# The health of dairy calves reared with udder access – A systematic review and epidemiological multi-herd study

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**Summary**

During the recent decade, cow-calf rearing systems, which allow calves to suckle milk from a dairy cow for parts or all of the rearing period are increasingly gaining public interest. However, the effect of udder access on calf outcomes has, to date, not been systematically documented and quantified. In this master thesis, I aimed to close the knowledge gap with regard to the performance, clinical health and cross-sucking behaviour of dairy calves reared with udder contact on their birth farm. First, I systematically reviewed the existing literature on trials involving cow-calf systems, focussing on calves past the age of three days, and documented the reported outcomes in a standardized format. Based on the reviewed literature, I defined three categories of cow-calf systems, as opposed to artificial calf rearing: (1) permanent and semi-permanent udder access, (2) restricted udder access and (3) prolonged post-natal dam contact with subsequent artificial rearing. My results revealed that calves reared with permanent access to an udder for suckling had the highest pre-weaning daily weight gains (0.84 kg to 1.43 kg), and gained daily up to 0.77 kg more than restrictively fed, artificially reared calves. After weaning, calves with permanent udder access and high milk allowances showed a marked weight gain depression, likely due to abrupt weaning. Differences in clinical health parameters across rearing systems could not be quantified due to insufficient reporting of these parameters in the reviewed literature. However, I found indications that calves with prolonged udder access experienced lower disease incidences and disease severity, particularly with regard to diarrhoea. Lastly, udder access, irrespective of daily suckling duration, significantly reduced (up to 93%) cross-sucking behaviour.

Secondly, I conducted an epidemiological, multi-heard study on the clinical health of dairy calves reared with udder access on their birth farm. I visited 14 organic dairy farms in Switzerland and Southern Germany and quantified the incidence densities (ID) of veterinary treatment events, antimicrobial treatment incidences (TI) and scored the clinical health of all present calves reared with udder access. Antibacterial drugs were used on 31% of farms and

antiparasitic drugs on 15% of farms. Overall, I found a median ID of 25 veterinary treatments per 100 calf-years, a maximum TI of 40 antimicrobial daily doses and a median calf mortality risk of 3%. The calves' health scores reveal nasal discharge to be the most frequent health impairment (24%), followed by ocular discharge (23%) and skin conditions (20%). Soiling of the perianal area was observed in 10% of calves. Five percent of calves qualified as severely health impaired according to their overall health score. Compared to reference values from the literature for artificially reared calves on Swiss and US conventional farms, calves reared with udder access on Swiss organic dairy farms:

1) had a substantially lower frequency of antimicrobial treatment events, measured as incidence densities (ID) per 100 calf-years.

2) used substantially lower amounts of antimicrobial drugs, measured as treatments incidences of used daily doses ($TI_{UDD}$) per 1000 calf-days.

3) had substantially better clinical health, measured as health scores using a standardised chart.

I attributed the observed differences with regard to antimicrobial drug use partly to the mind-set of organic farmers towards antimicrobial drugs and partly to improved overall calf health, especially with regard to diarrhoea.

It can be concluded that cow-calf rearing systems are a very diverse set of systems with are adaptable to fit the dairy farmers' needs and preferences and which produce calves with improved weight gain and clinical health as compared to artificially reared calves. No single health problem was found to be directly related to cow-calf rearing. In severe cases of calf disease, organic farmers should not be reluctant to resort to antimicrobial drugs, such as to prevent avoidable calf suffering and mortality.

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# Part I

# Performance, health and cross-sucking behaviour of dairy calves reared with udder access
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# A Systematic Review

## I - 1. Introduction

Within evolutionary history, lactation has proven to be a successful strategy for mammalian species of rearing offspring. Yet, in the dairy industry it is standard practice to separate cows from their calves within a few hours after parturition (Pempek et al., 2017). This practice is partly based on the belief that artificial rearing provides benefits to the clinical health and survival of the calf (Ventura et al., 2013). Nevertheless, artificial calf rearing is notorious for its high rates of morbidity and mortality, even for dairy calves being reared on their birth farm (Windeyer et al., 2014). Svensson et al. (2003), for instance, found morbidity rates of 23% among dairy calves in Sweden. Windeyer et al. (2014) found that 23% of dairy calves in the US were treated at least once for diarrhoea until the age of 3 month, and almost 22% of calves were treated for bovine respiratory disease (BRD).

During the last decade, increasing consumer concern with regard to early separation (Busch et al., 2017) has pushed dairy farmers, especially within the organic sector, to adopt so-called cow-calf rearing systems (Wagenaar and Langhout, 2007). These rearing systems allow calves to feed on milk by means of suckling a cow's udder during parts or the entirety of the milk feeding phase. Several recent reviews investigated cow-calf rearing systems on dairy farms, both with regard to the calves and to the nursing cow's behaviour, welfare, productivity (Meagher et al., 2019) and health (Beaver et al., 2019). Meagher et al. (2019) concluded that cow-calf rearing improves the calves' growth and consistently reduces abnormal oral behaviour, while Beaver et al. (2019) found no support for health benefits to the dairy calf from early separation and artificial rearing, in particular with regard to immunity, mortality, diarrhoea, and pneumonia. Both reviews, while being very comprehensive, used a qualitative approach to assess the effect of udder access on the calves outcomes. In this paper, we aim at documenting quantitative results regarding the daily weight gain, the clinical health and cross-sucking behaviour of dairy calves reared with udder access

on their birth farm, by systematically reviewing existing literature on cow-calf rearing systems.

## I - 2. Materials and Methods

The systematic literature review was implemented by two persons. The review was a priori developed according to the recommendations of the PRISMA statement (Liberati et al., 2009; Moher et al., 2009) and the AMSTAR measurement tool (Shea et al., 2007). We defined "cow-calf rearing with udder access" as any system of dairy calf rearing which provides the calf with the possibility to feed on milk by suckling the udder of a cow for more than three days post-partum. "Artificial rearing" is defined as the feeding of calves, which are older than three days, with cow milk or milk replacer by any means other than suckling of a cow's udder. The research question was designed following the PICOS scheme (Liberati et al., 2009): the *population* are calves in dairy farming, the *intervention* is prolonged udder access, the *comparator* is shorter udder access or artificial rearing, the *outcome* is the effect of prolonged udder access on clinical calf health and performance parameters, and the *study design* includes clinical trials with calves.

### I - 2.1 Search strategy

The online databases PubMed (https://www.ncbi.nlm.nih.gov/pubmed/) and Web of Science (https://apps.webofknowledge.com) were used as bibliographic sources. Both were consulted on 2017-11-30. For the automatic search, the search term **(cow* AND calf OR dam OR foster* OR calves) AND (rear* OR suck*)** was used. The search only included peer reviewed publications without limitation of age. Results in Pubmed were refined with regard to species (other animals), languages (English, German) and subjects (veterinary science). Results in Web of Science were refined with regard to categories (Agriculture Dairy Animal Science, Veterinary Science, Neuroscience, Behavioral Science, Zoology, Agriculture

Multidisciplinary) and document type (article). Matching references were downloaded and saved in an EndNote X6-Data file.

I - 2.2 Screening of scientific references

In order to identify eligible references, references were screened in successive steps. First, EndNote's duplicate search function was used to remove duplicates. Then, EndNote's key word function was used to exclude publications containing specific terms or term combinations outside the scope of this review. A detailed description of the key word search and the full list of used term combinations is provided in the research protocol (additional file I – 1, page 44). In a next step, references were manually screened. The title of each publication was read; if it matched predefined inclusion and exclusion criteria the reference was kept, otherwise it was excluded. This step was repeated with the abstract of remaining reference. Thereafter, the full paper was obtained and likewise screened. References whose full text could not be obtained or which did not meet the predefined inclusion and exclusion criteria were excluded.

I - 2.3. Inclusion and exclusion criteria

Only peer-reviewed publications, providing an English or German abstract, without limitation of age were considered. To be included in the review, publications had to investigate dairy calves and conduct a trial with at least two treatment groups: one allowing calves to suckle a cow's udder for a minimum of four days after birth, the other one allowing calves to suckle for a shorter period of time than in the first treatment group or not allowing suckling at all. Publications also had to report on the calves' performance (i.e. weight gain), cross-sucking behaviour or health. All matching references were compared to the references cited in existing reviews on cow-calf rearing (Flower and Weary, 2003; Johnsen et al., 2016; Beaver et al., 2019; Meagher et al., 2019). If a reference was cited in one of the reviews as reporting on

calf performance, cross-sucking or clinical health parameters and matched our inclusion and exclusion criteria but was not yet included in the review, the reference was additionally included.

References with missing information, such as authors or abstract, or whose full text could not be found online were excluded. All references were excluded which were only presented on conferences, which investigated beef calves, which did not conduct a trial (e.g. multi-herd studies, case reports) or which did not report the size of their treatment groups. We also excluded references reporting exclusively on the dam's outcome parameters, on calf behaviour other than cross-sucking (including nursing, challenge responses, cow-calf bonding or behaviour at weaning) or which only reported on nursed calves as adult animals. Lastly, studies allowing calves to suckle a cow's udder for not more than three days post-partum were excluded as well.

### I - 2.4 Full paper analysis

References remaining after the successive screening steps, were included in the literature review. For the analysis, a spreadsheet containing all reviewed studies was set up, each row capturing one treatment group within one study as defined by the authors of the original publication. Then, the calf rearing methodology as well as outcomes of calf performance, cross-sucking behaviour and of clinical health were systematically recorded. Publications reporting unambiguously about the same study, but published different results of it, were merged for the review.

#### I - 2.4.1 Calf rearing methodology

With regard to the calf rearing methodology, the housing type, milk feeding method (e.g. automatic milk feeder), number of milk feedings per day, length of udder access per day, average milk allowance, number of days after birth with permanent contact to the dam,

weaning age, fed milk type and frequency of milking of the nursing cows was recorded. Additionally, the calves age in days at the start and end of the study's observation period were recorded. Since many studies changed one or many of the rearing parameters during the course of treatment (e.g. calves were first housed individually and then group housed), only the method used for the majority of days from birth until weaning was recorded. For artificially reared calves the daily milk allowance was recorded in litres and, whenever possible, averaged from birth to weaning. A milk allowance of "10% of body weight" was considered being below 6 l/d. For calves suckling milk directly from the udder of a cow, an approximate milk allowance was defined as well. If calves were provided access for suckling at least twice per day for more than 30 min and had at least once per day access to a full udder, we considered these calves to have an *ad libitum* milk allowance (> 8 l/d). Otherwise, we considered milk allowance to be restrictive (≤ 8 l/d).

### I - 2.4.2 Classification of rearing systems

We defined four distinct categories of rearing systems (RS) based on the calf rearing methodology and classified each treatment group described in the reviewed publications accordingly: (RS1) **Permanent access systems** provide calves with eight or more hours of udder access per day until weaning. (RS2) **Restricted access systems** provide calves with udder access until weaning, but access is less than eight hours per day. (RS3) **Prolonged post-natal contact systems** provide more than three days of permanent udder access after birth, but access is discontinued before weaning and calves are subsequently artificially reared. (RS4) **Artificial rearing systems** separate calves from their dam within a maximum of three days; thereafter calves are reared artificially until weaning.

### I - 2.4.3 Outcome parameters

The mean daily weight gain of calves, pre- and post-weaning, as well as the rates of morbidity, diarrhoea, respiratory disease, navel infection, antibiotic/ veterinary treatments, mortality and cross-sucking were recorded. All rates were calculated as the percentage of calves having experienced or displayed the outcome parameter (e.g. disease or cross-sucking behaviour) at least once. Additionally, the calves average daily milk consumption as well as the consumption of concentrates and roughage, pre- and post-weaning, were recorded.

## I - 3. Results

### I - 3.1. Literature search and turn out

In total 8083 references matched the search term and were downloaded to EndNote (Figure I - 1, page 26). From these, 7195 references remained after the removal of duplicates and of references with missing information. The automatic keyword search excluded in total 5841 references. Manual screening of the titles eliminated 1078 references, screening of the abstracts eliminated 185 references and screening of the full texts eliminated a further 71 references. Twenty references were included in the full paper analysis after the systematic literature search. Five additional references were identified through the expert check with existing reviews (Flower and Weary, 2003; Johnsen et al., 2016; Beaver et al., 2019; Meagher et al., 2019), such that in total 25 publications were included in the review. The publications corresponded to 23 separate studies, since twice the results of two papers were merged. The studies totalled 70 treatment groups and 972 calves, with each treatment group comprising on average 14 ± 7 calves.

### I - 3.2. Results on calf rearing methodology

Table I - 1 (page 22) details the distribution of studies, treatment groups and animals over the four categories of rearing systems and gives a characterization of the methodology across the various studies. Calves with permanent udder access (RS1) were always housed with the dairy

herd or in foster groups, consisting of one or more adult nursing cows and several calves. Due to the permanent udder access, RS1 calves always had an unlimited number of milk feedings per day, an *ad libitum* milk allowance and access to whole milk. In all other RS, the vast majority of calves were housed either in calf groups or individually (97%) and fed milk once to twice daily (75%). Within RS2, calves generally received either fore- or hindmilk, while 42% of calves received an *ad libitum* milk allowance. RS3 were provided with prolonged post-natal dam contact of 4 to 21 days, and always had permanent udder access with an *ad libitum* milk allowance during that time. Thereafter, RS3 calves never received more than 8l of milk per day.

Within RS4, 77% of calves were separated within 24h after birth from their dam. Thereafter, 75% of RS4 calves received not more than 8 l of milk per day, and 54% of RS3 and RS4 calves were fed milk replacer at some point. Overall, the majority of calves (93%) were weaned before or at the age of three month (i.e. 94 days).

I - 3.3. Results on outcome parameters

Table I - 2 (pages 23 – 25) describes the type and values of clinical health parameters reported in the reviewed literature. From the 23 analysed studies, 19 measured and statistically analysed the calves' mean daily live weight gain (DWG) before weaning. Ten of the studies found higher pre-weaning DWG for calves with prolonged udder access (RS1, RS2 or RS3 vs RS3 (shorter contact) or RS4), seven studies found no statistically significant difference and two studies find a lower pre-weaning DWG for calves with prolonged udder access. Overall, calves with permanent udder access (RS1) achieved the highest DWG pre-weaning (0.84 – 1.43kg/d). Post-weaning, the weight gain pattern is reversed. Ten studies statistically analysed post-weaning DWG, of which two found higher post-weaning gains for calves with prolonged udder access. Three studies found no significant difference, while five studies found significantly lower post-weaning DWG for calves with prolonged udder access compared to

calves with less or no udder access. Of these five studies, all but one (Froberg and Lidfors, 2009; Froberg et al., 2011) gradually reduced the milk allowance of artificially reared calves prior to weaning, but weaned udder reared calves abruptly.

Only two studies statistically analysed parameters of clinical calf health. Both studies conducted regular health scores: Kisac et al. (2011) found no significant impact of prolonging post-natal udder access from 7 to 21 days on health scores, while Roth et al. (2009) found poorer health scores for calves with permanent udder access as compared to artificially reared calves, but found no significant difference in the rate of veterinary treatments. A number of studies mentioned or measured clinical health parameters without statistically analysing the results. Diarrhoea was the most frequently mentioned disease. From ten studies reporting on diarrhoea, five studies found diarrhoea to be less of a problem for calves with udder access. Three studies found no difference in diarrhoea rates between calves with and without udder access, although one study (Rajala and Castren, 1995) pointed out that artificially reared calves experienced more diarrhoea more severely than calves with udder access, having had almost three times as many days of diarrhoea. Two studies recorded higher diarrhoea rates for calves with udder access, but not more veterinary treatments. For bovine respiratory disease (BRD), Boonbrahm et al. (2004) and Little et al. (1991) recorded lower incidence rates for calves with udder access, while Bar-Peled et al. (1997) found no difference among treatments. Navel infections were mentioned in only two studies, none of the two finding a difference in infection rates among calves with and without udder access. Mortality rates were mentioned in 12 studies, nine of these did not find different mortality rates between calves with or without udder access, two studies found lower mortality rates for calves with udder access, while one study found a higher mortality rate. Overall, calves with prolonged udder access appear to have equal or lower rates of disease incidence and severity than artificially reared calves. Cross-sucking behaviour was measured in eight studies and statistically analysed in five. All five studies find a sharp decrease in non-nutritive sucking among calves with udder

access. Veissier et al. (2013) note that calves with udder access spent significantly more time licking, but not sucking, conspecifics than artificially reared calves.

## I - 4. Discussion

In the dairy industry, 90 to 95% of commercial dairy farms separate calves from their dams within 24 hours after parturition (Pempek et al., 2017). Choosing a window of 24 hours, rather than 3 days, for the definition of artificial rearing systems, would thus be more in line with standard practice. However, we chose the larger window in order to align with our research question. The effect of udder access within the three days post-partum on calf health and immunization is an already widely covered topic (Beaver et al., 2019). In the scope of our study we focused instead on the effect of udder access during the main milk feeding phase on calf outcomes.

### I - 4.1 Overall aspects

Rearing systems with permanent udder access led to the highest DWG in dairy calves and eliminated abnormal oral behaviours. When the nursing cow is the dam, permanent udder access moreover closely matches the social structure of feral cattle (Bouissou et al., 2001), which increases the cow and calves "natural living" (Wagenaar and Langhout, 2007). However, in order to prevent a post-weaning weight gain depression, as observed in the reviewed studies, milk intake before weaning needs to be reduced gradually (Steele et al., 2017) and the separation from the dam be decoupled from the separation of milk (Johnsen et al., 2018). Wagenaar and Langhout (2007) showed that by implementing successive phases of dam-bound and foster cow-bound udder rearing, successful weaning strategies within cow-calf rearing systems can be found.

### I - 4.2. Calf performance

Krohn et al. (1999) studied the DWG of calves with contact to the dam, but without udder access. Their results suggested that the mere presence of the dam might increase DWG in dairy calves, such that weight gains in calves with udder access might be due to a "mothering" effect rather than to the increased milk intake from suckling. We did not find support for such a mothering effect among the reviewed studies. When considering only studies providing a similar milk allowance across the different rearing systems (e.g. *ad libitum* udder access vs *ad libitum* artificial rearing), no clear weight gain advantage for calves with udder access could be found. Figure I - 2 (page 27) plots the pre-weaning DWG of calves from all four rearing systems against their actual daily milk consumption, as measured for instance through weigh-suckle-weigh procedures. This plot show a rather linear relationship between DWG and milk consumption, which is in line with the weight gain pattern of artificially reared calves in response to milk consumption (Rosenberger et al., 2017). Overall, our observations indicate that DWG in pre-weaned dairy calves rather depends on the level of milk consumption than on the milk feeding method (suckling vs artificial feeding) and that this relationship is likely linear.

### I - 4.3. Health parameters

There was contradicting evidence with regard to diarrhoea incidences among the reviewed studies. While most authors found diarrhoea to be less of a problem for calves with udder access, Bar-Peled et al. (1997) and Roth et al. (2009) found higher diarrhoea incidences, though without an increase in veterinary treatments. This pattern closely matches observations by Rincker et al., (2011), who offered *ad libitum* milk allowances to artificially reared calves and found that calves may experience more frequently loose faeces as a consequence. However, such type of loose faeces did not require medication or veterinary treatment. Since, unlike most artificial rearing systems, cow-calf rearing systems often provide *ad libitum* milk

allowances to dairy calves, both scientists and practitioners need to become more aware about milk induces loose stool and be careful not to confound it with infectious diarrhoea.

### I - 4.4. Cross-sucking

Self- and intersucking behaviour in dairy cows represents a considerable economic loss to dairy farms (Debreceni and Juhas, 1999; Bademkiran et al., 2007) and may cause teat deformities, injuries or udder infections (Bademkiran et al., 2007; Mahmoud et al., 2016). Cross-sucking behaviour during calfhood, in turn, has regularly been shown to favour self- and intersucking in adulthood (Keil et al., 2001; Lidfors and Isberg, 2003; de Passille et al., 2011). Our review confirmed that udder access until weaning is an effective means to significantly reduce cross-sucking behaviour in dairy calves, and might thus be a solution for dairy farmers struggling with self- and intersucking in their milking herd.

## I - 5. Conclusion

We assessed the effect of udder rearing on calf performance, clinical parameters of calf health and cross-sucking behaviour by defining four categories of calf rearing systems: (1) permanent / semi-permanent udder access, (2) restricted udder access, (3) prolonged post-natal dam contact, and (4) artificial rearing. Calves reared with (semi-)permanent udder access had the highest pre-weaning daily weight gains (0.84 kg to 1.43 kg), gaining up to 0.77 kg more per day than restrictively fed artificially reared calves. Post-weaning, calves with permanent udder access showed a marked weight gain depression, likely due to abrupt weaning. Although clinical health parameters were insufficiently reported in the reviewed literature, we found indications that calves with udder access experienced lower disease incidences and disease severity than artificially reared calves, particularly with regard to diarrhoea. Lastly, udder access significantly and consistently reduced cross-sucking behaviour. In future, the reporting of clinical health parameters of dairy calves reared with

udder access needs to receive more scientific attention in order to determine whether udder access is an effective means of reducing disease incidences and severity of dairy calves reared on their birth farms.

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**Table I - 1:** Characterization of the reviewed literature and methodology

| | *No. of studies* | | | | *No. of treatment groups* | | | | *No. of animals* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Rearing system[1]*** | 1. | 2. | 3. | 4. | 1. | 2. | 3. | 4. | 1. | 2. | 3. | 4. |
| ***Total*** | 7 | 13 | 6 | 20 | 9 | 17 | 9 | 35 | 136 | 210 | 159 | 467 |
| ***ø*** | | | | | | | | | 15.1 | 12.4 | 17.7 | 13.3 |
| ***SE*** | | | | | | | | | 8.08 | 4.85 | 12.45 | 6.03 |
| ***Housing*** | *7* | *13* | *7* | *22* | *9* | *17* | *9* | *35* | *136* | *210* | *159* | *467* |
| In dairy herd or foster group | 7 | . | . | 1 | 9 | . | . | 1 | 136 | . | . | 11 |
| With dam (single pen) | . | 1 | . | 1 | . | 1 | . | 1 | . | 6 | . | 6 |
| Group pen | . | 8 | 2 | 10 | . | 11 | 2 | 22 | . | 156 | 22 | 306 |
| Individual pen | . | 3 | 5 | 9 | . | 4 | 7 | 10 | . | 42 | 137 | 137 |
| missing information | . | 1 | . | 1 | . | 1 | . | 1 | . | 6 | . | 7 |
| ***Days with udder access*** | *7* | *13* | *7* | *20* | *9* | *17* | *9* | *35* | *136* | *210* | *159* | *467* |
| ≤ 1 | . | . | . | 14 | . | . | . | 18 | . | . | . | 247 |
| 2 - 7 days | . | 1 | 4 | 4 | . | 1 | 5 | 5 | . | 6 | 63 | 73 |
| 8 - 21 days | . | . | 3 | . | . | . | 4 | . | . | . | 96 | . |
| > 21 days | 7 | 12 | . | . | 9 | 16 | . | . | 136 | 204 | . | . |
| missing information | . | . | . | 2 | . | . | . | 12 | . | . | . | 147 |
| ***Frequency of milk feeding*** | *7* | *13* | *6* | *21* | *9* | *17* | *9* | *35* | *136* | *210* | *159* | *467* |
| 1 | . | 1 | . | 2 | . | 2 | . | 11 | . | 20 | . | 120 |
| 2 | . | 11 | 4 | 10 | . | 14 | 5 | 13 | . | 170 | 59 | 141 |
| > 2 | . | 1 | . | . | . | 1 | . | . | . | 20 | . | . |
| missing information | 7 | . | . | 6 | 9 | . | . | 8 | 136 | . | . | 148 |
| ***Average milk allowance[2]*** | . | . | 2 | 3 | . | . | 4 | 3 | . | . | 100 | 58 |
| *ad lib* (from udder) | *7* | *13* | *6* | *23* | *9* | *17* | *9* | *35* | *136* | *210* | *159* | *467* |
| restricted (from udder) | 7 | 6 | / | / | 9 | 7 | / | / | 136 | 88 | / | / |
| < 6 l | . | 7 | / | / | . | 10 | / | / | . | 122 | / | / |
| 6 - 8 l | / | / | 2 | 11 | / | / | 3 | 19 | / | / | 32 | 223 |
| > 8 l | / | / | 4 | 5 | / | / | 6 | 7 | / | / | 127 | 129 |
| ***Milk type[2]*** | / | / | . | 7 | / | / | . | 9 | / | / | . | 115 |
| Whole milk | *7* | *13* | *6* | *22* | *9* | *17* | *9* | *35* | *136* | *210* | *159* | *467* |
| Foremilk | 7 | 1 | 3 | 14 | 9 | 1 | 4 | 18 | 136 | 12 | 47 | 215 |
| Hindmilk | . | 6 | / | / | . | 7 | / | / | . | 82 | / | / |
| Whole milk & Milk replacer | . | 6 | / | / | . | 9 | / | / | . | 116 | / | / |
| Milk replacer | / | / | 1 | 1 | / | / | 1 | 1 | / | / | 12 | 7 |
| missing information | / | / | 2 | 5 | / | / | 4 | 13 | / | / | 100 | 188 |
| ***Age at end of observation*** | . | . | . | 2 | . | . | . | 3 | . | . | . | 57 |
| ≤ 28 | *7* | *13* | *6* | *20* | *9* | *17* | *9* | *35* | *136* | *210* | *159* | *467* |
| 29-84 days | 1 | 1 | . | 2 | 1 | 1 | . | 3 | 7 | 6 | . | 19 |
| 85-168 days | 2 | 5 | 5 | 10 | 3 | 7 | 6 | 21 | 40 | 78 | 109 | 270 |
| > 168 days | 3 | 3 | 1 | 4 | 4 | 3 | 3 | 6 | 74 | 40 | 50 | 109 |
| ***Age at weaning*** | 1 | 4 | . | 4 | 1 | 6 | . | 5 | 15 | 86 | . | 69 |
| ≤ 56 days | *7* | *14* | *6* | *20* | *9* | *17* | *9* | *35* | *136* | *210* | *159* | *467* |
| 57 - 94 days | 1 | 2 | 3 | 4 | 1 | 3 | 6 | 6 | 18 | 26 | 82 | 82 |
| ≥ 95 days | 4 | 8 | 3 | 12 | 5 | 9 | 3 | 24 | 89 | 124 | 77 | 343 |
| missing information | . | 3 | . | 1 | . | 4 | . | 1 | . | 54 | . | 12 |

[1]Rearing system: 1. Permanent udder access; 2. Restricted udder access; 3. Prolonged post-natal dam contact; 4. Artificial rearing
[2]A slash (/) signifies that the parameter's subcategory is not applicable to the treatment category.

**Table I - 2:** Outcomes of calf performance, clinical health and cross-sucking

| | **Number of studies reporting health parameter and corresponding outcomes by rearing system*** | | | | **Differences in mean outcomes per study and parameter** (Values = outcome of top rearing system - outcome of left rearing system; n.s.d = not statistically significant) | | |
|---|---|---|---|---|---|---|---|
| ***Parameters of clinical calf health*** | Not report-ed | Mentioned, not measured | Measured, not analysed | Measured and statistically analysed | Rearing system 1 | Rearing system 2 | Rearing system 3 |
| **Mean daily weight gain (kg/day) (pre-weaning)** | | | | | | | |
| Number of studies | 3 | 0 | 1 | 19 | | | |
| Rearing system 1 | | | | 0.84[14], 0.86[7], 0.86[7], 0.90[23], 0.90[23], 1.08[16], 1.10[19], 1.43[1/2] | | | |
| Rearing system 2 | | | 0.28[13], 0.32[13] | 0.28[10], 0.36[3/4], 0.38[3/4], 0.48[11], 0.53[12], 0.62[9], 0.80[21], 0.85[25], 0.98[20], 1.02[19], 1.1[8], 1.17[21] | n.s.d.[19] | | |
| Rearing system 3 | | | | 0.24[10], 0.35[18], 0.46[18], 0.52[22], 0.54[18], 0.9[17] | | n.s.d.[10] | +0.19[18] (21 vs 7 days of udder access) |
| Rearing system 4 | | | | 0.31[12], 0.39[9], 0.44[3/4], 0.45[17], 0.46[22], 0.47[11], 0.48[20], 0.56[25], 0.63[16], 0.66[1/2], 0.66[16], 0.76[19], 0.79[19], 0.81[21], 0.83[1/2], 0.9 [23], 0.97[7], 1[8], 1.02[14], 1.3[8] | +0.77[1/2], +0.61[1/2], +0.45[16], +0.42[16], +0.34[19], +0.31[19], n.s.d. (2x)[23/23], -0.11[7], -0.11[7] | +0.5[20], +0.35[21], +0.29[25], +0.26[19], +0.23[9], +0.23[19], +0.22[12], n.s.d. (5x)[8/8/11/14/21], -0.06[3/4], -0.08[3/4] | +0.45[17], +0.06[22], n.s.d.[15] |
| **Mean daily weight gain (kg/day) (post-weaning)** | | | | | | | |
| Number of studies | 12 | 0 | 1 | 10 | | | |
| Rearing system 1 | | | | 0.03[1.2], 0.75[16], 0.78[19], 0.8[7], 0.8[7] | | | |
| Rearing system 2 | | | 0.19[13], 0.25[13] | 0.15[3/4], 0.18[3/4], 0.35[25], 0.42[12], 0.53[20], 0.69[19], 0.75[21], 0.92[21] | n.s.d.[19] | | |
| Rearing system 3 | | | | 0.55 [18], 0.66 [18], 0.74[18] | | | +0.19[18] (21 vs. 7 days of udder access) |
| Rearing system 4 | | | | 0.13[3/4], 0.41[12], 0.70[16], 0.78[16], 0.82[20], 0.86[25], 0.99[21], 1.01[7], 1.02[19], 1.12[1/2], 1.12[1/2], 1.18[19] | n.s.d. (2x) [16/16], -0.21[7], -0.21[7], -0.24[19], -0.4[19], -1.09[1/2], -1.09[1/2] | +0.05[3/4], n.s.d. (5x)[3/4/12/21/21], -0.29[20], -0.33[19], -0.49[19], -0.51[25] | |
| **Morbidity rate (%)** | | | | | | | |
| Number of studies | 17 | 1 | 3 | 2 | | | |
| Rearing system 1 | | a[16] | | | | | |

**Table I - 2:** Outcomes of calf performance, clinical health and cross-sucking

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rearing system 2 | | | 0%[12], 11%[13], 17%[13] | | | | |
| Rearing system 3 | | | 53%[24] | | | | b[18] |
| Rearing system 4 | | | 29%[12], 79%[24] | | | c[19] | |
| **Diarrhoea rate (%)** | | | | | | | |
| Number of studies | 13 | 5 | 5 | 0 | | | |
| Rearing system 1 | | d[1/2], e[16] | f[19] | | | | |
| Rearing system 2 | | g[11], h[25] | 0%[12], 10%[9] , f[19] | | | | |
| Rearing system 3 | | i[10] | 0%[18], 0%[18], 6%[18], 47%[24] | | | | |
| Rearing system 4 | | d[1/2], g[11] | 14%[12], 30%[9], 71%[24], f[19] | | | | |
| **Respiratory disease rate (%)** | | | | | | | |
| Number of studies | 17 | 1 | 5 | 0 | | | |
| Rearing system 1 | | | j[19] | | | | |
| Rearing system 2 | | k[25] | 0%[12], 5%[9], j[19] | | | | |
| Rearing system 3 | | | 6%[18], 6%[18], 6%[18], 7%[24] | | | | |
| Rearing system 4 | | k[25] | 7%[24], 14%[12], 15%[9], j[19] | | | | |
| **Navel infection rate (%)** | | | | | | | |
| Number of studies | 21 | 0 | 2 | 0 | | | |
| Rearing system 1 | | | 0%[12] | | | | |
| Rearing system 2 | | | | | | | |
| Rearing system 3 | | | 6%[18], 6%[18], 6%[18] | | | | |
| Rearing system 4 | | | 0%[12] | | | | |
| **Antibiotic/ Veterinary treatment rate (%)** | | | | | | | |
| Number of studies | 20 | 0 | 2 | 1 | | | |
| Rearing system 1 | | | 6%[1/2] | 50%[19] | | | |
| Rearing system 2 | | | | 47%[19] | *n.s.d.*[19] | | |
| Rearing system 3 | | | 0%[18], 0%[18], 6%[18] | | | | |
| Rearing system 4 | | | 0%[1/2], 4%[1/2] | 43%[19], 50%[19] | *n.s.d.*[19] | *n.s.d.*[19] | |
| **Mortality rate (%)** | | | | | | | |
| Number of studies | 11 | | 12 | 0 | | | |

**Table I - 2:** Outcomes of calf performance, clinical health and cross-sucking

| | | | | | | |
|---|---|---|---|---|---|---|
| Rearing system 1 | | | 0%[1/2], 0%[7], 0%[23], 0%[23], 8%[7] | | | |
| Rearing system 2 | | | 0%[8], 0%[9], 0%[10], 0%[12], 0%[13], 0%[13], 0%[25], 21%[11] | | | |
| Rearing system 3 | | | 6%[18], 6%[18], 6%[18], 7%[24], 8%[10] | | | |
| Rearing system 4 | | | 0%[1/2], 0%[1/2], 0%[7], 0%[8], 0%[8], 0%[12], 0%[23], 0%[25], 7%[24], 8%[11], 15%[9] | | | |
| **Cross-sucking rate (percentage of calves having displayed cross-sucking at least once)** | | | | | | |
| Number of studies | 15 | 0 | 3 | 5 | | |
| Rearing system 1 | | | 0%[6], 31%[1/2] | 0%[19] | | |
| Rearing system 2 | | | 0%[5], 0%[6], 7%[6] | 7%[19], 20%[11], 33%[10] | n.s.d. | |
| Rearing system 3 | | | | 91%[10] | | -58%[10] |
| Rearing system 4 | | | 10%[5], 10%[5], 20%[5], 20%[5], 20%[5], 29%[6], 39%[1/2], 40%[5], 50%[5], 70%[5], 76%[1/2], 80%[5], 90%[5], 93%[6] | 93%[19], 93%[19], 100%[11] | -93%[19], m[7] | -80%[11], -86%[19], -1,28 & -1.66 cross-sucking events more per day[3/4] |

[*] Rearing system: 1. Permanent udder access; 2. Restricted udder access; 3. Prolonged post-natal dam contact; 4. Artificial rearing

*Sources:* [1]Froberg and Lidfors (2009); [2]Froberg et al. (2011); [3]Margerison et al. (2002); [4]Margerison et al. (2003); [5]Ude et al. (2009); [6]Hillmann et al. (2012); [7]Veissier et al. (2013); [8]Lupoli et al. (2001); [9]Boonbrahm et al. (2004); [10]Froberg et al. (2007); [11]Froberg et al. (2008); [12]Little et al. (1991); [13]Msanga and Bryant (2004); [14]Schiessler et al. (2002); [15]Wagenaar and Langhout (2007); [16]Roth et al. (2009); [17]de Passille et al. (2008); [18]Hepola et al. (2007); [19]Johnsen et al. (2015); [20]Valnickova et al. (2015); [21]Flower and Weary (2001); [22]Kisac et al. (2011); [23]Metz (1987); [24]Rajala and Castren (1995); [25]Bar-Peled et al. (1997)

*Qualitative statements/ results:*

a: "No immediate animal health problems linked to suckling systems occurred." Farmers observed improved disease resistance in calves.

b: *"No significant differences were found out in the health condition and faeces of calves."*

*c:* "[…] poorer health score for mother reared calves compared to artificially reared calves."

d: "Two-thirds of the calves in each treatment were noted for diarrhoea at least once during the 10-week-experimental period. Bloody diarrhoea only was recorded once in each of the three treatments."

e: "Diarrhoea […] was a less frequent problem in suckling systems."

f: 56,3% of veterinary treatments were for diarrhoea.

g: "All calves […] got diarrhoea usually during the first week of life."

h: Calves had diarrhoea during the first 14 days of life

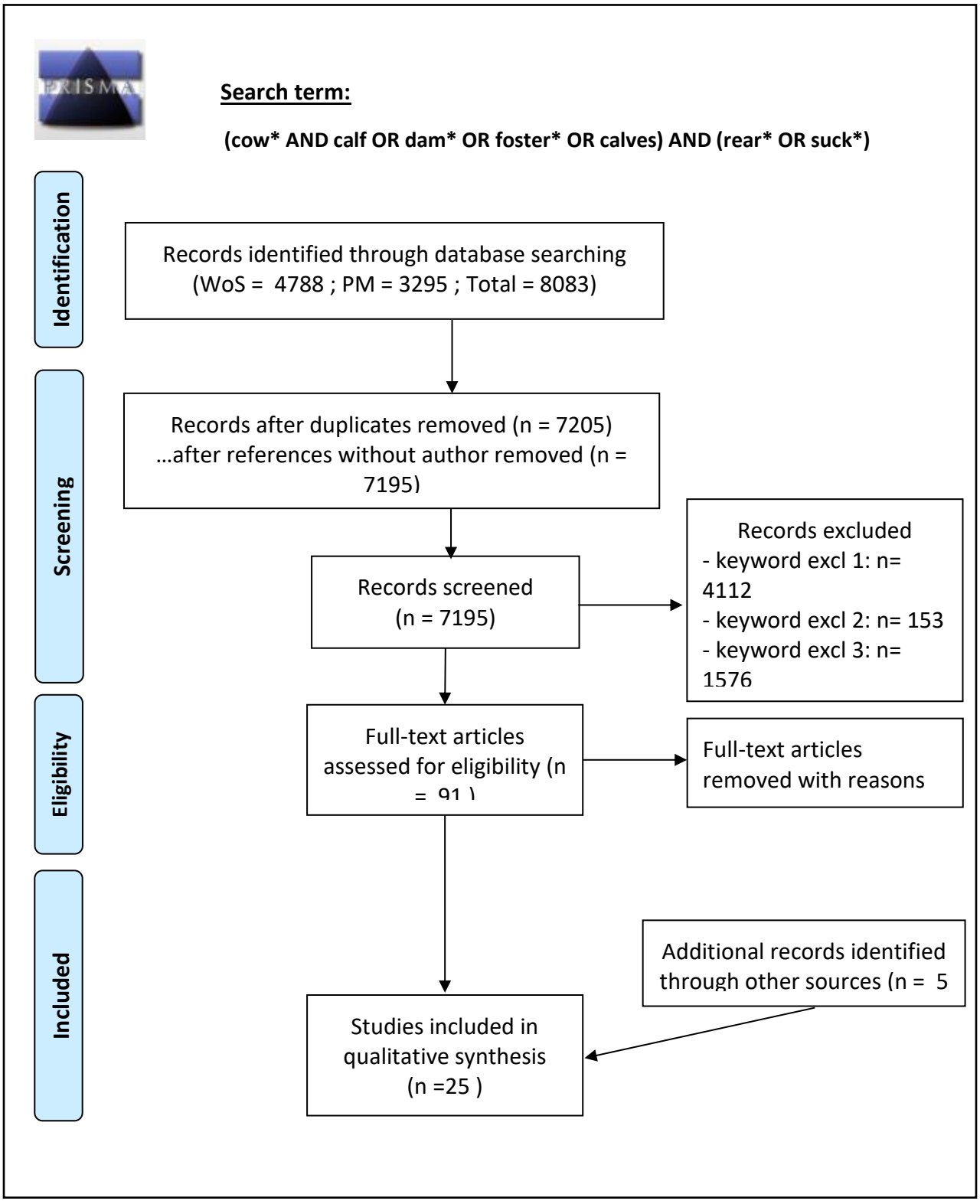
i: Many artificially reared calves suffered from diarrhoea. One calf (8%) died due to diarrhoea.

j: 22,9% of treatments were for respiratory disease.

k: BRD incidence was very low in all treatment groups

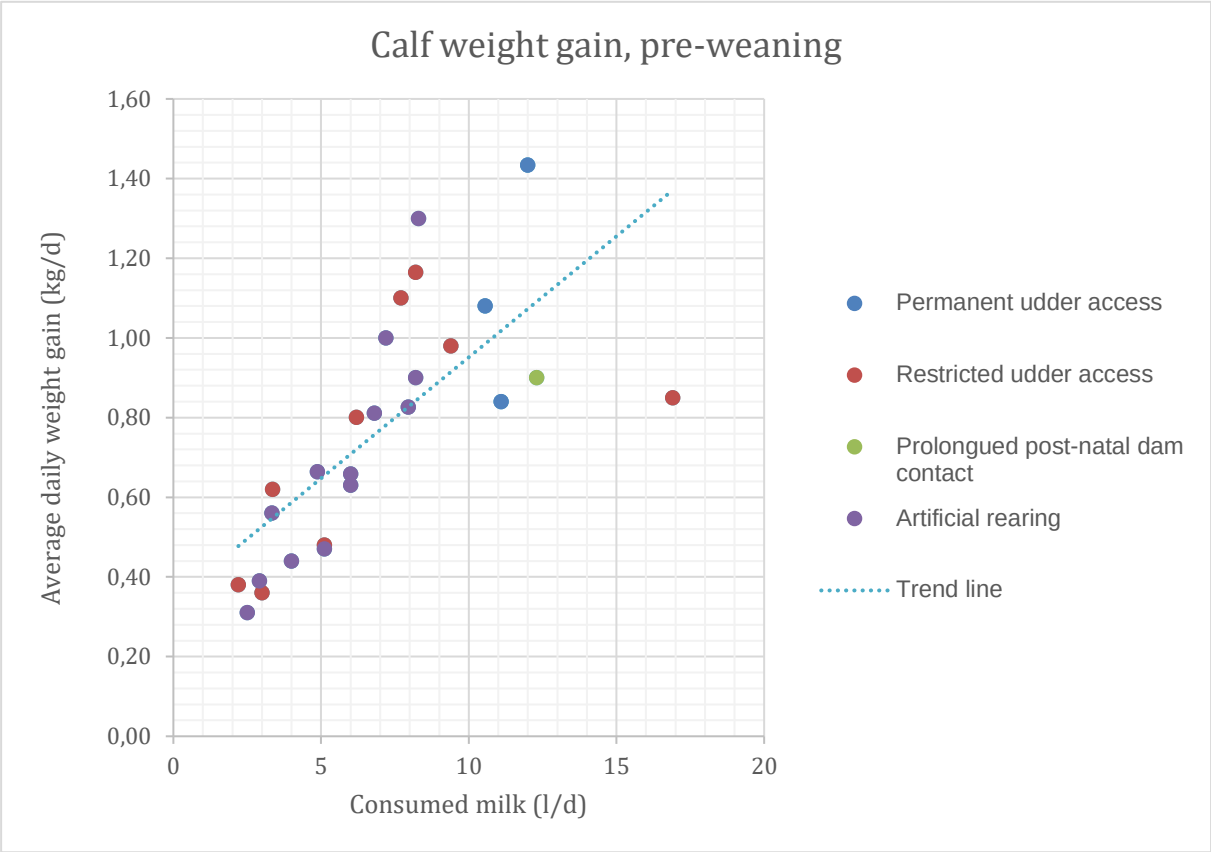
m: "Suckled calves spend significantly more time licking, but less time sucking foreign objects or other calves than artificially reared calves. After weaning, suckled calves spend less time with non-nutritive oral activities

**Figure I - 1:** PRISMA flowchart depicting the screening and appraisal process of the systematic literature search.




*Source:* Moher et al. (2009)

**Figure I - 2:** Daily weight gain of pre-weaned dairy calves by daily consumed milk amount




*Sources:* Little et al. (1991); Bar-Peled et al. (1997); Flower and Weary (2001); Lupoli et al. (2001); Margerison et al. (2002); Schiessler et al. (2002); Margerison et al. (2003); Boonbrahm et al. (2004); Hepola et al. (2007); Wagenaar and Langhout (2007); de Passille et al. (2008); Froberg et al. (2008); Froberg and Lidfors (2009); Froberg et al. (2011); Johnsen et al. (2015)

# Part II

# Antimicrobial drug use and clinical health scores of dairy calves reared with udder access on Swiss organic farms

## II - 1. Introduction

In the dairy industry it is standard practice to separate the dairy calf from its dam immediately after parturition (Pempek et al., 2017). Early separation is believed to reduce disease transmission and thus to improve calf health (Ventura et al., 2013). Yet, for heifer calves being reared on their birth farms, morbidity rates of 23% have been observed in Sweden (Svensson et al., 2003) and the US (Windeyer et al., 2014). On Swiss dairy farms, calves receive on average 53 antimicrobial treatments per 100 calf-years (Gonzalez et al., 2010). During the recent decade, increasing consumer concern with early separation (Busch et al., 2017), has pushed farmers to adopt cow-calf rearing systems during parts or all of the milk feeding phase (Wagenaar and Langhout, 2007). This has raised scientific interest about if and how cow-calf rearing impacts calf health (Beaver et al., 2019; Meagher et al., 2019). A systematic review by Eppenstein et al. (in press) concluded that udder rearing (i) increases pre-weaning weight gains, (ii) has no negative effects on calf health and (iii) eliminates cross-sucking. However, to date no epidemiological multi-herd study exists that evaluates calf health and antimicrobial drug use for dairy farms using cow-calf rearing systems. This study seeks to quantify veterinary and antimicrobial treatment incidences and clinical health scores for Swiss and German dairy calves reared with udder access on their birth farm.

## II - 2. Materials and Methods

The target population are farms producing saleable milk, located in Switzerland or Southern Germany, who use a cow-calf rearing system since at least two years (i.e. 2016). Potential participants were identified through two networks of the Research Institute of Organic Agriculture (FiBL). First, members of a FiBL-operated knowledge sharing platform for dairy producers on cow-calf rearing were invited via email or letter to participate. Second, known dairy producers who were already participating in a FiBL project on calf fattening using cow-calf rearing systems were additionally invited individually. From 23 interested dairy

producers, 14 qualified and were visited from February 2018 to April 2019. On each farm the farm manager was interviewed, data on veterinary treatments was collected, and the health of all calves reared with udder access was scored according to a pre-established health score (approved animal experiment number: 75716). The unit of analysis was the calf herd.

### II - 2.1 Data collection at farm level

At farm level, data about the cow-calf system was collected via interviews. The interview collected data about farm characteristics (total agricultural area; size of dairy herd; replacement from own herd (yes/no); sale of fattening calves (yes/no); average number of calves (replacement, beef, veal, other) per year; duration of stay of calves (beef, veal, other) on farm; number of dead calves during past 365 days and death causes; year of adoption of cow-calf system) and the rearing system (length of permanent dam contact after parturition (days); type of nursing cow; simultaneous milking of nursing cows (yes/no); number of suckling calves per cow; number of milk feedings per day; duration of contact to nursing cow per day (hours); place where calves suckle; length of suckling period (days)).

### II - 2.2 Collection of treatment data

For each farm the average number of calves per year and their respective durations of stay, stated in the interview, were used to estimate the number of calf days at risk (Frei et al., 1997). A maximum duration of stay of 180 days was defined and attributed to all replacement calves; thereafter calves were considered to be weaned feeder stock. Mandatory Swiss farm records on veterinary treatments (*Behandlungsjournal*) and veterinary bills provided data on the total number of veterinary treatments on calves 365 days retrospective to the farm visit. Any course of treatment connected to the same diagnosis, was counted as one treatment if not interrupted for longer than seven days (Gonzalez et al., 2010). Dehorning and castration were excluded for being deliberate medical interventions. We included into general treatments the

administrations of minerals or electrolytes by the veterinary, as well as any treatment that started before the defined observation period but reached into it. General treatments were differentiated by etiology (gastrointestinal disorders excluding parasites, respiratory disorders, umbilical, parasites, locomotor system, miscellaneous). Treatments involving antibacterial or antiparasitic drugs were included in general treatments, as well as counted separately. Antibacterial treatments were differentiated with regard to four indications (gastrointestinal disorder, respiratory disorder, umbilical, and miscellaneous), and antiparasitic treatments with regard to two indications (coccidiosis and intestinal worms).

II - 2.2.1 Processing of treatment data

One farm was excluded from the analysis of treatment data, since only 20% of its calves had udder access and could not be identified retrospectively in the treatment records. The frequency of general and antimicrobial (AM) treatment events was described for each farm as "incidence density" (ID) per 100 calf-years (Frei et al., 1997) :

ID = (Number of treatments / Number of risk days) * 100 * 365

Antibacterial and antiparasitic treatments were additionally quantified in terms of "treatment incidences" (TI), based on the defined daily dose methodology (Pardon et al., 2012; Lava et al., 2016b). For each AM drug, a long-acting factor (LA) was estimated based on the Swiss compendium for veterinary drugs (https://www.vetpharm.uzh.ch). The LA was multiplied with the number of dose repetitions to calculate the used daily doses (UDD) per treatment. AM treatment incidences (TI) expressed per thousand days at risk were then calculated for each farm as:

$TI_{UDD}$ = (Total number of UDD / Number of days at risk) * 1000

### II - 2.3 Calf mortality

Calf mortality was defined as any instance of unwanted calf death (including accidents) and euthanasia. Cases of calf mortality reported in the treatment journals during the last 365 days were compared to the self-reported mortality cases during the interview. When cited causes of death coincided the cases were merged, otherwise they were added to each other. Mortality rate (%) was calculated as the number of mortality cases over the average number of calves per year, times 100.

### II - 2.4 Clinical health scores

For the clinical assessment of calf health, we used a pre-established score chart developed by the Research Institute of Organic Agriculture (FiBL), the University of Kassel and the University of Natural Resources and Life Sciences, Vienna. It is closely related to the scoring chart used by Jorgensen et al. (2017), based on McGuirk and Peek (2014). Differing to the original score, this study dropped the parameter “hair coat condition”, due to inconsistencies in scoring, and added the parameters “skin condition”, “umbilical” and “ears”. Scores ranged from 0 to 1 or 0 to 2, with higher scores indicating poorer health. For each calf an overall weighted health score was calculated, for which a score of 4 or above indicates severely impaired health. The used score chart and a detailed description of the attributed weights for the overall health score are provided as additional file to this publication (Additional file II -1, page 50).

## II - 3. Results

### II - 3.1 Characterization of farms and rearing system

The studied farms utilized on average an agricultural area of 27.9 ha and possessed 31 milking cows. Farms totalled an estimated 445 calvings and 49,497 calf risk days, with a median of 32 calvings per year and an average stay of 114 days per calf. Figure II - 1 (page

43) characterises the diversity of encountered cow-calf systems. Dam rearing systems, in which all cows nurse their own calf while being milked, were used on 36% of farms. All remaining farms used foster rearing systems, in which selected cows nursed multiple foreign calves without additional milking. Figure II - 1 illustrates the diversity of encountered rearing systems, of which strikingly none resembled one another. Farmers adjusted the various parameters of their rearing system to fit their personal preferences, space allowances and even dairy breed.

### II - 3.2 Treatments

Nine of 13 farms (69%) recorded at least one veterinary calf treatment during the last 365 days, five (31%) recorded antibacterial and two (15%) antiparasitic treatments (Table II – 1, page 40). A total of 51 veterinary treatments were recorded, of which 17 (33%) involved antibacterial and 27 (53%) antiparasitic drugs. The full list of recorded AM drugs and corresponding LA factors can be found in the Additional file II – 2 (page 51). Among the farms with veterinary treatments, seven out of nine recorded bacterial or parasitic gastrointestinal disorders, making this the most commonly observed indication across farms. Coccidiosis accounted for 20 out of 51 treatments (39%), but was treated on two farms only. None of the farms recorded veterinary treatments for ear infections, lice or cattle ringworm. When considering all farms, the median ID was 25.4 veterinary treatments per 100 calf-years, and both the median antimicrobial ID and the median $TI_{UDD}$ were zero. When considering only farms with veterinary/antimicrobial treatments, the median ID was 34.9 vet treatments, respectively 44.3 AM treatments, per 100 calf-years, while the median $TI_{UDD}$ was 6.9 daily doses per 1000 days at risk. The highest ID (288.7 treatments/100 calf-years) and antimicrobial $TI_{UDD}$ (39.6 daily doses per 1000 risk days) were both recorded at the same farm with a problem of recurrent coccidiosis and intestinal worms. This farm accounted for 41.2% (21/51) of all veterinary treatments and 59.1% (39.6/67) of UDD.

### II - 3.3 Calf mortality

The median mortality rate on farm level was 3%, with a minimum mortality rate of 0% and maximum rate of 16%. Six out of 13 farms (46.2%) had zero cases of mortality.

### II - 3.4 Clinical health scores

Table II - 2 (page 41) details the distribution of clinical health scores in 152 calves scored on the 14 farms. Nasal discharge was the most common health impairment (23.5% of all calves, median: 23.2%), followed by ocular discharge (22.9%; median: 33.3%) and skin conditions (19.7%; median: 0%). Perianal soiling was observed in 10.2% (median: 0%) of calves. Poor body condition (Score 2) was never observed and medium body condition (Score 1) only once (0.7% of calves).

Table II - 3 (page 42) shows the distribution of weighted health scores for all calves and at farm level. Almost double as many female calves (96, 63%) were observed as male calves. At farm level, the median frequency of calves with an overall health score of 0 was 36% (min: 0%; max: 100%). the median frequency of calves with a health score of 4 or above was 0% (max: 14%).

## II - 4. Discussion

For the first time, an epidemiological, multi-herd study was conducted to determine the health of calves reared in cow-calf systems on commercial dairy farms. We retrospectively quantified mortality rates, veterinary and antimicrobial treatments of calves, and scored the health of all calves with udder access during our visit. Compared to the average Swiss dairy farm (BLW, 2018), the 14 studied farms used a similar agricultural area (27.9 ha vs 26.5 ha), but possessed an above average number of milking cows (31 vs 26). We found that the

majority of farms did not use antimicrobial treatments on calves during the observation period, the median mortality rate was 3% and less than 5% of calves were classified as "severely health impaired".

### II - 4.1 Diversity of rearing systems

Eppenstein et al. (in press) systematically reviewed cow-calf rearing systems and classified these into three categories of udder access: (1) Permanent udder access, providing half or full-day contact between nursing cows and calves, (2) Restricted udder access, providing twice daily cow-calf contact for suckling, and (3) systems in which calves have prolonged post-natal contact to their dam but are separated before weaning and then artificially reared. We found all of the three categories being used by the commercial dairy farmers we interviewed. Likewise to Wagenaar and Langhout (2007), the majority of farmers in our study used foster cows who nurse multiple calves, especially for calves with restricted udder access. Reasons for this stated by the farmers were poor milk-let down of nursing cows and better control over fed milk quantities. It was also found that cow-calf systems did not benefit all calves to an equal extent since dairy farmers preferentially reared female calves (Wagenaar and Langhout, 2007), and often sell males or surplus heifers at an age of about 24 days.

### II - 4.2 Treatments

Frei et al. (1997) and Gonzalez et al. (2010) studied incidence densities of calf health events and AM treatments among conventional Swiss dairy farms with artificial calf rearing. Likewise to both authors, we found that the majority of veterinary and AM treatments were related to digestive disorders (bacterial or parasitic), respiratory diseases or omphalitis. Contrary to our study, which recorded veterinary treatments, Frei et al. (1997) recorded calf health events, including those not requiring human intervention. Hence, a direct comparison of incidence densities was not possible. Gonzalez et al. (2010) found substantially higher AM

drug use for artificially reared calves at 95 conventional dairy farms, as compared to our study, both with regard to median AM treatment ID per 100 calf-years (34 vs 0) as well as mean ID (53 vs. 35). Apart from the rearing system itself, though, an important reason for lower drug use in our study was the differing mind-set of organic farmers towards AM drugs. Many of the interviewed farmers categorically stated for instance “never to use AM drugs”. Similar to Gonzalez et al., 2010, we found a rare use of *Highest Priority Critically Important Antimicrobial* drugs (WHO, 2017). Marbofloxacin was the only such drug employed by veterinarians in our study.

Calf purchase and a high number of fattened calves are major risk factors for AM treatments and mortality in calves (Lava et al., 2016a; Schnyder et al., 2019), thus setting the rearing of dairy calves on their birth farm apart from the rearing on commercial fattening farms. For calves reared on nine Swiss veal fattening farms without calf purchase, Schnyder et al. (2019) found a median AM $TI_{UDD}$ of 6.9 per 1000 risk days (2.5 per 365 days) and a mean of 14.8 per 1000 risk days (5.4 per 365 days). This is substantially higher than the antimicrobial $TI_{UDD}$ values per 1000 days we found in our study (median: 0; mean: 5.2).

In this study, we distinguished between antibacterial and antiparasitic drug use. In particular with regard to digestive disorders, the vast majority of antimicrobial $TI_{UDD}$ (92.5%) employed antiparasitic drugs, rather than antimicrobials. No other references reporting on antimicrobial TI for calves were found to differentiate between antibacterial and antiparasitic drug use. It is therefore not clear whether references reporting on antimicrobial $TI_{UDD}$ include antiparasitic drugs, and whether the found pattern is particular to organic farms using cow-calf rearing systems or is common among calf rearing operations.

### II - 4.3 Mortality

For Swiss veal fattening operations without calf purchase, Schnyder et al. (2019) report that 81.8% of herds had mortality rates ≤ 3%, while Lava et al. (2016a) find a median mortality

rate of 0%. This is lower than the mortality rates we find: 57.1% of herds had mortality rates ≤ 3% and the median mortality rate we found was 3%.

### II - 4.4 Clinical health scores

Jorgensen et al. (2017) scored the health of dairy calves in automated feeding systems in the US, using a similar health score to the one used in our study. When comparing the health scores found by Jorgensen et al. (2017) to the values we found (see Table II - 2), calves in our study appear to be overall healthier, showing substantially lower frequencies of scores ≥ 1, especially with regard to perianal soiling (41.9% vs. 10.2%) and vitality (16.1% vs. 1.3%). This is in congruence with farmer statements in Wagenaar and Langhout (2007) and during the interviews we conducted, that "diarrhoea is less of a problem in cow-calf rearing systems". Only nasal discharge (23.5% vs. 19.9%) and ocular discharge (22.9% vs. 25.5%) were scored at similar frequencies as in Jorgensen et al. (2017). Contrary to Jorgensen et al. (2017), however, we scored nasal discharge more strictly by including clear, dripping discharge as indication of impaired health (score 1).

## II - 5. Conclusion

This epidemiological multi-herd study showed that Swiss and German organic dairy farms rearing calves with udder access have lower incidences of antimicrobial treatments than conventional dairy farms using artificial calf rearing. This is true both with regard to the number of treatment events, as well as the used antimicrobial daily doses. Reduced antimicrobial drug use is partly attributed to the mind-set of organic farmers, as well as to the very good overall health of calves found during health checks with a standardized scoring chart. In severe cases of calf disease, organic farmers should, however, not be reluctant to resort to antimicrobial drugs such as to prevent avoidable calf suffering and mortality. Lastly, it has been shown that cow-calf rearing systems among organic farmers are highly diverse and

can be adapted to fit the farmers' needs with regard to the calves' milk allowance, housing, suckling length, and weaning age.

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**Table II - 1:** Estimated treatment frequencies and treatment incidences for calves under 180 days of age of 13 organic dairy farms in Switzerland and Southern Germany

| | **Farms with treatments (N=13)** | **Number of treatments** | **Incidence density (ID) per 100 calf-years** | | | **Treatment incidence (TI) per 1000 risk days** | | |
|---|---|---|---|---|---|---|---|---|
| | | | Median | Max | Median, farms with treatments | Median | Max | Median, farms with treatments |
| **Any type of treatment** | **9** | **51** | **25.3** | **288.7** | **34.9** | - | - | - |
| Gastrointestinal tract | 5 | 8 | 0 | 25.7 | 15.7 | - | - | - |
| Respiratory tract | 2 | 9 | 0 | 75.2 | 50.3 | - | - | - |
| Umbilical | 1 | 3 | 0 | 47.1 | 47.1 | - | - | - |
| Parasites | 2 | 27 | 0 | 288.7 | 181.9 | - | - | - |
| Locomotor system | 1 | 1 | 0 | 8.6 | 8.6 | - | - | - |
| Other | 2 | 3 | 0 | 34.9 | 28.7 | - | - | - |
| **Antimicrobial treatments** | **6** | **44** | **0** | **288.7** | **44.3** | **0** | **39.5** | **6.8** |
| **Antibacterial treatm.** | **5** | **17** | **0** | **75.2** | **25.7** | **0** | **12.0** | **2.3** |
| Gastrointestinal tract | 3 | 4 | 0 | 17.1 | 15.7 | 0 | 1.3 | 0.7 |
| Respiratory tract | 2 | 9 | 0 | 75.2 | 50.3 | 0 | 9.3 | 5.8 |
| Umbilical | 1 | 3 | 0 | 47.1 | 47.1 | 0 | 10.8 | 10.8 |
| Other | 1 | 1 | 0 | 8.6 | 8.6 | 0 | 0.5 | 0.5 |
| **Antiparasitic treatm.** | **2** | **27** | **0** | **288.7** | **181.9** | **0** | **39.5** | **20.8** |
| Coccidiosis | 2 | 20 | 0 | 192.5 | 133.8 | 0 | 21.1 | 11.6 |
| Intestinal worms | 1 | 7 | 0 | 96.2 | 96.2 | 0 | 18.5 | 18.5 |

**Table II - 2:** Distribution of health scores by health parameters in 152 preweaned dairy calves from 14 Swiss and German organic farms practicing natural rearing

| Health parameter[1] | No. of calves | Score 0 | Score 1 | Score 2 | Calves ≥ 1 (%) *All calves* | | Calves ≥ 1 (%) *Farm level* | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Our values | Jorgensen et al. (2017)[2] | Min | Median | Max |
| **Vitality** | 152 | 150 | 2 | - | 1.3 | 16.1 | 0 | 0 | 11 |
| **Body condition** | 152 | 151 | 1 | 0 | 0.7 | - | 0 | 0 | 11 |
| **Perianal soiling** | 147 | 132 | 15 | - | 10.2 | 41.9 | 0 | 0 | 67 |
| **Cough** | 152 | 134 | 18 | - | 11.8 | - | 0 | 0 | 55 |
| **Nasal discharge** | 149 | 114 | 35 | - | 23.5 | 19.9 | 0 | 23 | 75 |
| **Ocular discharge** | 118 | 91 | 27 | - | 22.9 | 25.5 | 0 | 33 | 75 |
| **Breathing** | 147 | 144 | 3 | - | 2 | - | 0 | 0 | 9 |
| **Skin condition** | 142 | 114 | 28 | - | 19.7 | - | 0 | 0 | 86 |
| **Umbilical** | 152 | 150 | 2 | - | 1.3 | - | 0 | 0 | 14 |
| **Ears** | 151 | 148 | 3 | - | 2 | 8.6 | 0 | 0 | 11 |

[1] Score definitions: Vitality = 0 (lively), 1 (little responding); Body condition = 0 (good), 1 (moderate), 2 (poor); Perianal cleanliness = 0 (clean), 1 (at least the area of a size of a palm is soiled); Cough = 0 (none), 1 (single or repeated cough); Nasal discharge = 0 (none), 1 (clear dripping or any opaque discharge); Ocular discharge = 0 (none), 1 (wet or dry ocular discharge of at least three fingers' breadth and/or any crust of at least 0,5 cm); Skin condition = 0 (normal), 1 (signs of skin disease or parasites); Umbilical = 0 (dry, not sensitive), 1 (thickened, wet, dolorous); Ears = 0 (normal ear play), 1 ( headshaking, scratching, uni- or bilateral droop)

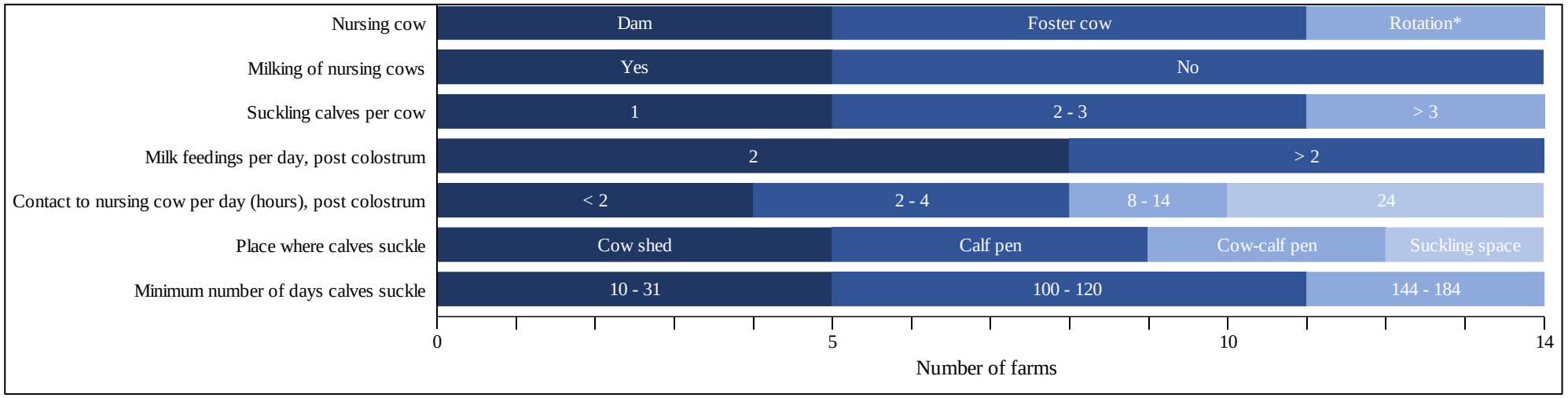
[2] Source: Jorgensen, M.W., Adams-Progar, A., de Passille, A.M., Rushen, J., Godden, S.M., Chester-Jones, H., Endres, M.I., 2017. Factors associated with dairy calf health in automated feeding systems in the Upper Midwest United States. J Dairy Sci 100, 5675-5686.. The author's attitude score corresponds to the parameter "vitality". Ear, eye and nasal scores correspond to the parameters "ears", "ocular discharge" and "nasal discharge", although nasal discharge was scored more strictly in our study for including clear dripping discharge additional to cloudy discharge in score 1. The authors' dirtiness score corresponds to our "perianal soiling" parameter.

**Table II - 3:** Distribution of total health scores by sex in 152 preweaned dairy calves from 14 Swiss and German organic farms practicing natural rearing

| Health score[3] | No. of calves | No. of calves (%) | Male calves (%) | Female calves (%) | No. of calves (%) - *Farm level* | | |
|---|---|---|---|---|---|---|---|
| | | | | | Min | Medium | Max |
| **0** | 73 | 48 | 46.4 | 49 | 0 | 36 | 100 |
| **1** | 42 | 27.6 | 21.4 | 31.3 | 0 | 31 | 67 |
| **2** | 19 | 12.5 | 19.6 | 8.3 | 0 | 11 | 57 |
| **3** | 11 | 7.2 | 5.4 | 8.3 | 0 | 0 | 29 |
| **≥4** | 7 | 4.6 | 7.1 | 3.1 | 0 | 0 | 14 |
| **No. of calves** | 152 | 152 | 56 | 96 | | | |

[3] A higher health score indicates poorer health. Calves with a total score of 4 or above are considered being "severely health impaired".

**Figure II - 1.** Characterisation of natural rearing systems used by 14 organic dairy farms in Switzerland and Southern Germany, 2018 - 2019




*Rotation: New dams after parturition nurse their own calves and foster at the same time older calves. When other dams give birth and join the group of nursing cows, the one's nursing the longest exist the group, while their calves continue to be nursed by the new dams.

# APPENDIX

**Additional file I - 1:** Protocol of the systematic review

Aim of the systematic review:
The aim of this systematic review is to document and quantify the effect of feeding milk to dairy calves by means of suckling an udder on performance, cross-suckling behavior and clinical parameters of calves' health.

Procedure:

1. Reading of two reviews (Flower and Weary, 2003; Johnsen et al., 2016; Beaver et al., 2019; Meagher et al., 2019) on udder rearing.

1.1 Selection of publications pertaining to weight-gain and cross-sucking for review.

2. Searching for publications in online databases, based on an automatic search.

2.1 PubMed (https://www.ncbi.nlm.nih.gov/pubmed/)

- Search term: (cow* AND calf OR dam* OR foster* OR calves) AND (rear* OR suck*)
- No limitation with regard to the publication date.
- Date of search 2017-11-30
- Refining the results with:
    - Species: Other animals
    - Languages: English, German
    - Subjects: veterinary science
- Saving the publications in an EndNote X6-Data file

2.2 Web of Science (https://apps.webofknowledge.com/)

- Search term: (cow* AND calf OR dam* OR foster* OR calves) AND (rear* OR suck*)
- No limitation with regard to the publication date.
- Date of search 2017-11-30
- Refining the results with:
    - "Web of Science Categories": Agriculture Dairy Animal Science, Veterinary Science, Behavioral Science, Neuroscience, Zoology, Agriculture Multidisciplinary
    - "Document types": Article
- Saving the publications in an EndNote X6-Data file

3. Removing the duplicates with the help of EndNote's duplicate search.
4. Refining of results using keyword search within EndNote

4.1. Exclusion of references containing one of the following terms in their title:

- antioxidant
- beef
- birch
- bird
- bone
- brain
- broiler
- buffalo
- camel
- chick

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- chronic
- cocaine
- cortex
- deer
- DNA
- dog
- donkey
- duck
- egg
- elephant
- embryo
- equine
- ewes
- fish
- flies
- foal
- frog
- gamma
- geese
- genotype
- giraffes
- GnRH
- goat
- heat
- hens
- horse
- in vitro
- kestrel
- lamb
- leaves
- liver
- lobsters
- loci
- meat
- mice
- mink
- models
- molecular
- monkey
- mouse
- mycoplasma
- pet
- pig
- porcine
- pup
- rabbit
- rat

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- rhesus
- salmon
- sheep
- sows
- soybean
- swine
- t-cell
- tick
- toxicity
- tumor
- turkeys
- vaccine
- yak
- zebra

Filing of references matching the term into an EndNote group named “excl *term*”.
4.2. Exclusion of references containing one of the following terms in their title, but not containing any of the word truncations “suck”, “nurs” or “rear”:

- cattle
- coccidiosis
- cryptosporidium
- diarrhea
- enteritis
- escherichia
- giardia
- lamness
- oestrus
- parasites
- pneumonia
- rota
- slaughter

Filing of references matching the term into an EndNote group named “excl 2 *term*”.
4.3. Exclusion of references containing none of the following word truncations in their title:

- cattle
- cow
- calf
- calves
- suck
- rear
- nurs
- dairy
- foster
- dam
- mother

Filing of excluded references into an EndNote group named “excl 3”.
4.4. Exclusion of references containing either of the word truncations “suck”, “nurs” or “rear” in their title, but none of the following: “cattle”, “cow”, “calf”, “calves”, “dairy”, “foster”,

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"dam", "mother". Filing of excluded references into an EndNote group named "excl 3 *suck nurs rear*".
4.5. Exclusion of references containing the word "cow" in their title, but none of the following: "calf", "calves", "suck", "rear", "nurs", "dairy", "foster", "dam", "mother". Filing of excluded references into an EndNote group named "excl 3 *cow*".
4.6. Exclusion of references containing the word "calf" in their title, but none of the following: "cow", "dam", "mother", "suck", "rear", "nurs", "dairy", "foster". Filing of excluded references into an EndNote group named "excl 3 *calf*".
4.7. Exclusion of references containing the word "calves" in their title, but none of the following: "cow", "dam", "mother", "suck", "rear", "nurs", "dairy", "foster". Filing of excluded references into an EndNote group named "excl 3 *calves*".

5. Sample check of excluded references
   To avoid the exclusion of relevant publications, the files with excluded references are checked randomly by one person.
6. Relevance screening based on a manual procedure
   In a first step screening of the title and in a second step the abstract if the references match predefined inclusion and exclusion criteria. If references do not fit those criteria, they are excluded. The amount of publications remaining after the first step and after the second step are sampled.

6.1 Inclusion criteria
Inclusion of references which:

- Are published in peer-reviewed journals
- Provide an abstract written in English or German
- Investigate dairy calves
- Assess the calves' rearing method in vivo or in a clinical trial
- Are cited in either Flower and Weary (2003), Johnsen et al. (2016), Beaver et al. (2019) or Meagher et al. (2019) as reporting on calf performance, cross-sucking or clinical health parameters.

And dealing with:

- Rearing methods that allow the calf to suckle milk from an udder, indicated through the following keywords:
  - cow-calf
  - dam rearing
  - natural rearing
  - suckling
  - foster rearing
  - udder rearing

AND

- Allow the calf to suckle past three days of age
- Report clinical parameters of calf performance, cross-sucking behavior or health, indicated by the following keywords:
  - weight gain
  - growth
  - health
  - disease
  - performance
  - cross-sucking

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- morbidity
- mortality

6.2 Exclusion criteria

Exclusion of all references which:

- Have missing information (e.g. missing author, missing abstract)
- Cannot be found or accessed as full paper in an online database.
- Are only presented on conferences and not in peer-reviewed journals
- Investigate calves of beef breeds or in rearing systems aimed for meat production
- Do not have treatment and control groups (i.e. case reports and reviews)
- Do not report the size of treatment and control groups

Or exclusively report on:

- Dam performance and health
- The effect of suckling up to 3 days postpartum (i.e. Colostrum intake, Immunoglobulin transfer and absorption, etc)
- Calf behavior other than cross-sucking
- Health, wellbeing or behavior of nursed calves as adult animals
- The cow-calf relation and bonding
- Nursing behavior of calves
- Weaning strategies and methods

7. Data processing

Set up of a spreadsheet containing all reviewed studies, each row capturing one treatment group within one study.

7.1 Study methodology

For each treatment group methodological information on the publication and rearing system is systematically recorded:

- Reference number
- Title of publication
- Author of publication
- Year of publication
- Cattle breed
- Number of observed calves in treatment group
- Milk feeding method (e.g. Automatic milk feeder, bucket, suckling of mother, etc)
- Housing type (Group pen refers to calf-only groups)
- Number of milk feedings per day
- Average length of udder access per day (in h)
- Average milk allowance per day (l)
- Qualitative description of the suckling management *(for suckling treatments only)*
- Number of days with permanent contact to dam after birth (if contact less than 24h = 0)
- Start of observation period (day of life)
- End of observation period (day of life)
- Weaning age (in days)
- Milk type used in the majority of milk feedings
- Frequency of milking of nursing cow per day *(for suckling treatments only)*

7.2 Definition of treatment categories

# APPENDIX

Four categories of treatments are defined and each recorded treatment group classified accordingly:

- **1** – **(Semi-)permanent udder access**: Treatments in which the average length of udder acces per day equals 8 h or more. Udder access is provided until weaning.
- **2** – **Restricted udder access**: Treatments in which the average length of udder access per day is below 8 h, but greater than 0. Udder access is provided until weaning.
- **3 - Artificial rearing with extended post-natal suckling**: Treatments in which the number of days with permanent contact to the dam (including udder access) after birth equals 4 or more. Thereafter, calves are reared artificially (Average length of suckling per day (in h) = 0)
- **4** – **Standard artificial rearing**: The maximum number of days with permanent contact to the dam (including udder access) after birth is 3. After separation from the dam, calves are reared artificially until weaning.

7.3 Outcome with regard to calf based parameters

For each treatment group, information on the outcomes of calf based parameters are recorded:

- Mean daily weight gain, pre-weaning (kg/day)
- Mean daily weight gain, post-weaning (kg/day)
- Morbidity rate (%)
- Diarrhoea rate (%)
- Respiratory disease rate (%)
- Navel infection (%)
- Antibiotic/ Veterinary treatment rate (%)
- Mortality rate (%)
- Cross-sucking rate (% of calves having displayed cross-sucking at least once)
- Total daily milk consumption (l or kg / day)
- Consumption of concentrates/roughage, pre-weaning (kg)
- Consumption of concentrates/roughage, post-weaning (kg)

Significant differences between treatment groups within one study are recorded.

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# APPENDIX

**Additional file II - 1:**

**Table A1:** Health score chart used during data collection

| Clinical parameter | Description | Score |
|---|---|---|
| **Vitality** | Lively | 0 |
| | Little responding or downer calf; and/or hunched back or clearly drooping ears | 1 |
| **Body condition** | Good to very good | 0 |
| | Moderate: ribs and spinous processes visible, edgy hip bone | 1 |
| | Poor: sharp ribs and striking spinous processes, weak musculature, clearly visible tail base without fat cover, weakly developed muscles at the hindquarter | 2 |
| **Perianal soiling** | Clean or only slightly dirty around tail | 0 |
| | Manure plaques around tail amounting to at least the size of the palm of a hand (fresh or dry soiling) | 1 |
| **Cough** | No cough | 0 |
| | Single or repeated cough | 1 |
| **Nasal discharge** | No nasal discharge | 0 |
| | Clear effluent dripping from nose or any opaque discharge | 1 |
| **Ocular discharge** | No ocular discharge | 0 |
| | Clearly visible wet or dry ocular discharge of at least three fingers' breadth and/or any crust (at least 0.5 cm) | 1 |
| **Breathing** | Normal | 0 |
| | Hampered or forced breathing | 1 |
| **Skin condition** | Normal coat and skin | 0 |
| | Visible signs of skin disease or parasites | 1 |
| **Umbilical** | Dry, not pressure-sensitive | 0 |
| | Thickened, wet, dolorous | 1 |
| **Ears** | Inconspicuous, normal ear play | 0 |
| | Increased headshaking, scratching, uni- or bilateral droop | 1 |

**Description of the attribution of weights for the calculation of an overall health score:**
In order to calculate an overall health score per calf, a total score of 4 or above was defined as indicating "severely impaired health". Each clinical parameter was then attributed a weight accordingly. Vitality was attributed a weight of 4, since reduced vitality invariably and unambiguously indicates severely impaired health. Body condition (BC) was attributed a weight of 3, such that a moderate BC scores (score = 1) in insolation does not indicate severely impaired health, but a poor BC scores (score = 2) does. The parameters Perianal soiling, Cough, Nasal discharge, Ocular discharge and Skin condition were all attributed a weight of 1, since these parameters were found to indicate severely impaired health rather in conjunction than isolation. The parameters Breathing, Umbilical and Ears were attributed a weight of 2, for indicating a health impairment in isolation, but not necessarily a severe one. The individual, overall health score was thus calculated as:

Overall health score = Vitality*4 + BC*3 + Perianal Soiling + Cough + Nasal discharge + Ocular discharge + Breathing*2 + Skin condition + Umbilical*2 + Ears*2

**Additional file II - 2:**

**Table A2:** Antimicrobial drugs used on calves on 14 organic dairy farms in Switzerland and Germany using cow-calf rearing systems according to the ATCvet classification system of the World Health Organization and importance for human medicine

| ATCvet | Drug | Antimicrobial class | Longacting factor (LA)[1] | Importance for human medicine[2] | Priority[2] |
|---|---|---|---|---|---|
| *Intestinal Antiinfectives* | | | | | |
| QA07AB20 | Sulfadimidin – Sulfaguanidin - Bismuth subnitrat | Sulfonamides | 1 | Highly important | - |
| *Antibacterials for systemic use* | | | | | |
| QJ01AA06 | Oxytetracyclin | Tetracyclines | 5 | Highly important | - |
| QJ01BA90 | Florfenicol | Florfenicol | 2 | Highly important | - |
| QJ01CA04 | Amoxicillin | Penicillins | 2 | Critically important | High |
| QJ01CE30 | Benzylpenicillin - Penicillin G | Penicillins (β-lactamase sensitive) | 5 | Critically important | High |
| QJ01EQ30 | Sulfadimidin - Sulfamethoxypyridazin | Sulfonamides | 1 | Highly important | - |
| QJ01EW13 | Sulfadoxin - Trimethoprim | Sulfonamides + trimethoprim | 1 | Highly important | - |
| QJ01GB03 | Gentamicin | Aminoglycosides | 1 | Critically important | High |
| QJ01MA93 | Marbofloxacin | Fluoroquinolones | 1 | Critically important | Highest |
| QJ01RA01 | Penicillin G - Dihydrostreptomycin | Penicillins + other antibacterials | 1 | Critically important | High |
| *Antiparasitics* | | | | | |
| QP51AJ01 | Toltrazuril | Triazines | 2 | - | |
| QP51AX08 | Halofuginon | Other antiparasitics | 1 | - | |
| QP54AA03 | Doramectin | Avermectine | 7 | - | |
| QP54AA04 | Eprinomectin | Avermectine | 7 | - | |

[1] Estimations based on the Swiss compendium for veterinary drugs (https://www.vetpharm.uzh.ch).
[2]According to the ranking of medically important antimicrobials for risk management of antimicrobial resistance due to non-human use by the World Health Organisation (WHO, 2017).