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Improving consistency in cow-calf contact studies: the benefits of a protocol for colostrum supply and near ad libitum milk feeding for separated calves

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Abstract

Background Studies on cow-calf contact (CCC) systems often report better weight gain and sometimes an improved health in calves. However, calves in CCC systems with unrestricted suckling opportunities are often compared to artificially reared calves who are fed a restricted amount of milk. Our study investigated the growth rate and the health status of 41 German Holstein calves during their first nine weeks of life. Calves had either whole-day contact to their dam in the dairy herd (Contact, $n=24$) or were artificially reared by providing 16 L d^{-1} whole milk (Control, $n=17$). The provision of colostrum for all calves followed the same protocol. The Brix level of the colostrum and the transition milk collected during the three first milkings postpartum of all dams was recorded, as well as the Brix level in blood serum of all calves. The occurrence of diarrhea in calves was recorded daily, while health status and weight gain were assessed weekly.

Results The transfer of passive immunity was successful in Control (LSM ± SE: 9.5 ± 0.4% Brix) and Contact calves (8.9 ± 0.3% Brix, $P=0.105$). Calf presence did not affect the Brix level of the dam's colostrum and transition milk. Control calves consumed on average 10.3 ± 2.8 L d^{-1} of the offered 16 L milk, suggesting that they were fed near ad libitum. The average daily weight gain did not differ between Control (987 ± 55 g) and Contact calves (1051 ± 46 g, $P=0.319$) and increased with calf age. No effect of cow contact on the occurrence of diarrhea, the weekly health status or veterinary treatments in calves was found.

Conclusions Prolonged contact with the calf does not affect the Brix values of the dam's colostrum or transition milk. Calves that are not separated from their dam after calving do not experience failure of transfer of passive immunity when fed high-quality colostrum from a bottle. When compared to CCC calves during their first months of life, artificially reared calves should be fed at least 16 L d^{-1} whole milk.

Keywords Brix value, Transition milk, Growth, Health

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Background

The increased number of studies on cow-calf contact (CCC) systems in recent years reflects a growing interest in understanding the implications of dam-calf contact on the development and health of the calf [1]. One reason for implementing CCC systems is to enable the cow-calf pair to perform natural behavior [2, 3], as cows and calves in natural settings are strongly motivated to stay together [4–6]. However, although the European Food Safety Authority recommends keeping calves with their dams for at least 1 day following birth [7], more research is needed to protect and promote the welfare of calves kept with their dams after calving [8]. On dairy farms, ensuring optimal development of healthy dairy calves is a critical issue [9]. Long-term health of calves depends on adequate intake of high-quality colostrum in the hours following birth. This provides the calf with essential immunoglobulins (IgG) and growth factors which are essential to warrant an adequate transfer of passive immunity, since calves rely on colostrum to build their immunity [10]. For calf welfare, successful transfer of passive immunity is important, since failure of transfer of passive immunity (FTP) is associated with higher rates of neonatal morbidity and mortality [11]. However, FTP can occur when colostrum provision is poorly managed, e.g. quality and quantity of colostrum not sufficient or delayed provision of colostrum [12]. This issue concerns all types of calf-rearing systems. In artificial rearing systems, in which calves are separated from their dams after birth, FTP has been associated with the provision of low-quality colostrum or a distribution of colostrum later than 4 h after birth [13–15]. In CCC systems, FTP occurs when calves do not begin suckling soon after birth or fail to consume a sufficient amount of colostrum [16, 17]. This is one of the reasons why the implementation of CCC is also viewed critically [8].

The transition milk is another important feed for the calves after birth because it provides them with additional IgG [18], enhances intestinal development, promotes cell proliferation and improves the growth [19] and the health of calves [20]. Over postpartum (*p.p.)* time, the concentration of IgG per liter of transition milk produced by the dam decreases [18, 21]. However, almost 50% of the IgG secreted by the dam in early lactation are present in transition milk [18]. Therefore, transition milk is a relevant feed to prevent calves from FTP, benefiting calf performance and health beyond the time of transition milk feeding [20]. Nevertheless, the impact of separating the cow-calf pair within hours following birth on the quality of colostrum and transition milk produced by the dam has received limited attention. A previous study reported that the presence of the calf without suckling does not affect the Brix value of the colostrum of the dam measured at first milking *p.p.* [22]. However, to the best of our knowledge, there is no study that addressed the impact of the presence of the calf including suckling on the quality of the colostrum and transition milk of the dams during the first days *p.p.*.

The effects of CCC on calf performance and health are often assessed by comparing calves with whole-day contact to their dam (almost 24 h daily contact between the calf and its dam, definition in [23]) to those reared artificially. Most studies reported that calves with whole-day contact gained more weight than artificially reared calves [24–26]. However, whole-day contact calves were either compared to artificially reared calves fed 10.5 L d^{-1} milk and housed in different places (paired calf hutch vs. group pen including the dams [26]) or artificially reared calves fed only 8 L d^{-1} milk and housed together in the same place [24]. Nevertheless, similar weight gains between whole-day contact and artificially reared calves fed 12–14 L d^{-1} whole milk have also been observed [27].

The opportunity to suckle unrestricted has been reported to be the main factor leading to higher growth rates in whole-day contact calves (reviewed by [28]). However, ad libitum milk allowance might be also associated with a higher rate of nutritional diarrhea [24, 29, 30]. Negative [25, 26] and positive [30] effects of cow-contact on calf health were both reported. Nonetheless, rearing calves with contact to the cows does not lead to a significant increase in antibiotic use compared to artificially reared calves [24, 26]. Furthermore, the prevalence of *Cryptosporidium* infections in calves may be more attributable to the housing system, rather than to the effect of suckling the dam [31]. Additionally, the authors of this review [31] reported disparities in colostrum management, milk allowances and housing conditions between experimental treatments in most studies that compared whole-day CCC to artificial rearing of calves. Therefore, due to the confounding effects of experimental treatments, milk allowance, and housing conditions present in most studies, it is difficult to draw a clear conclusion about the effects of whole-day CCC on calf growth and health.

In natural settings, calves suckle their dams on average five times per day and have unrestricted suckling opportunities (reviewed by [32]). The daily frequency of suckling bouts decreases as calves age, from 10 suckling bouts per day at the first month of age to 8 suckling bouts per day at 4 months of age [33]. In calves aged from 2 to 10 weeks that were fed milk replacer ad libitum at the automatic milk feeder (AMF), nearly the same number of 8 visits per day has been reported [34]. Therefore, rearing calves using an AMF with ad libitum milk provision could be a suitable reference method for studying the effects of cow contact on calves, rather than comparing it to the widespread practice of restrictive milk feeding in artificial rearing. Thus, our study aimed to compare the performance and health of calves that had whole-day contact to cows with artificially reared calves, kept under similar housing conditions and that were fed whole milk near ad libitum via an AMF. It was hypothesized that [1] calves kept with their dams would not suffer from FTP when colostrum provision would follow a standardized protocol and [2] the performance and health status of calves with whole-day contact to the cow herd would not differ from those of artificially reared calves fed milk near ad libitum. Additionally, it was tested whether the presence of the calf in the calving pen affects the quality of the dam's colostrum and transition milk.

Methods

The experiment was approved by the local authorities (experiment IX552-109514/2023 (39 –7/23V)) and was conducted in two experimental periods (period 1: August 2023 – April 2024, period 2: August 2024 – April 2025) at the research farm of the Thünen Institute of Organic Farming, Germany. Two dairy herds differing in horn status (horned, genetically polled) were kept and managed similarly in two different sides of an identical mirrored-barn [35]. During the indoor season, lactating and dry cows were kept together in the two herds. They shared the same cubicles but fresh/higher yielding cows and low yielding/dry cows had access via transponder-controlled selection gates to two different feeding areas offering different diets. On both sides of the cow barn, the calf area was adjacent to the cow area. A transponder-controlled selection gate between the cow and the calf area allowed the calves to enter and exit the cow area. Therefore, the barn design allowed to rear calves either with CCC or artificially.

Calving and colostrum management

Two months preceding the calving date, cows were dried off following a quarter-selective dry cow therapy. Only quarters infected with major pathogens were treated with antibiotics [36]. Twelve to three weeks preceding the planned calving date, cows were vaccinated (Fencovis®, Boehringer Ingelheim Vetmedica GmbH, Germany) to prevent infections with *Escherichia coli*, bovine rotavirus and bovine coronavirus in newborn calves. The dam was moved to a single calving pen before calving (– 5.6 ± 4.4 d).

All calvings were video recorded and analyzed by the same observer. As the main author of the study was also the observer, who defined the time points which should be recorded, she was not blinded to the treatment and did not receive training before analyzing the videos. The following time points were determined: when the calf's entire body has been completely delivered from the cow, when the calf was fed colostrum from a teat bottle, and when the calf suckled the dam for the first time. Due to the top-down view of the cameras, a suckling event was defined when the calf's neck was located continuously under the dam's body at udder level for at least 1 min.

Within the first hours following birth, calves were weighed using a commercial calf weighing scale (Patura, Germany, accuracy: ±1%). Thereafter, all calves were provided via a teat bottle with 4 L of thawed (ColoQuick Thaw, Denmark), unpasteurized colostrum from the herd's colostrum bank (Brix value > 22%) or with fresh colostrum from their dam when the cow could be milked (Brix value > 22%). At the same time, 7 mL of iron supplementation (Ursoferran®, Serumwerk Bernburg AG, Germany) were administrated orally. The colostrum intake was recorded. Eighty-eight calvings of 69 cows were considered for the study.

Starting with the first milking time post-partum, all experimental cows were milked together with the two dairy herds twice daily in a tandem milking parlor (at about 5:30 a.m. and 4:30 p.m.). During the 3 first milkings *p.p.*, the Brix value of the dam's colostrum (1st milking *p.p.*) and transition milk (2nd and 3rd milking *p.p.*) was measured using a portable refractometer (MHRB 40 ATC, Mueller Optronic, Germany).

Experimental treatment

This study was part of a larger experiment testing different weaning strategies (two for contact calves, one for artificially reared calves). Therefore, the treatment of the calf was decided at birth. The calves were assigned to treatments based on dam parity, herd, and calf sex to ensure an even distribution of calves across dam parity, herd, and sex in all treatments. Until weaning, calves were raised either artificially (Control) or with whole-day cow contact (Contact). Calves were studied from birth until the day preceding the beginning of the weaning process (67 ± 2 d of age).

Calf housing and feeding

According to the farm management plan, Control calves were separated from their dams within 24 h after birth. They were housed in individual igloos during the first 7 days of life and were provided with 4 L of transition milk from their own dam three times daily in a teat bucket. At 8 d of age, Control calves were moved to the calf area adjacent to the cow area of their dam's herd.

Contact calves remained with their dam in the single calving pen for the first 5 days of life. Farm staff assisted these calves to suckle until they were able to suckle independently. Contact calves joined the calf area on their 5th d of age, while their dams were moved into their respective herd.

In the calf area, calves were kept in a mixed-age group ranging from 6 to 106 days old. The size of this group varied weekly due to new calves arriving or older calves leaving after weaning. The median number of calves was 14 (range: 3–19) and 11 (range: 3–20) in the calf group of the horned herd and of the polled herd, respectively. Contact calves had access the whole-day (about 17 h per day, no access during milking) to the cow area via a transponder-controlled selection gate. Control calves could not access the cow area.

In the calf area, an automatic milk feeder (AMF, Förster Technik GmbH, Germany) allowed Control calves to drink up to 16 L whole milk d^{-1} (maximum of 4 L $meal^{-1}$). Following the consumption of the initial 4-liter portion of the day, whether in a single portion or in multiple portions, calves had to wait for a period of two hours before receiving the subsequent 4-liter portion of milk. The accuracy of milk delivered by the AMF was checked once every two weeks and the AMF was recalibrated when needed. The provided milk was of food quality, unpasteurized and stored in a cooling tank next to the AMF. There was one AMF with one nipple in each calf area. The AMF was equipped with side barriers but not rear barriers. Contact calves could not receive milk from the AMF, since the nipple of the AMF was made accessible only when the calf was entitled to receive milk. When the calf's head was no longer in the RFID-detection area of the AMF, a flap closed and the calf had no longer access to the nipple. Therefore, in case of displacement, the portion of milk of the displaced calf could not be stolen by another one. The level of competition between Control calves to access the AMF was low, since only 3.2 ± 2.0 Control calves were entitled to access the AMF at the same time [37].

All calves were provided ad-libitum with water, hay and a total mixed ration (63.6% grass silage, 30.0% corn silage, 6.2% concentrate feed, and 0.2% mineral feed). In addition, the calves had access to an automatic concentrate feeder (Förster Technik GmbH, Germany) which provided up to 1.5 kg of pelleted concentrate feed d^{-1} (56% wheat, 32% triticale, 10% peas, 2% minerals) in 50 g portions.

Calf health

Health of the calves was monitored daily by trained farm staff. A diarrhea event was recorded when the calf had dirty and wet hindquarters. In such case, a diarrhea test (Fassisi® BoDia, Fassisi Gesellschaft für Veterinärdiagnostik und Umweltanalysen mbH, Germany) was performed to check for infection with rotavirus, coronavirus, *E. coli K99*, *Cryptosporidium parvum*, or *Clostridium perfringens*. The calves were treated according to the decision of the veterinarian.

A vaccination plan was applied to the calves to prevent respiratory diseases. Calves were vaccinated against calf influenza (Bovalto Respi Intranasal®, Boehringer Ingelheim Vetmedica GmbH, Germany) at 10 d of age. Thereafter, they were vaccinated against the Bovine Respiratory Disease (Bovigrip®, Merck & Co., Inc., USA) at 1 month of age, with a booster shot given four weeks later.

Data collection

Between 2 and 8 days after birth, a veterinarian took a blood sample from the jugular vein of each calf to assess the transfer of passive immunity. The Brix value of blood serum was measured using a digital refractometer (MA871 Digital Brix Refractometer, Milwaukee, Hungary). This method was chosen because it is a reliable on-farm method [38, 39].

Calves were weighed weekly using a commercial calf weighing scale (Patura, Germany, accuracy: ±1%). The average daily weight gain (ADG) of the calf was calculated by dividing the difference between two weekly weighings by seven. Also, a weekly health monitoring was performed by trained technicians during the fixation of the calves in the weighing scale. The rectal temperature was measured using a rectal thermometer, and a score of 2 was attributed for rectal temperatures > 39.5 °C or < 38 °C, otherwise the score was 0. Clinical symptoms (nasal discharge, ocular discharge, spontaneous cough, navel inflammation) as well as cleanliness of the hindquarters as indicator of diarrhea were scored according to a method described in [40] using a 0-1-2 scoring scale for each clinical parameter (0: no health issue, 1: mild symptom, 2: severe symptom). For each calf, the scores of rectal temperature and clinical symptoms were summed weekly into a weekly health score (WHS). Veterinary interventions and medications received by each calf and each dam were documented.

Data preparation

Before performing the data analyses, 47 calvings were excluded from the dataset for the following reasons: dry-cow therapy using antibiotics (1 case), vet assistance at calving (2 cases), birth of twins (1 case), postnatal death (2 cases), udder injury (1 case), and severe health issue in calf (1 case). Since calves received either fresh colostrum from their own dam or were fed thawed colostrum from another dam obtained from the colostrum bank, the colostrum status fed to the calf was confounded with the colostrum donor. To avoid a confounding effect of colostrum donor and colostrum status during the data analysis, 28 cases with provision of fresh colostrum from their own dam were excluded. Furthermore, 10 cases without video recordings and 2 cases without results of blood sampling had to be excluded. Therefore, only 41 calvings of 39 cows in total were considered in the data analysis. Two cows were included in both experimental periods. One was assigned to the Contact treatment during both experimental periods, while the other cow was assigned

Table 1 Distribution of calves across treatments (Control: artificially-reared calves, Contact: whole-day contact with the dam)

Treatment	Calf sex	Experimental period 1	Experimental period 2
Control	Male	8	2
	Female	4	3
Contact	Male	8	5
	Female	5	6
Total		25	16

to the Control treatment in period 1 and to the Contact treatment in period 2. Regarding the number of calvings by parity, 8 primiparous and 16 multiparous cows were included in period 1, whereas 4 primiparous and 13 multiparous were included in period 2. Calves from both sexes were included in the data analysis (Table 1).

Data analysis

Statistical analyses were performed with the software R version 4.1.2 [41]. To check for absence of differences in post-calving management (birthweight, time of colostrum feeding, quality of the colostrum provided to the calves, colostrum intake, first suckling time at the dam's udder) between the treatment groups and the sex of the calves, data were checked for normality using the Shapiro-Wilk test before conducting a t-test or Wilcoxon test. To identify differences in clinical health issues between treatment groups, Fisher's exact test were performed for the following variables: number of veterinary treatments received by the dams *p.p.*, number of veterinary treatments received by the calves, and number of infectious diarrheas detected in calves. A Fisher's exact test was used because the number of treatments and cases of infectious diarrhea per animal was zero-inflated, resulting in non-convergence of a Poisson model.

To analyze the effects of the calf presence on the Brix values of colostrum and transition milk of the dam, a linear mixed model was run. Treatment (Control, Contact), herd (horned, polled), experimental period (1,2), parity status (primiparous, multiparous) and number of milking *p.p.* (1: colostrum at 1st milking, 2: transition milk at 2nd milking, 3: transition milk at 3rd milking) were used as fixed effects. A cross-random effect of the period and the cow was included to account for the repetition of measures on each cow. The cow was the experimental unit.

To examine the effects influencing the transfer of passive immunity in calves, a linear model with the Brix value of blood serum as response variable was run. Treatment (Control, Contact), colostrum Brix value, colostrum intake, calf birthweight, occurrence of suckling before bottle-feeding (0: absence of suckling before colostrum feeding, 1: suckling before colostrum feeding) and the age at blood sampling were used as explanatory variables. To analyze the effects of whole-day contact to the dam on the performance indicators measured in calves (ADG, WHS, and number of diarrhea tests performed per calf), different models were used (Table 2). The calf was the experimental unit.

In Control calves only, the relationship between the daily milk intake at the AMF and the age of the calf was analyzed with a linear mixed model. Age of the calf (in d), experimental period (1,2), sex (male, female), and herd (horned, polled) were used as explanatory variables. The calf was the experimental unit and was used as random effect to account for the repetition of measures on each calf.

All variables tested were kept in all models, whether they had a significant effect or not on the target variable. Besides, all interactions between variables were checked. If an interaction was significant, it was kept; otherwise, it was removed. For all models except the WHS one, the assumptions of distribution and homoscedasticity of the model residuals were checked graphically using the package "performance" [42]. For the WHS model, the Akaike Information Criterion was used to ensure that the chosen explanatory variables improved the model compared to a simpler one. Results from descriptive statistics are reported as mean ± SD, while results from the models are reported as LSM ± SE. The significance level for all tests carried out in statistical analyses was set at $P < 0.05$.

Table 2 Models used to analyze the effects of whole-day contact on calves' performance indicators

Response variable	Type of model	Explanatory variables						Random effects	
		Treatment	Period	Sex	Herd	Age	Colostrum Brix value	Calf	Calves in group
		[Control, Contact]	[1, 2]	[male, female]	[horned, polled]	[in d]	[in %]	[41 levels]	[≤ 5, 6–10, 11–15, 16–20]
ADG [g d^{-1}]	Linear mixed	x	x	x	x	x	x	x	x
WHS	Cumulative link mixed	x	x	x	x	x	x	x	x
Diarrhea tests $calf^{-1}$	Generalized linear Poisson	x	x	x	x		x		

Results

Results are based on data from 17 Control calves (11 in period 1 and 6 in period 2) and 24 Contact calves (13 in period 1 and 11 in period 2). The average birthweight of the calves was 38.4 ± 4.6 kg and did not differ between treatments (t-test, $P = 0.523$), neither between sex (male calves: 39.4 ± 4.6 kg, female calves: 37.1 ± 4.5 kg, t-test, $P = 0.523$). For both calves' areas, the median number of calves was higher in period 1 than in period 2 (calf area of the horned herd: 14 vs. 11, Wilcoxon-test, $P < 0.001$ and calf area of the polled herd: 17 vs. 8, Wilcoxon-test, $P < 0.001$).

Colostrum management and quality

The video analysis showed that weighing of calves occurred 2.1 ± 1.8 h after birth. Control calves were separated from their dams and moved out of the calving pen on average 4.0 ± 5.1 h (range: 0.9–19.3 h) after birth. One Control calf suckled its dam before being fed colostrum by the farm staff. Four out of 17 Control calves suckled their dam on their own in the first 4 h following birth. Seven Control calves suckled their dam before leaving the calf area. Those 7 calves stayed for 7.5 ± 3.8 h with their dams in the calving pen (range: 5.9–11.4 h). However, 10 Control calves did not suckle their dams while they were in the calving pen. Nine of those calves stayed for 2.8 ± 1.8 h with their dams in the calving pen (range: 0.9–6.6 h), while one Control calf stayed for 19 h in the calving pen with its dam and was not observed suckling on its own.

Contact calves were moved out of the calving pen on average 5 ± 0 d after birth. Only 4 Contact calves suckled their dam before being fed colostrum by the farm staff. Eleven of the 24 Contact calves suckled their dam on their own in the first 4 h following birth.

The average timespan between birth and first independent suckling at the dam's udder was 4.4 ± 3.8 h for the 7 Control calves that suckled their dams and 6.1 ± 4.6 h for the 24 Contact calves. It did not differ between treatments (Wilcoxon-test, $P = 0.257$), neither between sex (in h, 5.7 ± 4.7 in male calves, 5.7 ± 4.2 in female calves, Wilcoxon-test, $P = 0.751$). For all caves that suckled in the calving pen, the parity status of the dam had no effect on the timespan between birth and first independent suckling (in h, 5.8 ± 5.7 in calves born from primiparous cows, 5.6 ± 3.9 in calves born from multiparous cows, Wilcoxon-test, $P = 0.877$).

Table 3 Comparison of post-calving management indicators between Control and Contact calves

	Unit	Control ($n = 17$) Mean ± SD	Contact ($n = 24$) Mean ± SD	Test	*P*-value
Brix value of the colostrum bottle-fed to the calf	% Brix	25.3 ± 2.2	24.0 ± 2.2	t-test	0.069
Colostrum intake by bottle feeding	L	2.1 ± 0.7	2.2 ± 0.7	t-test	0.906
Time between birth and colostrum bottle-feeding	h	1.7 ± 1.3	2.4 ± 2.0	Wilcoxon-test	0.151
Age at blood sampling	d	4.3 ± 2.0	4.5 ± 1.7	Wilcoxon-test	0.696

The mean Brix value of the colostrum offered to the calves, the colostrum intake, and the time between birth and the provision of thawed colostrum by bottle did not differ between treatments (Table 3). The colostrum intake did not differ between sex (in L, male: 2.2 ± 0.6, female: 2.1 ± 0.8, t-test, $P = 0.514$). Calves who did not suckle independently before colostrum feeding had a similar colostrum intake to that of calves that were observed suckling before being bottle-fed (respectively 2.1 ± 0.7 L and 2.3 ± 0.9 L, t-test, $P = 0.961$).

The Brix value of the blood serum did not differ between Control (9.5 ± 0.4% Brix) and Contact calves (8.9 ± 0.3% Brix, $P = 0.105$). A higher Brix value in colostrum fed to the calf resulted in a higher Brix value of the blood serum (R^2 = 0.197, $P = 0.029$). No effect of colostrum intake ($P = 0.167$), calf birthweight ($P = 0.726$), the occurrence of suckling before colostrum feeding ($P = 0.841$), and age at blood sampling ($P = 0.710$) was found on the Brix value of the calves' blood serum.

Contact to the calf ($P = 0.853$), experimental period ($P = 0.235$) as well as herd ($P = 0.958$) had no effect on the Brix value of the colostrum measured at 1st milking *p.p.*, neither on the Brix value of the transition milk measured at the 2nd and 3rd milking *p.p.*. The Brix value of the colostrum as well as the Brix value of the transition milk was 2.0 ± 0.9% higher in multiparous than in primiparous cows ($P = 0.027$). For each treatment, the Brix value measured in milk decreased with each milking *p.p.* (1st milking: 22.5 ± 0.5%, 2nd milking: 16.2 ± 0.5% and 3rd milking: 13.4 ± 0.5%, $P < 0.001$, Fig. 1).

During the 6 weeks *p.p.*, the number of cows that received a veterinary treatment did not differ between the treatments (Fisher's exact test for count data, $P = 0.679$). Six cows (1 Control, 5 Contact) received a veterinary treatment for mastitis, while one Control cow was treated for *p.p.* joint sprain.

Milk intake of control calves

The milk intake of Control calves increased by 0.082 ± 0.004 L for each additional day of life ($P < 0.001$, Fig. 2C). Sex ($P = 0.733$), herd ($P = 0.889$) and the experimental period ($P = 0.643$) had no effect on the daily milk intake at the AMF. Control calves consumed on average 10.3 L d^{-1} milk in their first 9 weeks of life.

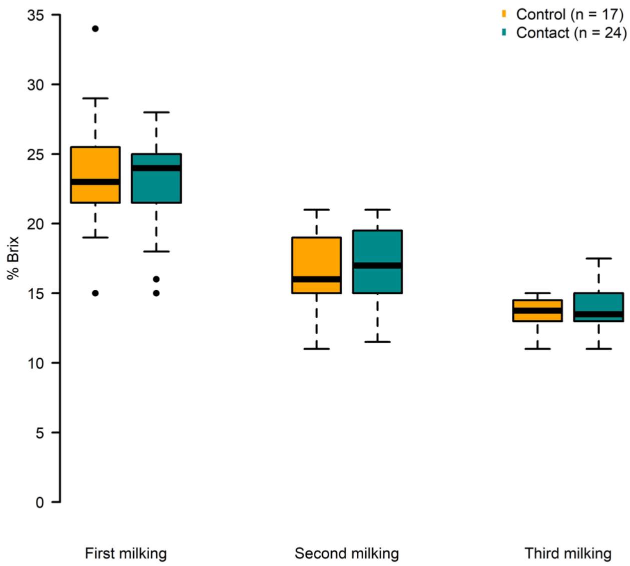

Fig. 1 Brix value of the dam's colostrum (1st milking) and transition milk (2nd and 3rd milking); The box plots show the distribution of the raw data. Horizontal lines within each box represent the median Brix value. The whiskers extend up to 1.5 times the interquartile range, and individual dots indicate outliers beyond these limits. Each Control dam was separated from her calf within hours of birth, while each Contact dam remained with her calf in a single maternity pen

Out of a total number of 997 days for which milk intake was recorded at the AMF, only 31 days accounted for a total milk intake of 16 L of milk. Eleven out of 17 Control calves consumed up to 16 L milk d^{-1} at least once (only one day: 5 calves, between two and five days: 4 calves, between six and eight days: 2 calves). Calves that consumed the full 16 L milk allowance at least on one day were on average 52 ± 15 d old.

Calf growth

The ADG of all calves increased with age ($P < 0.001$, Fig. 3). Control (987 ± 55 g) and Contact calves (1051 ± 46 g) had a similar ADG ($P = 0.319$). Sex ($P = 0.081$), herd ($P = 0.267$), experimental period ($P = 0.577$) and colostrum Brix value ($P = 0.993$) had no effect on the ADG. At the end of the experimental period (calf age: 67.2 ± 2.0 d), Control calves weighed 108.4 ± 10.5 kg and Contact calves weighed 108.9 ± 15.7 kg.

Calf health

The highest WHS possible on the scale used was 12. The WHS varied from 0 to 7 in Control calves and from 0 to 6 in Contact calves. The WHS of Control (2.0 ± 0.2) and Contact calves (1.7 ± 0.1) did not differ ($P = 0.124$). Colostrum Brix value ($P = 0.090$), age ($P = 0.636$), sex ($P = 0.198$), and herd ($P = 0.296$) did not influence the WHS. However, WHS was higher in period 1 (2.1 ± 0.2) than in period 2 (1.6 ± 0.2, $P = 0.009$).

The number of calves that received at least one veterinary treatment did not differ between Control and Contact calves (Fisher's exact test for count data, $P = 1.000$), neither between experimental periods ($P = 0.501$). Six

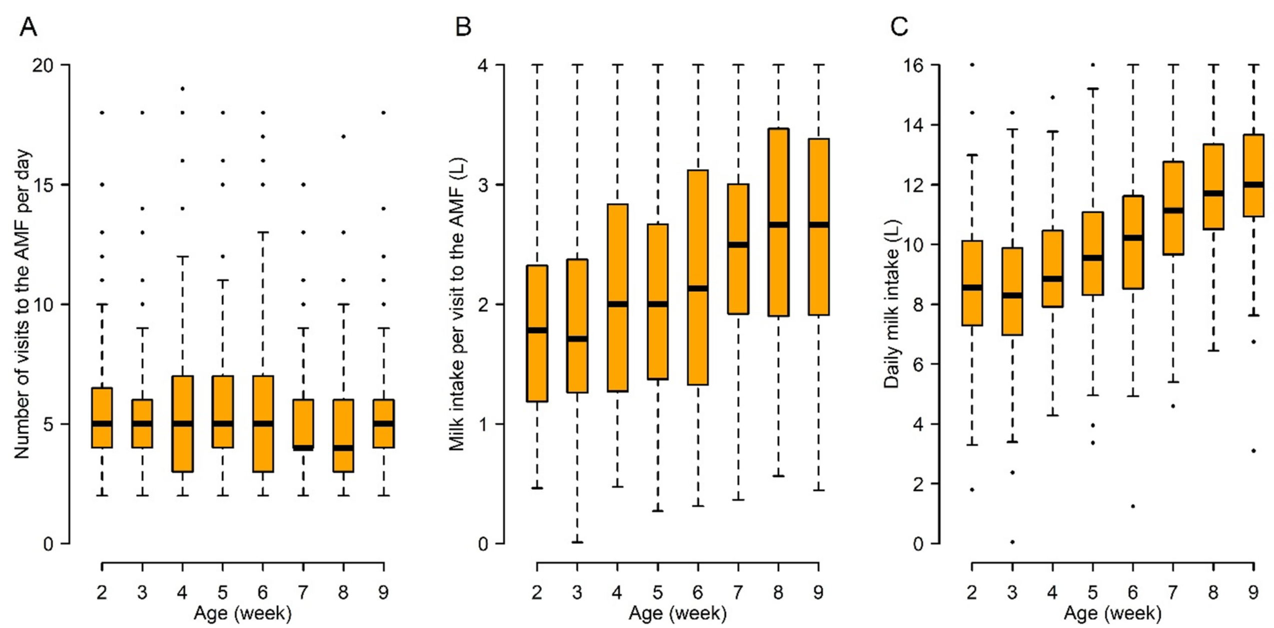

Fig. 2 Visits and milk intake of Control calves ($n = 17$) at the automatic milk feeder (AMF); The number of visits to the AMF per day for each calf is shown as a weekly average in subfigure (**A**). The milk intake per visit to the AMF for each calf is shown as a weekly average in subfigure (**B**). The daily milk intake for each calf is shown as a weekly average in subfigure (**C**). The box plots show the distribution of the raw data. Horizontal lines within each box represent the median of the response variable measured. The whiskers extend up to 1.5 times the interquartile range, and individual dots indicate outliers beyond these limits

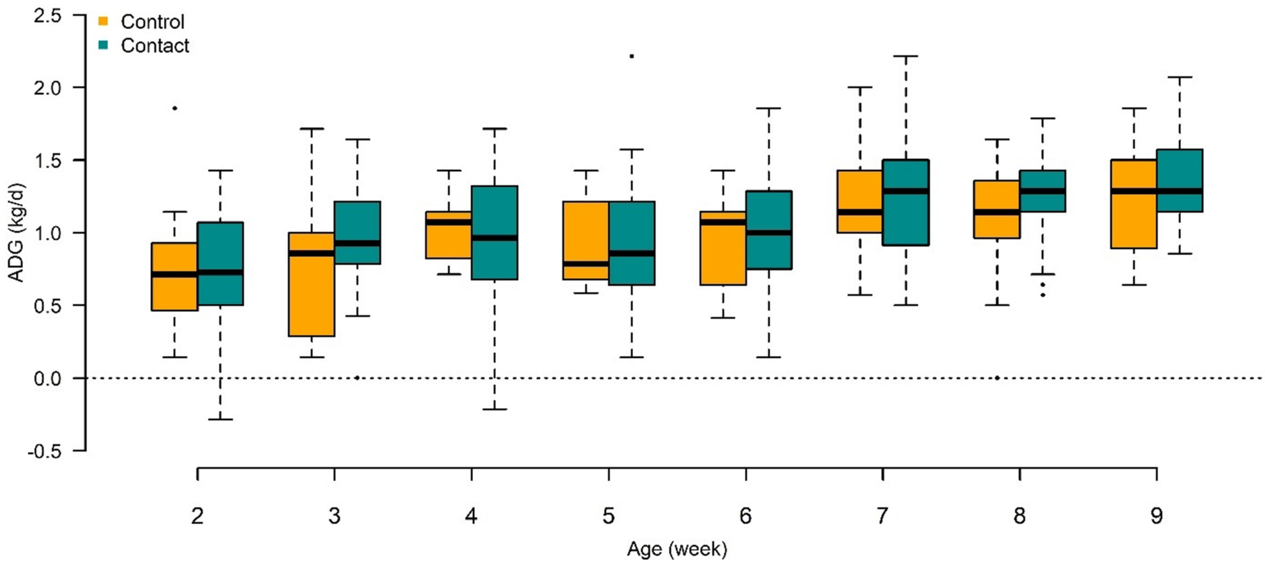

Fig. 3 Average daily weight gain (ADG) calculated weekly in Control ($n=17$) and Contact ($n=24$) calves; The box plots show the distribution of the raw data. Horizontal lines within each box represent the median ADG value. The whiskers extend up to 1.5 times the interquartile range, and individual dots indicate outliers beyond these limits. Control calves could drink up to 16 L whole milk d^{-1} at the automatic milk feeder. Contact calves had whole-day contact to their dams including unrestricted suckling opportunities

Control calves received at least one veterinary treatment (2 umbilical infections, 1 musculoskeletal disorder, 4 respiratory issues), while 8 Contact calves received at least one veterinary treatment (3 umbilical infections, 1 musculoskeletal disorder, 4 respiratory issues, 3 enteritis).

In total, 35 diarrhea tests were carried out during both experimental periods (17 in Control calves, 18 in Contact calves). The number of tests performed per calf did not differ between treatments (Control: 0.9 ± 0.2, Contact: 0.6 ± 0.2, $P=0.229$). The rate of diarrhea per calf tended to decrease by 15% for every 1% increase in the Brix value of the colostrum that was fed to the calves ($P=0.053$). The sex ($P=0.510$), herd ($P=0.112$) and experimental period ($P=0.220$) had no effect on the number of diarrhea tests performed per calf. Only 7 tests were positive for rotavirus infection (3 in Control calves, 4 in Contact calves). A Fisher's exact test for count data indicated no difference in the number of infectious diarrheas between Control and Contact calves ($P=1.000$).

Discussion

Colostrum management and quality

Contact calves are only at a higher risk of FTP when they are not assisted with colostrum feeding because the colostrum intake depends on calf sucking ability, udder conformation and maternal behaviour of the dam [16, 43, 44]. In Germany, the Regulation for protection and keeping of production animals [45] requires that the calves should be fed colostrum within the 4 h following birth. In our study, calves received colostrum on average 2.1 h after birth fulfilling the regulation. Therefore, calves had a limited time span to suckle on their own dam before being provided with colostrum by the barn staff. This may explain why only 7% of the calves suckled their dam before being fed colostrum. Calves were observed to suckle their dam independently on average 5.7 h after birth, with great interindividual differences (range: 0.7 –17.2 h *p.p.*). A previous study reported that only 36% of dairy calves observed in a loose-housing barn successfully suckled their dam within 3 h of birth [46]. Therefore, calves with weak suckle reflex, lower vigour or that experienced a difficult birth are the most at risk for FTP because they might not achieve to consume enough colostrum by 4 h after birth [47, 48].

Calves in the present study who did not suckle independently before colostrum feeding had a similar colostrum intake to that of calves that were observed suckling before being bottle-fed. For calves that suckled before colostrum feeding, the observed suckling occurred on average 1.3 h (range: 0.2–4.1 h) prior to the colostrum feeding. The similar colostrum intake of calves that previously suckled or not suggests that the registered suckling was in reality a suckling attempt or that the calf only consumed a very small amount of colostrum. It is also possible that some calves were hungry again when the colostrum was bottle fed. Overall, these observations emphasize the importance of feeding colostrum to all calves, because visually checking that calves are suckling may be not enough to ensure that they actually achieve a satisfying colostrum intake. According to the results presented in this study, feeding good quality colostrum to calves kept in CCC system is an efficient method to ensure an adequate transfer of passive immunity. Furthermore, management of colostrum feeding by a human caretaker in CCC system improves calves' relationship to humans [49].

In order to exclude poor-quality colostrum, on-farm methods for measuring colostrum quality must be fast and inexpensive [50]. Although Brix refractometry is primarily used to determine the concentration of dissolved solutes, such as proteins and sugars, Brix refractometry is a reliable method to discard poor quality colostrum (Brix value < 22%) in order to maximize the transfer of passive immunity in calves [15, 21, 51, 52]. However, the reliability of Brix refractometry to assess the quality of colostrum is discussed [18, 50, 53]. Nevertheless, in the present study, on farm practicability was preferred over laboratory analysis. Therefore, we used Brix refractometry to assess the quality of colostrum and transition milk produced by the dam. The Brix level measured in colostrum and transition milk decreased over time after calving and was influenced by the parity status of the dam. The time interval between calving and colostrum collection had a negative effect on the protein and total solids content of colostrum of Holstein cows, while the parity had a positive effect on it [54], which is in line with our observations. In CCC systems, nursing the calf can cause a disturbed milk ejection, which results in a decreased fat concentration in the milk of machine milked cows [55]. However, contrary to the protein content, the fat content of the colostrum and transition milk does not affect the Brix value measured using Brix refractometry [18]. Even though the effect of nursing on the protein content of the milk remains unclear [55, 56], no effect of nursing the calf was detected on the Brix value of the dam's colostrum and transition milk.

Calf growth and milk consumption

The similar growth rates observed in Control and Contact calves suggest that the feed intake was comparable in both treatments, which differs from previous studies in which artificially reared calves were fed restricted amounts of milk and were compared to calves with unrestricted suckling opportunities [24–26]. Before being weaned off milk, milk is the main source of metabolizable energy for calves and it drives their weight gain, since their rumen is not fully developed for digesting solid feed [57]. Control calves were fed whole milk of food quality, which had a comparable composition to that of the milk suckled by the Contact calves. Moreover, Control calves consumed milk at the AMF on average 5.6 ± 3.4 times per day. This reflects the observed suckling frequency of 5 times per day in whole-day contact calves kept in a loose-housing system (2nd to 8th week of life: 4.8 ± 0.8 times per day [58], first 15 weeks of life: 4 to 5 times per day [59]). Furthermore, the ADG of Control and Contact calves was similar to that observed in Danish Holstein calves that were artificially reared and fed whole milk to satiation until 8 weeks of age (range: 800 to 1100 g d^{-1}) [60], as well as to that observed in Swedish Red and Swedish Holstein calves that were kept in a whole-day CCC system from birth to 4 months of age (1300 ± 100 g d^{-1}) [61]. Therefore, near ad libitum milk intake and frequent milk consumption bouts can explain the similar ADG observed between the two treatments in our study (from birth to the 9th week of life: 987 ± 55 g d^{-1} in Control calves, 1051 ± 46 g d^{-1} in Contact calves). Consequently, future studies aiming to compare whole-day CCC calves to artificially reared calves should provide milk near ad libitum to artificially reared calves in order to achieve similar performance in calves, regardless of the contact with the dam.

Control calves rarely consumed the full milk ration of 16 L d^{-1}. They consumed on average 10.3 L d^{-1} milk in their first 9 weeks of life. This aligns with the findings of several studies. Artificially reared calves fed 14 L d^{-1} whole milk consumed on average 10.7 L d^{-1} milk in their 6 first weeks of life [27]. Artificially reared calves fed ad libitum consumed on average 10.4 ± 2.8 L d^{-1} milk replacer in their first 11 weeks of life [34]. Eight-week-old calves rarely achieved to consume 16 L d^{-1} milk replacer [62]. Therefore, providing 16 L d^{-1} milk to calves in their first 9 weeks of life seems to be equivalent to near ad libitum feeding. However, when calves are older, providing 16 L d^{-1} milk may no longer be enough to feed them near ad libitum. During their first two months of life, the daily milk consumption of Control calves continued to increase without ever plateauing or decreasing. Therefore, it cannot be assumed that calves will consume less milk during their third month of life, meaning that more than 16 L d^{-1} milk should be provided to feed calves near ad libitum at that time. Further studies are needed to confirm this assumption.

Calf health

The health status did not differ between Control and Contact calves. However, the WHS in period 1 was higher than in period 2. In period 1, there were more calves present in the calf group than in period 2. Nevertheless, the number of calves present in the calf group had no effect on the WHS. In the months preceding the experimental period 2, the calf area was renovated and the rubber mats in the cow and calf areas were replaced by new ones. Consequently, the disinfection of the barn followed by an absence of animals for several months during barn renovation may have reduce the risk of infection for calves in period 2. This hypothesis is supported by the findings of previous studies, that reported that the different housing conditions of their experimental calves during the preweaning period might have been more responsible for the observed differences in health status between the rearing treatments than the rearing treatment themselves [25, 26]. Our results highlight the importance of keeping all calves in the same calf group when comparing whole-day contact calves to artificially reared calves, to ensure that all calves are exposed to a similar pathogen pressure resulting from the calf area.

The prevalence of infectious diarrhea due to rotavirus was not influenced by the access to the cow herd. Rotavirus is one of the main pathogens responsible for diarrhea in calves. Colostrum feeding in newborn calves, vaccination of the dam, and proper housing are effective measures to reduce the prevalence of rotavirus infection in calves (reviewed by [63]). In our study, all dams were vaccinated before calving, all calves were fed good quality colostrum and received transition milk from their dam. Therefore, Control and Contact calves were able to receive the same benefits from their dam's transition milk, which may have promoted a similar development of their immunity. This may explain the lack of differences in the frequency of health disorders among Control and Contact calves. Furthermore, all calves shared the same calf area, so that Control calves might have also been exposed to adult cow pathogens brought back from the cow herd by Contact calves. However, the weekly health checks did not allow us to assess the severity or duration of the recorded health disorders. Nevertheless, the prevalence of 17% of rotavirus infection in our study was within the range of rotavirus prevalence (0–50%) reported in calves aged between 7 and 21 days, that were tested in 62 German commercial dairy farms [64].

The number of veterinary treatments administrated to calves did not differ between the two experimental periods, neither between Control and Contact calves. In the present study, 19.5% of all calves were treated for respiratory issues, 12.2% for umbilical infections and 7.3% for diarrhea. Health monitoring of group housed calves with a comparable large age difference of 60 days, without contact to adult cow, indicated similar proportions for respiratory issues (23.2%) and umbilical infections (12.5%), but higher for diarrhea (26.7%) [65]. In line with our former study [66], these results suggest that the contact with an entire dairy herd does not worsen the health status of calves kept in groups.

Conclusion

Prolonged contact with the calf does not affect the Brix values of the dam's colostrum or transition milk. Management of colostrum feeding by a human caretaker effectively prevents failure of passive immunity transfer in calves. Our study has clearly shown that calves reared in so-called CCC systems are not at risk of FTP, provided the standard procedures of colostrum management recommended for artificial calf rearing are followed. Moreover, the experiment showed that near ad libitum feeding of Control calves resulted in similar weight gain and health status than in Contact calves. Therefore, in order to compare calves at the same performance level when investigating the effect of cow contact on Holstein calves in their first two months of life, artificially reared calves should be fed at least 16 L d^{-1} milk and kept in the same calf group as CCC calves.

Abbreviations

CCC	Cow-calf contact
IgG	Immunoglobulins
FTP	Failure of transfer of passive immunity
p.p.	*post partum*
AMF	Automatic milk feeder
ADG	Average daily weight gain
WHS	Weekly health score

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Author contributions

RG: Conception, Data curation, Investigation, Formal analysis, Visualization, Writing – original draft; EH: Writing – review & editing; KB: Funding acquisition, Conception, Supervision, Writing – review & editing. The authors used DeepL Translate and DeepL Write in the writing process. All authors read and approved the final manuscript.

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Data availability

The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethical approval

The study protocol and all procedures related to animal were conducted with the approval of the Ministry of Agriculture, Rural Areas, Europe and Consumer Protection of the State of Schleswig-Holstein, Germany (experiment IX552-109514/2023 (39 –7/23V)).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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