Original study

Effect of milk replacer feeding program on performance of Belgian Blue double-muscled rearing calves

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Abstract

One hundred and four Belgian Blue double-muscled calves were divided into four groups to examine the effects of different milk replacer (MR) programs. Calves in treatment group 1 received a MR diet reconstituted at 125 g/l, fed at 10 % of their initial live weight in two meals daily. Weaning occurred abruptly at a concentrate intake of 0.5 kg/d. Treatment 2 was similar to treatment 1, except that weaning occurred at a concentrate intake of 0.75 kg/d. Treatment 3 was similar to treatment 2, except that MR was fed once daily at 5 % of initial body weight from a concentrate intake of 0.5 kg/d onwards. Treatment 4 was similar to treatment 3, except that MR at a concentration of 200 g/l was fed once daily from the third week until a concentrate intake of 0.5 kg/d. Similar concentrates and grass hay were fed. Pre-weaning gain averaged 0.51, 0.57, 0.56 and 0.53 kg/d, respectively ($P<0.05$; SEM: 0.01). Daily nutrient intake was lowest for treatment 1. No effect on diarrhoea was found. Post-weaning gain did not differ among treatments. Daily gain during the whole rearing period (20 weeks) averaged 0.83 kg and was not affected by treatment. Calves assigned to treatment 1 had a lower daily intake of MR, while feed efficiency tended to be worse. Weaning can be successfully accelerated by skipping over a meal when concentrate intake exceeded 0.5 kg/d, or by combining one MR meal daily with an increased concentration of 200 g/l from an age of three weeks onwards.

Keywords: double-muscled calves, milk replacer concentration, meals per day

Abbreviations: BBDM: Belgian Blue double-muscled, CL: concentrate intake level, DM: dry matter, LW: live weight, MR: milk replacer, SEM: standard error of mean

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Introduction

Pre-weaning growth rate (Miller *et al.* 1999) or weaning weight (Freking & Marshall 1992) are both positively correlated with milk intake by the young beef calf. Robison *et al.* (1978) reported a correlation between weaning weight and total milk intake of 0.63. Similar effects were found in Belgian Blue double-muscled (BBDM) calves, with a correlation coefficient of 0.81 between average daily milk intake and pre-weaning live weight (LW) gain (Fiems *et al.* 2008). However, milk yield of BBDM dams is often low or even insufficient for calf rearing, so that calves are mostly reared on a milk replacer (MR) diet. Feeding MR is labour-intensive and time-consuming and MR is more expensive than solid feeds. Therefore, management systems resulting in earlier weaning can be interesting. Weaning involves the change from a milk diet to solid feed and this transition can be stressful. Rumen development is a normal physiological process and can be considered necessary for the welfare of the calf (Stull & Reynolds 2008). The development of the rumen depends on the solid feed availability. Therefore, solid feed intake can be used as a criterion to determine when to wean rearing calves. Previous studies showed that weaning of BBDM calves should be delayed until a daily concentrate intake of at least 0.75 kg for reasons of welfare, although performance was hardly improved in comparison with weaning at a daily concentrate intake of 0.5 kg (Fiems *et al.* 2005). Abrupt weaning at a daily concentrate intake of 0.5 or 0.75 kg was used as a negative or a positive control group, respectively, in this experiment. Digestive upsets may occur when the capacity of the abomasum is exceeded with the result of excess milk flowing back into the rumen, or milk moving too rapidly to the intestines. Because of the reduced organ size of BBDM animals (Fiems 2012), they may be more prone to digestive disorders than calves from other breeds. Belgian Blue double-muscled animals are characterized by a lower intake capacity compared to non-double-muscled ones (Fiems *et al.* 1997). Although solid feed was freely available, BBDM calves did not compensate a lower milk intake by an increased concentrate and hay intake during the first four months of life (Fiems *et al.* 2008). Consequently, BBDM calves are commonly weaned at a higher age than non-double-muscled calves. An earlier initiation of solid feed intake in calves fed milk according to a step-down method stimulates the metabolic and physical development of the rumen in comparison with feeding milk at a constant amount (Khan *et al.* 2007a). Therefore, the effect of gradual weaning (step-down regimen) was investigated when MR was fed once daily from two different ages onwards. Only for the youngest calves, dry matter (DM) concentration of the MR was increased because of the reduced fluid intake. Increasing DM concentration in the MR may increase pre-weaning growth rate (Jenny *et al.* 1982).

The objective of this experiment was to examine the effect of different MR feeding programs on the duration of the pre-weaning period, LW gain and feed intake in BBDM newborn calves.

Material and methods

Experimental procedures were according to the standards of the European Union for the use of experimental animals (Anonymous 1986).

Animals, housing and management

One hundred and four BBDM female calves with an initial age and LW of 7.0±2.1 days and 53.7±7.2 kg, respectively, and born out of the beef cow herd of the institute (ILVO - Animal Sciences Unit, Melle, Belgium), were used to investigate the effect of the milk feeding program on animal performance during the rearing period. Calves were introduced when they were between three and nine days old. Colostrum was fed the first day after birth followed by cow milk for the next two days and MR afterwards. The experimental period lasted 140 days, including a pre- and a post-weaning period. Throughout the experiment calves were confined in individual 1.4×2.3 m outdoor hutches with a 1.3×1.75 m fenced walking area. A single weighing occurred at the start of the experiment and at one and two weeks after weaning, with a double weighing at weaning and at the end of the rearing period. Furthermore, calves were weighed at two or four-week intervals before and after the eighth experimental week, respectively. Beside the milk diet all calves received a similar concentrate and grass hay. Concentrate ingredients were (g/kg): barley: 211, beet pulp: 200, palm kernel cake: 200, soybean meal: 224.2, beet molasses: 60, pollards: 51, lard: 11, limestone: 11.3, dicalcium phosphate: 2.1, salt: 1.9, vitamin and trace element premix: 17.5, binder (lignosulphonate): 10. Ingredients were ground to pass a 6-mm sieve, and pelleted using a 6 mm die. Concentrate intake was levelled off at a maximum of 3 kg per day. Grass hay was fed ad libitum and drinking water was always available.

Experimental treatments

Calves were divided into four comparable groups (26 calves per group) based on initial LW. They were fed a MR diet (50 % skim milk powder, 26 % whey powder, 16.5 % vegetable oil (mixture of palm oil, coconut oil and soybean oil), and 5 % wheat starch) at 40 °C by teat-bottle. Calves of treatments 1 and 2 received a milk diet reconstituted at 125 g MR powder per litre, fed at a constant daily level of 10 % of their initial LW, and equally divided over a morning and

Table 1
Schematic lay-out of the experimental treatments

	Treatments			
Timing	1 Early and abrupt weaning	2 Abrupt weaning at higher CL	3 Gradual weaning at higher CL	4 Gradual weaning at higher CL, reduced MR with increased concentration
Week 1-2	MR: 125 g powder/L; 5 % of initial LW in the morning & 5 % of initial LW in the evening			
Week 3 till a weekly concentrate intake of 3.5 kg	MR: 125 g powder/L; 5 % of initial LW in the morning & 5 % of initial LW in the evening			MR: 200 g powder/L; 5 % of initial LW once daily in the morning
From a weekly concentrate intake of 3.5 to 5.25 kg	Weaning (CL 0.5)	MR: 125 g powder/L; 5 % of initial LW in the morning & 5 % of initial LW in the evening	MR: 125 g powder/L; 5 % of initial LW once daily in the morning	
From a weekly concentrate intake of 5.25 kg		Weaning (CL 0.75)		

The bold line denotes a similar post-weaning management, CL: concentrate intake level (kg/day), MR: milk replacer, LW: live weight an evening meal. Weaning occurred abruptly when the weekly concentrate intake achieved 3.5 (concentrate intake level (CL) 0.5; Treatment 1: early and abrupt weaning) or 5.25 kg (CL 0.75; Treatment 2: abrupt weaning at higher CL). Treatment 3 (gradual weaning at higher CL) was similar to treatment 2, except that the MR diet was fed once daily in the morning (5 % of initial LW) when a weekly concentrate intake of 3.5 kg was achieved. Treatment 4 (gradual weaning at higher CL with a reduced fluid intake in combination with an increased DM concentration of the MR) was similar to treatment 3, except that MR diet was fed once daily from the third week onwards, and MR concentration amounted to 200 g powder per litre until a weekly concentrate intake of 3.5 kg. Treatments are shown schematically in Table 1. Faeces consistency was observed daily.

Analytical procedures

MR powder, concentrate and hay were sampled monthly and pooled at the end of the experiment. Chemical composition was determined using reference methods for ash (ISO 2002), moisture (Anonymous 1971), protein (ISO 2005) and fat (ISO 1999). Neutral detergent fibre (NDF) was analysed using an Ankom 200 fibre analyser (Ankom Technology, Macedon NY, USA). Heat-stable α-amylase and sodium sulfite were added to the neutral detergent solution. Neutral detergent fibre was expressed on an ash-free base (Van Soest *et al.* 1991). Net energy (NE) was estimated from the cellulase *in vitro* organic matter digestibility (De Boever *et al.* 1999). Mean composition and NE value of the feeds are shown in Table 2.

Table 2
Chemical composition and energy value of the feeds fed to Belgian Blue double-muscled calves during the rearing period

	Milk replacer	Concentrate	Grass hay
Dry matter, DM; g/kg	964	903	896
Composition of DM, g/kg			
Crude protein	221	206	139
Crude fat	191	40	14
Crude fibre		124	282
Ash	76	73	97
NDF		263	569
ADF		144	317
ADL		25	29
Net energy*, MJ/kg DM	10.7	7.0	5.8

*The net energy was estimated using the cellulose *in vitro* organic matter digestibility (De Boever *et al.* 1999).

Statistical analysis

The Statistica software (StatSoft 2009, StatSoft Inc., Tulsa, OK, USA) procedure for general linear models was used for a one-way analysis of variance. Differences between treatments were tested for significance by the Newman–Keuls test. Calf was used as the statistical unit. Results are presented as least squares means±standard error. The effect of abrupt weaning vs. gradual weaning (W) was studied by comparing the results of treatment 1 and 2 with those of treatments 3 and 4. The effect of CL was investigated by comparing the results of treatment

1 with those of treatments 2, 3 and 4. The effect of a reduced MR supply at an increased DM concentration (Treatment 4) on energy intake and LW gain during the 3rd and the 4th experimental week was compared with the effect of the MR feeding program of treatments 1, 2 and 3. Within CL 0.75 once daily MR feeding (treatments 3 and 4) was compared with twice daily milk feeding (treatments 2). Treatment effects were presented as significant when $P<0.05$ and trends were identified at $0.05<P<0.10$. Calves developing scours during the pre-weaning period and receiving electrolytes were assigned a value of 1 while the others were assigned a value of zero. The chi square test was used to compare the frequency of scours. Pearson's correlations between daily concentrate intake during the week prior to weaning and daily gain during the first week after weaning, the first two weeks after weaning and the entire rearing period were calculated. Pearson's correlations between intake of total amounts of MR, concentrate and hay were also calculated. A Pearson's correlation between daily gain during the first week after the adaptation of the MR concentration and concentrate intake during the first two weeks was calculated for treatment 4.

Results

Pre-weaning period

Pre-weaning growth rate (0.51 kg/d) and LW at weaning (76.9 kg) were lower for calves weaned at a weekly concentrate intake of 3.5 kg compared to a weekly concentrate intake of 5.25 kg (0.56 kg/d and 84.6 kg, respectively; treatments 2, 3 and 4; CL effect; Table 3). A lower daily concentrate intake and a small tendency for a lower hay intake were observed for CL 0.5. The pre-weaning period was shorter for treatment 1 in comparison with treatments 2 and 3. The time span to achieve a CL 0.5 for treatments 2, 3 and 4 amounted to 51.2, 47.7 and 46.0 days, respectively, and was not different between treatments. Afterwards, the period to increase CL from 0.5 to 0.75 averaged 8.6, 8.1 and 6.5 days, respectively, and was neither significantly different ($P>0.1$). As a consequence, groups 3 and 4 had a similar management during only 20.5 days of the pre-weaning period.

No calves were weaned before the 5th experimental week. Total NE intake during the 3rd and the 4th experimental week from MR, concentrate and MR plus concentrate averaged 77.9, 17.2 and 95.1 MJ, respectively, for calves receiving a reduced amount of MR at an increased concentration in one meal daily (treatment 4). The mean total NE intake for treatments 1, 2 and 3 during this period amounted to 87.8, 16.7 and 104.5 MJ, respectively. Net energy intake from MR, and from MR plus concentrate was for lower for treatment 4 ($P<0.05$), while NE intake from concentrate was not significantly increased, compared to the mean NE intake from concentrate of calves subjected to treatments 1, 2 and 3. Although NE intake from MR plus concentrate was different, LW gain during the 3rd and the 4th experimental week was not different between group 4, on the one hand, and groups 1, 2 and 3, on the other hand ($P>0.1$).

Weaning abruptly or gradually (W effect) did not significantly affect LW at weaning (82.4 vs. 82.9 kg) and pre-weaning growth rate (0.54 vs. 0.55 kg/d). Within CL 0.75, LW at weaning tended to be lower when MR was fed once daily (Groups 3 and 4) compared to twice daily feeding (Group 2; 82.9 vs. 87.9 kg; $P=0.063$), but the pre-weaning period also tended to be

Table 3
Effect of the milk replacer program on performance of Belgian Blue double-muscled calves during the pre-weaning period

	Treatments					*P*-value		
	1	2	3	4	SEM	T	W	CL
Number of calves	26	26	26	26				
Initial weight, kg	53.7	53.9	53.7	53.7	0.7	0.999	0.964	0.966
Initial age, d	6.5	7.4	7.0	7.1	0.2	0.454	0.888	0.164
Weight at weaning, kg	76.9^{a}	87.9^{b}	84.9^{b}	81.0^{ab}	1.1	0.002	0.809	0.002
Age at weaning, d	51.7^{a}	67.2^{b}	62.7^{b}	59.6^{b}	1.4	<0.001	0.338	<0.001
Duration, d	45.2^{a}	59.8^{b}	55.7^{b}	52.5^{ab}	1.4	0.001	0.562	<0.001
Live weight gain, kg/d	0.51	0.57	0.56	0.53	0.01	0.077	0.602	0.034
Days with scours								
Number, d	4.4	5.2	4.1	3.3	0.4	0.328	0.132	0.811
Relative frequency*,%	10.6	8.5	7.7	6.5	0.8	0.482	0.117	0.365
Daily intake								
Milk replacer, kg DM	0.57^{ab}	0.58^{a}	0.54^{ab}	0.52^{b}	0.01	0.031	0.007	0.234
Concentrate, kg DM	0.21^{a}	0.30^{b}	0.32^{b}	0.29^{b}	0.01	<0.001	<0.001	<0.001
Grass hay, kg DM	0.03	0.05	0.05	0.05	0.01	0.254	0.289	0.105
Total dry matter, kg	0.82^{a}	0.93^{b}	0.92^{b}	0.84^{a}	0.01	<0.001	0.662	0.001
Net energy, MJ	7.80^{a}	8.58^{b}	8.43^{b}	7.72^{a}	0.10	0.001	0.518	0.050
Crude protein, kg	0.17^{a}	0.20^{b}	0.19^{b}	0.18^{a}	0.01	<0.001	0.863	0.004
Daily concentrate intake during the week prior to weaning, g								
Per kg initial weight	12.1^{a}	12.1^{a}	18.8^{b}	17.7^{b}	0.4	<0.001	<0.001	<0.001
Per kg weaning weight	8.4^{a}	10.4^{b}	12.9^{c}	14.6^{d}	0.3	<0.001	<0.001	<0.001

[abcd]Values without or with similar superscripts are not different ($P>0.05$). T: treatment, W: weaning abruptly or gradually, CL: daily concentrate level at weaning (0.5 vs. 0.75 kg)
*Number of days with scours/duration of pre-weaning period (days)

shorter (54.1 vs. 59.8 days; $P=0.071$), so that growth rate was not affected. Early weaned calves (treatment 1) had a lower daily intake of concentrate, DM, energy and protein than calves subjected to treatments 2 and 3, but values did not differ from treatment 4, except concentrate intake. Daily MR intake was lower for treatment 4 than for treatment 2.

Feeding MR once daily at an increased DM concentration (treatment 4) did not affect the incidence of scours compared to other treatments (Table 3).

Relative daily concentrate intake during the week prior to weaning (g/kg weaning LW) was different between treatments, even when the same absolute CL was applied for weaning in treatments 2, 3 and 4. Expressing concentrate intake per kg initial LW resulted in a similar intake for treatments 1 and 2, which was lower than the intake for treatments 3 and 4. Concentrate intake during the week prior to weaning, expressed per kg initial LW (r=0.216; $P=0.028$) or weaning LW (r=0.224; $P=0.022$) was only weakly correlated with growth rate during the first week after weaning. A weak correlation between concentrate intake (g/kg weaning LW) and growth rate during the first two weeks after weaning was observed (r=0.185; $P<0.060$). The correlation between concentrate intake prior to weaning and growth rate during the entire rearing period was close to 0. One calf assigned to treatment 4 lost weight during the first week after the adaptation of the MR concentration. No significant correlation between daily gain during the first week after the adaptation of the MR concentration and concentrate intake during the first two weeks of the pre-weaning period was found.

Post-weaning period

Post-weaning growth rate, final age and final LW were not different between treatments ($P>0.1$; Table 4). The post-weaning period was longest for treatment 1 ($P<0.001$), but this was due to the shorter pre-weaning period. Daily intake data were unaffected by treatment.

Weaning abruptly or gradually only tended to affect growth rate during the first weeks after weaning. All parameters were affected by CL, except final LW, final age and hay intake. Calves weaned at CL 0.5 gained slower during the first week after weaning than for CL 0.75: 0.57 vs. 0.75 kg/d ($P=0.006$). Similar results were found for the first two weeks after weaning: 0.75 vs. 0.89 kg/d ($P=0.006$). One calf assigned to treatment 1 lost weight during the first week after weaning.

Entire rearing period

Growth rate during the whole rearing period was not affected by treatment, weaning method (W) or CL and averaged 0.83 kg/d. Intakes of feed and nutrients were not affected by treatment, except MR. Concentrate intake level exerted a significant effect on the efficiency of DM (2.52 vs. 2.43 kg, respectively for CL 0.5 and 0.75) and crude protein (0.50 vs. 0.48 kg) utilisation, with a trend for a lower efficiency of energy utilisation (18.1 vs 17.6 MJ; $P=0.092$). No effect of abrupt or gradual weaning on the efficiency of nutrient use was observed.

Total concentrate-DM intake was inversely related with the amount of MR-DM consumed: r=−0.789; $P<0.001$. Total intakes of MR-DM and hay-DM were not correlated ($P>0.1$), while total intakes of concentrate-DM and hay-DM were moderately correlated: r=0.342; $P<0.001$.

Table 4
Effect of the milk replacer program on post-weaning performance of Belgian Blue double-muscled calves

	Treatments					*P*-value		
	1	2	3	4	SEM	T	W	CL
Final weight, kg	169.9	171.0	170.5	170.3	1.5	0.9960	1.000	0.833
Final age, d	146.5	147.4	147.0	147.1	0.2	0.454	0.888	0.164
Duration, days	94.8[a]	80.2[b]	84.3[b]	87.5[ab]	1.4	0.001	0.562	<0.001
Live weight gain, kg/d								
First week post-weaning	0.57[a]	0.73[ab]	0.73[b]	0.77[b]	0.03	0.047	0.070	0.006
First 2 weeks post-weaning	0.75[a]	0.87[b]	0.90[ab]	0.89[ab]	0.02	0.049	0.053	0.006
Total period	0.98	1.04	1.01	1.02	0.01	0.172	0.701	0.043
Daily intake								
Concentrate, kg DM	2.33	2.41	2.42	2.41	0.02	0.101	0.150	0.013
Grass hay, kg DM	0.34	0.44	0.35	0.35	0.01	0.353	0.386	0.431
Total dry matter, kg	2.68	2.81	2.77	2.76	0.02	0.199	0.643	0.046
Net energy, MJ	18.33	19.16	18.93	18.88	0.14	0.184	0.563	0.038
Crude protein, kg	0.53	0.55	0.55	0.54	0.01	0.174	0.493	0.033

[abc]Values without or with similar superscripts are not different ($P>0.05$). T: treatment, W: weaning abruptly or gradually, CL: daily concentrate level at weaning (0.5 vs. 0.75 kg)

Discussion

Pre-weaning performance

The MR feeding program clearly affected growth rate, with the widest range of gain between groups 1 and 2. Weaning at CL 0.5 resulted in a shorter pre-weaning period and a lower pre-weaning growth rate. Although CL at weaning was different between treatments 1 and 2 (0.5 vs. 0.75 kg/d), concentrate intake during the week prior to weaning was similar, amounting to 12.1 g/kg initial LW. Greenwood *et al.* (1997) proposed dry feed intake as a percentage of birth weight as a criterion to wean dairy calves, which is not confirmed by our results, obtained with calves of a specialized beef breed. This means that there is no optimal weaning method to realize maximum calf performances. A similar CL of 0.75 kg/d at weaning (treatments 2, 3 and 4) exerted a significant effect on concentrate intake per kg initial or weaning LW. Therefore, these results suggest that an absolute concentrate intake, e.g. a CL of 0.75 kg/d, may be more appropriate in BBDM calves than a feed intake as a percentage of birth weight. Within treatments applying weaning at a CL of 0.75 kg/d, differences in concentrate intake can be related to the step-down feeding of the MR. However, a step-down method as such is not a guarantee for an increased concentrate intake, because of a possible interaction between the method of weaning and the amount of the milk diet (Khan *et al.* 2007b, Sweeney *et al.* 2010). Considerably higher amounts of the milk diet were fed in experiments of Khan *et al.* (2007b) and Sweeney *et al.* (2010): 20 % of LW or 12 kg/d, respectively, in comparison with 10 % of LW in our experiment. Hill *et al.* (2012) reported that over 0.7 kg DM from milk or MR daily will result in a reduction of the post-weaning growth rate by depressing starter intake, but gradual weaning over two to three weeks could avoid this reduction. However, this threshold DM intake of 0.7 kg/d DM from the MR was not consumed by the calves assigned to treatments 1 and 2. Gradual weaning resulted in a higher pre-weaning intake of concentrate in comparison with abrupt weaning in our experiment, although intakes of total DM, energy and protein were not different. The lower concentrate intake of calves weaned abruptly was in accordance with results of Sweeney *et al.* (2010), but the similar energy intake in our experiment was not confirmed by the latter authors. This can be explained by the higher intake of milk and weaning at a fixed age in the experiment of Sweeney *et al.* (2010).

Treatment 4 was a combination of once daily MR feeding during part of the rearing period, gradual weaning and a reduced fluid intake combined with an increased DM concentration of the MR. Once daily feeding can increase outbreaks of diarrhoea (Gleeson *et al.* 2007). Dry matter concentration cannot be increased in case of whole milk feeding. Because of the smaller organ size in double-muscled animals (Fiems 2012) high amounts of MR may accelerate the overload of the abomasum, which may increase the occurrence of diarrhoea. Therefore we increased DM concentration of the MR to avoid digestive upsets. Dry matter concentration of the reconstituted milk had a positive effect on pre-weaning LW gain, but overall LW gain was not affected by DM concentration in experiments of Jenny *et al.* (1982). These authors also found that pre-weaning starter intake decreased, while the incidence of scours increased linearly with increasing DM concentration. Jenny *et al.* (1982) fed MR once daily at 10 % of LW, while MR at 200 g powder per litre was fed once daily at 5 % of LW to BBDM calves. Frequency of diarrhoea was not increased in the current experiment. In an experiment of Kehoe *et al.* (2007) calves were switched over from twice daily feeding at 10 %

of birth weight to once daily feeding at 10 % of birth weight at 15 days of age, and MR was further reduced to 5 % of birth weight one week prior to weaning. No differences in growth rate and feed efficiency were found.

Post-weaning performance

Weight loss during the first week after weaning, as observed for one calf of group 1, and the lower LW gain during the first weeks after weaning can be considered as an indication of a negative or a lower energy balance, respectively, owing to an insufficient feed intake when the milk diet was omitted, resulting in weaning stress. A negative energy balance should be avoided (EFSA 2006). Previous experiments did not reveal a detrimental effect of a CL of 0.5 kg/d at weaning on subsequent development (Fiems *et al.* 2005). Calves subjected to treatment 1 in the current experiment were also able to compensate for the lower weaning LW at the end of the post-weaning period, although calves have a reduced capacity to compensate for a lower feeding level during calf hood (Berge 1991).

Performance during the entire rearing period

The average daily gain of 0.83 kg was far above the threshold of 0.6 kg to safeguard the development of double-muscled females during their subsequent life (Fiems & De Brabander 2009). Overall rate of gain was not affected by treatment, weaning method or CL. However, the efficiencies of DM and protein utilisation were reduced by CL 0.5, with a tendency for a lower energy efficiency. The reason for this lower efficiency is not clear, but it cannot be due to a lower dietary protein concentration. Winter (1978) also found a tendency for a lower feed efficiency for early weaning of dairy calves. Weaning occurred earlier in the experiment of Winter (1978) than in our experiment: two vs. five weeks of age. The worse efficiency can be due to the low digestive capacity in calves during the first two to three weeks of life (Longenbach & Heinrichs 1998). Because calves in our experiment were older at weaning, this reason cannot be responsible for the reduced efficiency for early weaned calves, unless the development of the digestive tract is retarded in double-muscled calves.

A high intake of milk or MR often lowers concentrate intake (Huber *et al.* 1984, Quigley *et al.* 2006). This phenomenon is confirmed by the results of the current experiment where we found a significant negative correlation between the DM intake of MR and concentrate. The consequence of a reduced MR feeding is that calves are reared at lower feed costs, due to savings in MR powder. Assuming current prices for MR, concentrate and hay of 2.4, 0.4 and 0.1 €/kg, respectively, and taking the actual feed intake into account, results in lower total costs and a lower feed cost per kg LW gain (Table 6). Furthermore, a shorter pre-weaning period (Table 3) and feeding MR once daily (treatments 3 and 4) may also be labour saving. Galton & Brakel (1976) reported that calves fed once daily required 39 % less labour in milk feeding than calves fed twice daily. The lower NE intake from MR plus concentrate during the 3rd and the 4th experimental week in group 4 in comparison with the intake in the other groups, and the fact that one calf lost LW during the 3rd week, suggest that it may be difficult to further accelerate weaning without detrimental effects on animal performance. This is in agreement with previous results from suckling calves, where concentrate intake hardly compensated a lower milk intake (Fiems *et al.* 2008).

Table 5
Effect of the milk replacer program on performance of Belgian Blue double-muscled calves during the rearing period (140 days)

Treatments	1	2	3	4	SEM	P value T	W	CL
Live weight gain, kg/d	0.83	0.84	0.83	0.83	0.01	0.994	0.977	0.807
Daily intake								
Milk replacer, kg DM	0.18a	0.25b	0.22ab	0.19a	0.01	<0.001	0.402	0.019
Concentrate, kg DM	1.65	1.51	1.58	1.62	0.02	0.204	0.677	0.152
Grass hay, kg DM	0.24	0.25	0.24	0.24	0.01	0.964	0.628	0.852
Total dry matter, kg	2.08	2.00	2.04	2.04	0.02	0.741	0.826	0.374
Net energy, MJ	14.92	14.63	14.81	14.71	0.15	0.906	0.952	0.541
Crude protein, kg	0.41	0.40	0.41	0.41	0.01	0.718	0.941	0.365
Intake per kg body weight gain								
Dry matter, kg	2.52	2.39	2.44	2.46	0.02	0.112	0.826	0.036
Net energy, MJ	18.10	17.49	17.71	17.70	0.11	0.327	0.742	0.092
Crude protein, kg	0.50	0.48	0.49	0.49	0.01	0.102	0.864	0.034

[abc]Values without or with similar superscripts are not different (*P*>0.05), T: treatment, W: weaning abruptly or gradually, CL: daily concentrate level at weaning (0.5 vs. 0.75 kg)

Table 6
Effect of the milk replacer program on feed costs of Belgian Blue double-muscled calves during the rearing period (140 days)

	Treatments 1	2	3	4
Total intake				
Milk replacer, kg	26.7	35.9	32.0	27.4
Concentrate, kg	255.9	234.1	245.7	250.5
Grass hay, kg	37.8	38.2	36.5	37.2
Total body weight gain, kg	116.2	117.1	116.8	116.6
Feed costs*, €				
Total costs per calf	170.2	183.6	178.7	169.7
Cost per kg body weight gain	1.46	1.57	1.53	1.46

*Unit prices for MR, concentrate and hay: 2.4, 0.4 and 0.1 €/kg, respectively

It can be concluded that daily gain of BBDM calves during the entire rearing period and the occurrence of diarrhoea during the pre-weaning period were not affected by the MR feeding program, although weaning at a daily concentrate intake of 0.5 kg resulted in a lower pre-weaning growth and a lower growth rate during the first weeks after weaning in comparison with weaning at a daily concentrate intake of 0.75 kg. Abrupt weaning did not influence pre-weaning growth rate, but daily intake of MR was higher and daily intake of concentrate was lower in comparison with gradual weaning. Feed was less efficiently converted during the entire rearing period for early weaned calves. Weaning can be successfully accelerated in BBDM calves by skipping over a MR meal when concentrate intake exceeded 0.5 kg/d, or by a combination of a once daily MR feeding with an increased concentration of 200 g/L from the age of three weeks onward.

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