consumption level of 1500 g concentrate, for example, 3 L milk were provided to the calf. The correlation between milk amount and concentrate amount was linear. The daily milk allowance was based on the average amount of concentrate consumed over the last 4 days. Milk quantities were rounded up to the nearest half- or full-litre level. In the case of reduced concentrate consumption, the amount of milk remained constant. In contrast to conventionally weaned calves, the length of periods 1 and 2 was thus defined by each calf individually.

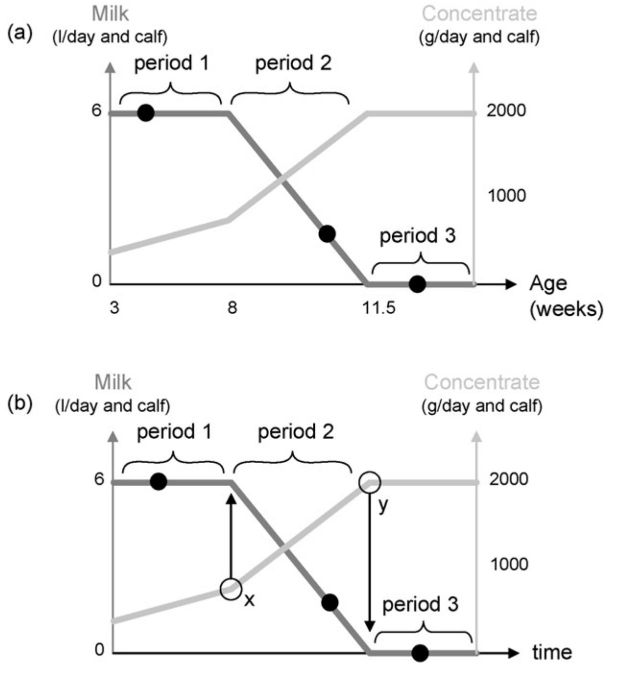

Fig. 1. Weaning method of (a) conventionally weaned calves: experimental periods were defined based on milk allowance. Each of the two consecutive days of observation is marked by (●) and (b) weaning method of individually weaned calves: experimental periods were defined based on milk allowance. Reduction of milk was regulated by concentrate consumption: (x) the intake of 700 g concentrate over a 4-day period triggered the start of milk reduction; (y) the intake of 2000 g concentrate over a 4-day period defined the end of milk provision. Each of the two consecutive days of observation is marked by (●).

2.3. Behavioural observations and calculation of weight gain

Each calf was observed at each of the three periods for two consecutive days using direct (10 h per day, from 6–11 a.m. and 4–9 p.m., according to Keil and Langhans (2001) the most active times of the calves) and video observations (15 h/day on the same days, from 6 a.m. to 9 p.m.). In period 1, the calves were observed 1 week after grouping at an age of 7 weeks (range 5–9 weeks). In period 2, observation was conducted when there was a daily milk allowance of between 1 and 2.5 L (about 1 week before the end of milk provision). The last observation was conducted in period 3, on average 8 days (range 5–12 days) after milk provision had stopped. Observation days were therefore set for each calf according to its feeding schedule.

Cross-sucking was recorded by direct observation. We noted the start and end of each sucking bout and which body part was sucked. To compare cross-sucking occurring independently of milk intake and cross-sucking elicited by milk ingestion, each cross-sucking bout was assigned to the temporally closest visit to the milk feeder on the same day. Each visit to the milk feeder and its time and duration were automatically recorded by the computer. Cross-sucking bouts were defined as milk-dependent and milk-independent. Milk-dependent cross-sucking was recorded if sucking bouts occurred within 15 min after a calf had left the milk feeding stall and had received milk (Weber and Wechsler, 2001). To distinguish the two categories clearly, sucking bouts occurring 15–30 min after the calf had left the stall with milk intake were omitted (26 of 596 observed cross-sucking bouts). All other cross-sucking was defined as milk-independent.

To examine feeding behaviour and assess the calves' capability to eat dry food, hay feeding, ruminating, concentrate consumption and weight performance parameters were recorded. The number of visits to the concentrate feeder, their time and duration, and the amount of concentrate consumed were recorded automatically by the feeding computer. Rumination was recorded individually using time-sampling from the video recordings (at 5-min intervals). In addition, duration of hay feeding was recorded individually by direct observations. The calves were weighed twice weekly. The daily weight gain of each animal per period was calculated on the basis of its weight at the beginning and end of each period.

2.4. Statistical analysis

2.4.1. Comparison of data in period 1

To ensure the equality and statistical comparability of the two groups at the start of the study, all parameters of sucking behaviour, feeding behaviour, weight and age of conventionally and individually weaned calves in period 1 were compared by using ANOVA. Explanatory variables were treatment (conventionally or individually weaned), origin (institute's own or purchased) and sex of the calves.

The only difference was found for the outcome variable weight gain where the institute's calves showed a better gain. However, all calves were distributed over experimental groups evenly, thus differences in treatment cannot be caused by this difference in origin. Neither treatment nor sex showed any significant effect on any of the outcome variables.

2.4.2. Analysis of sucking behaviour and weight gain

To account for the hierarchical design due to repeated measures on the same animal, generalised linear mixed effects models were used to analyse the influence of the two weaning methods on cross-sucking and weight gain. We evaluated three models, analysing (a) total cross-sucking (dependent and independent of milk intake, min per animal and 10 h observation period, logarithmically transformed), (b) cross-sucking independent of milk intake (number of animals exhibiting independent cross-sucking per period), and (c) weight gain (g/day, average of period) as outcome variables.

To account for the hierarchical structure of the experimental design, the random effect of the calf was included in all models. All models included the fixed effects of experimental period (as an ordered factor with the levels P1, P2 and P3), weaning method (conventional, individual), provenance of the calves (home-reared or purchased), and the interaction of period and weaning method.

Because some of the covariates we wanted to use in our analysis might be influenced by the treatment and/or by the experimental periods themselves the potential continuous explanatory variables were first analysed as outcomes in dependence of treatment and period. Four variables were found to co-vary with treatment and/or period with almost no overlap between some treatment/period combinations (frequency of visits to the milk feeding stall without milk provision, duration of visits to the milk feeding stall with milk provision, quantity of milk consumed and amount of concentrate consumed). These were no longer used as explanatory variables. In addition, the correlations between all continuous variables were calculated before inclusion in the model because highly correlated explanatory variables can lead to instability of regression coefficients. In case of a correlation higher than ± 0.75, only the variable with the stronger explanation for our hypothesis was used.

Because normal distribution of errors could not be achieved, the number of animals showing milk-independent cross-sucking had to be analysed by a generalised model based on binomial distribution of the data (model (b)). Milk-independent cross-sucking was defined as a dichotomous outcome variable, meaning that in each period, calves were classified as animals exhibiting or not exhibiting independent cross-sucking during observation time. Because our sample size was too small for a backward model we used a stepwise forward method.

For all models, duration of concentrate feeding (min/animal/day), frequency of visits to the concentrate feeder without feed intake (number/animal/day), duration of hay feeding (min/animal/10 h), frequency of rumination (number/animal/15 h) and – in models a and b – weight gain (g/animal/day/period) were used as covariates in the full model.

For model (c) analysing weight gain, only data from periods 2 and 3 were used, since differences in weight gain due to weaning method were only expected for these two periods. As covariates, the covariates described above were used and, additionally, the duration of cross-sucking dependent and independent of milk intake (min/animal/10 h).

Starting from the full models (a) and (c), 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 versus significant variables. The stepwise forward approach used for model (b) used the same set of potential variables. In all final models, experimental period and treatment were retained as fixed effects independent of their p-value. All calculations were done using S-Plus (version 6.1 and 6.2).

3. Results

3.1. Duration of experimental periods and feeding behaviour

Owing to the variation in the age of the calves at grouping, as well as the different weaning methods used, the duration of periods 1 and 2 could differ between the two groups. The duration

Table 1
Average values and range of the covariates used, in relation to the weaning method (individually weaned calves, conventionally weaned calves) and the experimental period (P1: 6 L milk per day; P2: reduction of milk; P3: after the end of milk provision)

	Individually weaned calves	Conventionally weaned calves
Duration of visits to the milk feeding stall with milk provision (min/animal/10 h)	P1: 10.7 (5.0–19.8); P2: 6.5 (0.0–17.6); P3: 0.0 (0.0–0.0)	P1: 9.8 (6.5–13.2); P2: 5.7 (1.4–11.3); P3: 0.0 (0.0–0.0)
Frequency of visits to the milk feeding stall without milk provision (number/animal/10 h)	P1: 5.3 (1.0–11.5); P2: 4.9 (1.5–11.0); P3: 1.4 (0.0–4.0)	P1: 5.2 (0.0–17.5); P2: 5.4 (2.5–8.5); P3: 2.6 (0.0–14.0)
Duration of concentrate feeding (min/animal/day)	P1: 23.6 (0.0–49.3); P2: 35.1 (25.8–57.4); P3: 30.7 (23.9–52.8)	P1: 16.4 (0.0–33.7); P2: 24.8 (0.0–46.7); P3: 29.0 (0.0–45.3)
Frequency of visits to the concentrate feeder without feed intake (number/animal/day)	P1: 10.2 (0.0–28.0); P2: 20.6 (2.0–110.5); P3: 47.1 (2.0–141.5)	P1: 10.7 (0.0–28.0); P2: 10.8 (0.0–27.5); P3: 24.4 (0.0–74.5)
Duration of hay feeding (min/animal/10 h)	P1: 86.4 (27.7–155.1); P2: 107.1 (43.8–167.0); P3: 132.6 (73.8–206.6)	P1: 71.9 (22.9–136.8); P2: 121.3 (75.9–201.0); P3: 141.4 (100.5–240.6)
Frequency of rumination (number/animal/15 h)	P1: 26.9 (2.0–43.0); P2: 27.7 (10.0–38.0); P3: 35.8 (29.0–45.0)	P1: 32.8 (13.0–56.0); P2: 35.4 (22.0–46.0); P3: 35.8 (21.0–55.0)
Quantity of milk consumed (L/animal/day)	P1: 5.6 (4.9–5.9); P2: 3.2 (1.9–4.1); P3: 0.0 (0.0–0.0)	P1: 5.6 (5.0–5.9); P2: 3.4 (3.2–3.4); P3: 0.0 (0.0–0.0)
Amount of concentrate consumed (kg/animal/day)	P1: 0.3 (0.1–0.5); P2: 1.5 (1.1–1.8); P3: 2.0 (1.9–2.0)	P1: 0.3 (0.0–0.6); P2: 1.0 (0.0–1.6); P3: 1.7 (0.0–2.0)

of period 1 was similar in both groups, however (conventionally weaned calves: mean 25.5 days, range 12–35 days; individually weaned calves: mean 24.9 days, range 16–37 days). In period 2, individually weaned calves terminated the weaning process on average after 32.9 days (range 21–42 days, median 33.0 days), whilst for all conventionally weaned calves this period was set at 24.0 days. Whereas some individually weaned calves increased their consumption of concentrate very quickly and were therefore weaned rapidly, the milk consumption of other individually weaned calves remained constant at specific levels before the calves again increased their concentrate consumption. Only one (conventionally weaned) calf never visited the concentrate feeder. All other conventionally weaned calves usually consumed the provided amount of concentrate. All parameters of the feeding behaviour in relation to the weaning method and the experimental period are listed in Table 1.

3.2. Cross-sucking

3.2.1. Total cross-sucking, dependent and independent of milk intake

Eighty-five per cent of the calves (13 individually weaned and 10 conventionally weaned calves) were observed cross-sucking at some stage. All these calves exhibited cross-sucking in period 1, and either stopped or continued cross-sucking in periods 2 or 3. More than 98% of all cross-sucking bouts in all periods were directed to the udder, prepuce or scrotum.

The duration of total cross-sucking (dependent and independent of milk intake) decreased with both weaning methods from periods 1 to 3 ($F_{2,51} = 5.24$, $P = 0.009$, Fig. 2). In periods 1 and 2, the proportion of cross-sucking independent of milk intake accounted for at least 62.3% and 71.3% of all sucking bouts in conventionally and individually weaned calves, respectively. Calves spending more time feeding hay cross-sucked other calves for shorter durations ($F_{1,51} = 4.21$, $P = 0.045$). Neither weaning method, nor any other fixed effect had a significant impact on the duration of total cross-sucking.

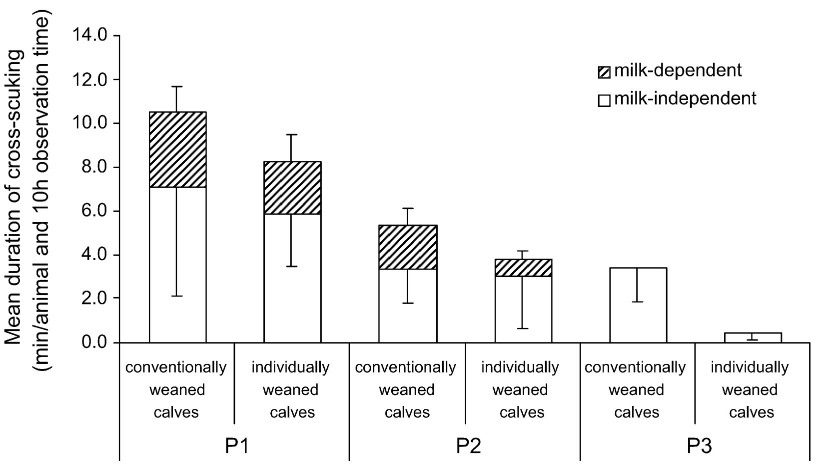

Fig. 2. Mean duration of total cross-sucking (min/animal and per 10 h observation period ± S.E.), classified as milk-dependent (hatched bars) and milk-independent (open bars) cross-sucking, in relation to the experimental period (P1, 6 L milk per day; P2, reduction of milk; P3, after the end of milk provision) and weaning method (conventional, conventionally weaned calves; concentrate-dependent, individually weaned calves). No significant influence by weaning method was found.

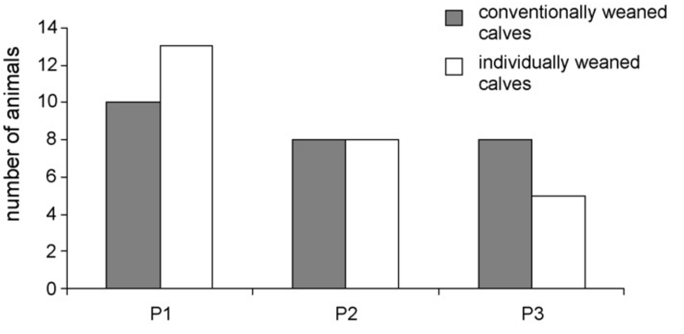

Fig. 3. Total number of conventionally weaned calves (conventional weaning, grey bars) and individually weaned calves (concentrate-dependent weaning, open bars) exhibiting milk-independent cross-sucking in the experimental periods (P1, 6 L milk per day; P2, reduction of milk; P3, after the end of milk provision). Weaning method had a significant influence (period × weaning method: $t_{50} = 3.26$, $P = 0.002$).

3.2.2. Milk-independent cross-sucking

The number of animals exhibiting milk-independent cross-sucking decreased from periods 1 to 3 (Fig. 3) and this process differed between individually and conventionally weaned calves (period × weaning method: $t_{50} = 3.26$, $P = 0.002$). With individually weaned calves, independent cross-sucking decreased constantly over the three periods: 13 calves cross-sucked in the beginning, 5 of which still cross-sucked after the end of milk provision (period 3). In contrast, out of 10 conventionally weaned calves which cross-sucked in period 1, 8 calves still cross-sucked after milk provision was stopped. In addition, calves spending more time feeding hay were less likely to exhibit milk-independent cross-sucking ($t_{50} = -2.21$, $P = 0.032$).

3.3. Weight gain

There was a tendency for weight gain in individually weaned calves to increase steadily, whereas the weight gain of conventionally weaned calves remained constant after milk provision

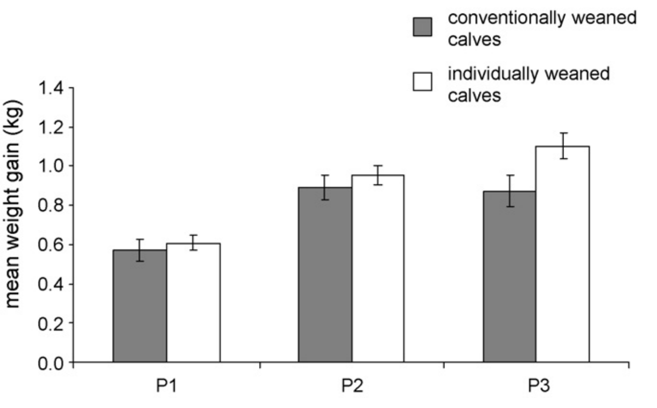

Fig. 4. Daily weight gain (mean values in kg ± S.E.) of conventionally weaned calves (conventional weaning, grey bars) and individually weaned calves (concentrate-dependent weaning, open bars) over the experimental periods (P1, 6 L milk per day; P2, reduction of milk; P3, after the end of milk provision). Individually weaned calves tended to reach better weight gain (period × weaning method: $F_{1,24} = 3.63$, $P = 0.069$).

was stopped (period × weaning method: $F_{1,24} = 3.63$, $P = 0.069$, Fig. 4). Weight gain in individually weaned calves averaged 952 g/day before the end of milk provision (period 2) and 1103 g/day after the end of milk provision (period 3). Conventionally weaned calves had an average daily weight gain of 895 g before and 874 g after milk provision was stopped. The duration of feeding hay had a significant negative influence on weight gain ($F_{1,24} = 15.91$, $P = 0.001$).

4. Discussion

The results of the present study show that the individual and concentrate-intake-dependent weaning method improved weight gain and reduced milk-intake-independent cross-sucking as compared with conventional weaning.

Total cross-sucking (both milk-independent and milk-dependent) decreased over the experimental periods. Milk-dependent cross-sucking was recorded if sucking bouts occurred within 15 min after milk ingestion, cross-sucking outside this time period was recorded as milk-independent (for further explanation see Section 2). The result of total cross-sucking is in line with other studies, where sucking behaviour decreased with increasing age of the calves (e.g. Reinhardt and Reinhardt, 1981; Lidfors, 1993; Keil and Langhans, 2001). Nevertheless, no influence of weaning method on total cross-sucking was found. This was not unexpected, because according to our hypothesis the different feeding schedules were most likely to affect milk-independent cross-sucking. It is known that milk-dependent cross-sucking is mostly influenced by milk intake per se, e.g. frequency of milk ingestion, milk intake from an artificial teat instead of a bucket, or the design of the teat (e.g. Sambraus, 1984; de Passillé, 2001; Jensen, 2003; Lidfors and Isberg, 2003). These factors were not investigated in this study, and we also had intended to minimise milk-dependent cross-sucking by equipping the stall with a self-enclosing mechanism allowing the calves to engage in non-nutritive sucking at the soft rubber teat in the milk feeder after milk intake without being displaced. The usefulness of a self-enclosing mechanism in reducing milk-dependent cross-sucking has been shown by Weber and Wechsler (2001).

Our concentrate-intake-dependent weaning method aimed to ensure the covering of the calves' nutritional requirements, and this was apparently expressed in a decreasing number of individually weaned calves cross-sucking independently of milk intake. As hunger is known to enhance sucking motivation (de Passillé and Rushen, 1997), these findings support our hypothesis that a nutritional undersupply can promote cross-sucking, and that concentrate-intake-dependent feeding reduces cross-sucking by preventing such an undersupply. These considerations are supported by the excellent weight gain of the individually weaned calves, especially after milk provision was stopped in period 3. In contrast to individually weaned calves, the weight gain of the conventionally weaned calves remained constant after milk provision was stopped, although this result failed to reach significance. A weight gain of 750 g/day in the first 4 months after birth is recommended in artificial rearing, and a diminished weight gain directly after the end of milk provision is very common in dairy calves (Kirchgessner, 2004).

At birth, the rumen of a calf is undeveloped and the transition to a fully functioning rumen is stimulated by the ingestion of solid food (Garnsworthy, 2005). A smooth transition from monogastric to ruminant with minimal loss in growth requires adequate rumen development for efficient utilisation of forage-based feeding schedules (Garnsworthy, 2005). The duration of feeding hay influenced both, cross-sucking and weight gain, in such direction that the more hay was fed the less cross-sucking was shown but less weight was gained. No effect of the frequency of rumination on cross-sucking or weight gain was found. A positive effect of feeding duration on cross-sucking was also found in dairy calves directly after weaning (Keil and Langhans, 2001) and may be attributed to provision for behavioural needs (i.e. oral occupation). The negative effect of feeding hay on weight gain could be explained by our qualitative observation that there were two different types of conventionally weaned calves which consumed large amounts of hay. The first type consumed sufficient concentrate for its nutritional needs, whereas the second type had a far too low concentrate intake. It is known that propionic acid is primarily responsible for the growth of rumen papillae by digesting starch from concentrate (Kirchgessner, 2004). In contrast to calves of the first type, calves of the second type may have had insufficiently developed rumens, and as the milk allowance decreased, attempted to satisfy their nutritional needs by increased hay feeding. Therefore, we believe that neither hay feeding nor rumination on its own are suitable parameters for estimating rumen development at this age. To explore this in greater depth, further studies are required to measure rumen development in calves.

5. Conclusion

Compared to a conventional weaning method, a concentrate-intake-dependent weaning method meeting the individual nutritional needs of dairy calves reduced the number of calves exhibiting cross-sucking (occurring independently of milk intake) and improved weight gain, particularly after milk provision was stopped. In conclusion, in order to improve artificial rearing of dairy calves, the calves' capability to eat dry food (i.e. the transition to ruminant), should be considered on an individual basis. This will lead to better performance and an improvement in the calves' welfare.

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