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Invited review: Reduced milking frequency: Milk production and management implications

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ABSTRACT

Most dairy cows throughout the world are milked twice daily. In intensive dairying systems, however, it is not uncommon to increase milking frequency to between 3 and 6 times daily to increase milk production. Reducing milking frequency is much less common; however, once-daily milking of dairy cows, practiced either strategically during certain parts of the lactation or for the entire lactation, is not uncommon in key dairying countries where less emphasis is placed on milk production per cow. The practice fits well with more extensive dairy production systems, particularly those based on grazed pasture. A feature of once-daily milking is that it reduces milk yield by approximately 22%, depending on stage of lactation, breed, and parity, and it may adversely affect lactation length and persistency. However, it can offer several positive farm management options, especially related to labor requirements and farm working expenses. In addition, it may provide a tool to better manage the metabolism and energy balance of cows during early lactation or during periods of pasture deficit, and it may help to improve reproductive performance and animal health and welfare. Once-daily milking, representing one extreme of the mammary function spectrum, has attracted considerable research interest over the years. Consequently, substantial scientific information is available on its effects on mammary function, at both the physiological and molecular levels. This review focuses instead on the management of the cow milked once daily, covering the production response in relation to breed, stage of lactation, and parity, and its effect on energy status, reproduction, health and welfare, as well as on milk composition and processability.
Key words: milking frequency, reproduction, nutrition, milk yield

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INTRODUCTION

In most modern dairy farming systems, cows are milked twice daily (**TDM**), with the interval between milkings being as similar as practically possible. In high-producing herds, however, it is increasingly common for cows to be milked more frequently (Bar-Peled et al., 1995; Erdman and Varner, 1995), particularly with the advance of automated milking systems on farms (Hovinen and Pyörälä, 2011). Therefore, milking cows only once daily (**ODM**), either strategically during part of the lactation or for the entire lactation, appears contradictory and unconventional. Yet, in systems where less emphasis is placed on milk production per cow, ODM may offer a viable and practical alternative management system (Rémond and Pomiès, 2005; Clark et al., 2006). With labor costs recognized as one of the highest contributors to farm working expenses (Stockdale, 2006), the cost savings associated with ODM are important. However, there are many more reasons why ODM has been adopted as a profitable farming system, including animal, farm-system, and labor benefits.

Once-daily milking can reduce heat stress and lameness in dairy cows as cows walk less to and from the milking parlor and spend less time standing around on concrete waiting to be milked, particularly in hot summer afternoons (Gleeson et al., 2007; Kendall et al., 2008). Once-daily milking partially alleviates the negative energy balance that occurs immediately postpartum or during periods of energy deficits (Phyn et al., 2011a; Kay et al., 2012) and can improve BCS. In addition, ODM can improve the reproductive performance of dairy cows, with a reduced postpartum anestrus interval, decreased use of hormonal intervention, and increased submission rates and final pregnancy rates (Rhodes et al., 1998; Rémond et al., 2004; O'Brien et al., 2005b; Clark et al., 2006).

In regard to farm system and labor benefits, ODM provides flexibility in managing labor requirements. Less time is spent in the milking parlor, providing more time to focus on other activities such as pasture management, heat detection, or tending to unhealthy cows, all of which are essential aspects of a profitable pasture-based dairy system (Bewsell et al., 2008). Furthermore, ODM enables land that would not traditionally be suitable for dairying, due to hilly terrain or long walking distances, to be used, and enables farmers to maintain or increase their herd size without capital expenditure, when farm infrastructure (i.e., number or size of milking parlors, walking races) may not support this (Bewsell et al., 2008). In Europe, ODM also allows farmers to manage milk production while meeting their milk quota restrictions.

However, a significant feature associated with ODM is a reduction in milk yield. Just as an increase in milking frequency from TDM increases milk yield (Erdman and Varner, 1995; Stelwagen, 2001), a decrease in milking frequency lowers production (Davis et al., 1999; Stelwagen, 2001). In short-term experiments, the average decrease in milk yield associated with ODM ranges from 7 to 40%; in full-lactation studies, the losses were as high as 50% (Davis et al., 1999; Phyn et al., 2010). However, production losses vary considerably, depending on factors such as stage of lactation (Stelwagen and Knight, 1997), breed (Carruthers et al., 1993a; Clark et al., 2006), and parity (Clark et al., 2006).

Marked physiological changes occur within the mammary gland during the first 24 h of an extended milking interval. Mammary blood flow and nutrient uptake decrease, a transient intramammary inflammatory response occurs (i.e., epithelial tight junctions become "leaky" and there is an influx of leukocytes and innate immune factors into the milk), and milk composition changes; the latter changes include an elevation of protease activity (Davis et al., 1999; Stelwagen, 2001; Guinard-Flament et al., 2006, 2011b). In addition, differences are apparent at the cellular level, with reported changes in mammary signaling and an overall increase in the expression of genes involved in apoptotic pathways (Singh et al., 2005; Bernier-Dodier et al., 2010; Littlejohn et al., 2010; Grala et al., 2011).

The effects of ODM on mammary function, at both the physiological and molecular levels, have been previously reported in the literature (Davis et al., 1999; Stelwagen, 2001; Littlejohn et al., 2010). This review focuses on production losses following both short-term and full-lactation ODM and the associated farm management implications related to nutrition, reproduction, animal health and welfare, and milk composition.

MILK PRODUCTION LOSSES

Most of the available data on milk yield loss associated with ODM have been obtained from short-term studies conducted at various stages of lactation. Only a few controlled full-lactation studies have been reported in which cows were on ODM for the entire lactation. In this section, we will discuss milk production responses to ODM. This discussion will include the effects of breed, stage of lactation, and parity, and will focus on both the immediate response and the carryover response when cows are switched to TDM.

Short-Term and Full-Lactation Studies

An immediate reduction in milk yield is the most common and consistent observation when cows are milked once daily, regardless of the duration of ODM (Davis et al., 1999; Stelwagen, 2001; Rémond and Pomiès, 2005; Phyn et al., 2010). However, the extent of the production loss in short-term studies (lasting from days to several weeks) varies considerably and ranges from as little as 7% in late lactation (Stelwagen et al., 1994a) to as high as 40% in early lactation (Rémond et al., 1999). The average milk yield loss across 30 different international short-term studies, including cows at different stages of lactation and parity and of different breeds, was 22% (reviewed by Davis et al., 1999 and Phyn et al., 2010). In contrast, only 4 controlled research studies have been reported in which cows were milked once daily during the entire lactation (Claesson et al., 1959; Holmes et al., 1992; Rémond et al., 2004; Clark et al., 2006). The decrease in milk yield relative to TDM ranged from 22 to 50% and averaged 34% in these experiments. As with the short-term studies, these full-lactation studies included different breeds, parities, and management systems (i.e., pasture only or pasture plus supplements), which may explain some of the variability in milk loss between studies. Taken together, these data indicate that the average milk yield loss is greater when cows are milked once daily for the entire lactation compared with only part of the lactation.

Regardless of the duration of ODM, the milk yield loss reported in the different studies varies considerably when expressed as an absolute decrease (i.e., kg/d) relative to TDM. In the short-term studies reviewed in Davis et al. (1999) and Phyn et al. (2010), the average decrease in milk yield was 4.0 kg/d (±2.7; range 0.9 to 13.3 kg/d), and in the 4 full-lactation studies it was 5.4 kg/d (±2.0; range 2.6 to 7.2 kg/d). Hence, the production loss associated with ODM cannot be described by a fixed decrease in daily milk yield, as was reported by Erdman and Varner (1995) for the increase in milk yield due to thrice-daily milking (**TrDM**) compared with TDM.

The greater milk yield loss when cows are milked once daily in full-lactation studies compared with short-term experiments may be due to a decreased secretory ability of the mammary gland. Apoptotic genes in the mammary gland are upregulated during ODM (Littlejohn et al., 2010; Grala et al., 2011), indicating that longer term ODM may result in a sustained increase in secretory cell loss. Indeed, evidence indicates that both ODM and continued incomplete milking enhance mammary regression, as measured by functional udder capacity (Ziesack et al., 1986; Carruthers et al., 1993b). Moreover, Li et al. (1999) reported that the decrease in milk yield in lactating goats after 4 wk of ODM was associated with a reduction in mammary alveolar size, due to increased loss of secretory cells through apoptosis, whereas 10 wk of ODM resulted in a heterogeneous population of secretory, resting, and involuting alveoli that contributed to a faster rate of udder regression. These data are consistent with a report that full-lactation ODM results in lower lactation persistency (Hickson et al., 2006). Rémond et al. (2004) did not report a difference in lactation persistency; however, they did report a shorter lactation length in cows on ODM, as did Clark et al. (2006). Therefore, lower daily milk yields as well as fewer days in milk contribute to the greater milk production loss when cows are milked once daily for an entire lactation.

Production expressed as milksolids (i.e., combined fat and protein yields) is also lower with ODM relative to TDM (Rémond et al., 2004; Clark et al., 2006), despite milk fat and protein contents typically increasing (Davis et al., 1999). The increase in fat and protein content is obviously not sufficient to compensate for the decrease in milk volume. To compensate for the loss of milk in individual cows while attempting to maintain the proposed farm management benefits of full-lactation ODM, stocking rate (i.e., number of cows per unit land) is often increased (Clark et al., 2006; Dalley et al., 2008). However, this would only make economic sense in systems where feed is not limiting (Armstrong and Ho, 2009), because underfeeding cows that are milked once daily further reduces their production (Guinard-Flament et al., 2006; Kay et al., 2011). In addition, it may not be possible to increase cow numbers in systems where cows are routinely housed because of barn capacity restrictions. Alternatively, it has been reported that treatment with the galactopoietic hormone bST may overcome the production loss associated with ODM (Carruthers et al., 1991; Stelwagen et al., 1994a). It must be noted, however, that although the use of bST in dairy cows is allowed in some countries, it is forbidden in many other countries.

Breed

The adverse effects of ODM on milk yield appear to be universal across different breeds and have been reported in Holstein-Friesian and Jersey cows (Clark et al., 2006), in Swedish Red and White cows (Claesson et al., 1959), in Montbéliarde cows (Pomiès et al., 2007), and in Brown Swiss cows (Schlamberger et al., 2010). However, the extent of milk loss, in both absolute and relative terms, varies among breeds, with smaller losses in Jersey (Carruthers et al., 1993a; Clark et al., 2006) and Montbéliarde (Pomiès et al., 2007) cows compared with the higher yielding Holstein-Friesian cows. Davis et al. (1999) investigated the relationship between gross milk composition and udder capacity and reported that cows that produce a more concentrated milk (i.e., a higher milksolids content) are better able to tolerate ODM. This may explain why Jersey cows had smaller milk yield losses when milked once daily than Holstein-Friesian cows. However, in a 2-yr farm system trial, Holstein-Friesian cows selected for either high or low milksolids content (8.9 vs. 7.8%) did not differ in their milk production response to ODM (Kay et al., 2012). Therefore, different breeds may have alternative characteristics that alter the milk production response to ODM and this area requires further investigation.

The differences observed among breeds in ODM performance relative to that of TDM performance are indicative of a genetic basis for the variation in the ODM yield response. In addition, the large individual variation in the response to ODM (Davis et al., 1999; Phyn et al., 2010) provides the potential to select cows that will lose less milk when milked once daily. In New Zealand, Livestock Improvement Corporation (Hamilton, New Zealand) developed an ODM index using TDM breeding values to develop predictive regression equations to estimate ODM breeding values for 4 production traits (milk volume, milk fat, milk protein, and SCC). This is possible because the TDM and ODM breeding values for these traits are highly correlated ($r = 0.75$ to 0.85; McPherson et al., 2007). At present, further development of a ODM breeding scheme is on hold because it is believed that the benefits of a specific ODM breeding index can only be realized when there is a large enough population of ODM cows from which to select (McPherson et al., 2007). Meanwhile, the Jersey and Montbéliarde breeds appear to offer the best attributes to minimize production loss, although these characteristics may not necessarily maximize farm profitability. An alternative to the ODM breeding scheme is to identify potential phenotypic markers to select cows that lose less milk when milked once daily compared with twice daily. Attributes such as udder capacity, milksolids percentage, and lactose percentage have been considered; however, no potential markers have been identified to date (Carruthers et al., 1993a; Guinard-Flament et al., 2011a; Kay et al., 2012).

Further research is required to improve the selection potential of cows to undergo ODM.

Stage of Lactation

A British study indicated that the relative production loss due to ODM was significantly greater in early lactation than in late lactation in fully fed cows (Stelwagen and Knight, 1997). Similarly, production losses were greater during mid lactation compared with late lactation in a New Zealand study using pasture-fed cows (Carruthers et al., 1993a). A more recent New Zealand trial involving hundreds of cows also established that production losses after a 7-d ODM challenge were greater in mid lactation (22%) compared with late lactation (13%; Davis et al., 2006). These data indicate that production losses may be dependent on the stage of lactation.

The functional capacity of the mammary gland and its alveolar and cisternal milk storage characteristics are important factors in determining milk losses associated with ODM (Davis et al., 1998). In particular, the ability of the alveolar compartment to drain into the cistern is an important parameter (Davis et al., 1998) and offers a possible explanation for the observation that cows that store a smaller proportion of their milk in the mammary cisternal compartment have greater milk losses (Knight and Dewhurst, 1994). Moreover, the relative cisternal size (i.e., proportion of total milk stored in the cistern) increases with advancing lactation (Dewhurst and Knight, 1993), perhaps explaining the smaller losses during late lactation. It must be noted that in a seasonal farming system based on pasture grazing with minimal supplementary feeding, yield losses from ODM may be exacerbated during the latter parts of lactation because of lower DMI or, at least, energy intakes. This nutritional influence may also explain the poor repeatability between milk yield losses under grazing conditions when the same cows are milked once daily for a short period in mid lactation and again during late lactation (Davis et al., 2006). In fully fed cows, the repeatability of the percentage milk loss measured at different stages of lactation but within the same animal is high (r = 0.91; Rémond and Pomiès, 2007).

Parity

Parity is another factor determining the milk production response to ODM. Rémond and Pomiès (2005) reported that in 2 full-lactation studies in France, the milk yield loss was greatest in primiparous compared with multiparous cows, but no parity effect was recorded in a short-term (i.e., 3 wk) study. In New Zealand, Clark et al. (2006) also reported that the milk yield loss due to full-lactation ODM was greater in 2- and 3-yr-old Holstein-Friesian cows compared with those aged 4 yr and older, but no such difference was observed in Jersey cows, indicating a parity by breed effect on milk yield loss with ODM. Dewhurst and Knight (1993) reported no difference in the proportion of milk stored in the mammary cistern between primiparous and multiparous cows. Thus, the difference in milk yield responses to ODM between primiparous and multiparous cows is not related to milk storage characteristics of the udder. Consistent with this notion, the increase in milk yield response from TDM to TrDM is similar between primiparous and multiparous cows (Erdman and Varner, 1995). Hence, the negative effect of ODM can be greater in primiparous than in multiparous cows, depending upon breed and duration of ODM, but the reasons why this occurs are still unclear.

Carryover Effects

Milking cows 6 times a day compared with TrDM during the first 6 wk of lactation not only resulted in an immediate increase in milk yield, but also in a sustained increase during the remainder of lactation, when cows had been switched back to TrDM (Bar-Peled et al., 1995). These results sparked an interest in investigating the possible carryover effects on milk yield of changing milking frequency for short periods of time. Several studies in which frequent milking during early lactation was practiced (Hale et al., 2003; Dahl et al., 2004; Wall and McFadden, 2008) reported positive carryover effects, although studies by Soberon et al. (2010) and Phyn et al. (2011b) did not. Interestingly, a narrow window of opportunity of only a few weeks may exist during early lactation when the mammary gland is responsive to frequent milking with regard to carryover effects (Wall and McFadden, 2012), indicating that this process may be under acute epigenetic regulation (Singh et al., 2010). In contrast, brief periods of ODM during early lactation led to a sustained negative effect on milk yield, even after cows were switched to TDM (Rémond et al., 1999; McNamara et al., 2008; Loiselle et al., 2009; Kay et al., 2011; Phyn et al., 2011b), and no difference was found between primiparous and multiparous cows (Rémond et al., 1999). When both the immediate and carryover effects of ODM are considered, a curvilinear relationship is observed between the duration of ODM postcalving and the full-lactation loss in milksolids yield (as a percentage of TDM; Figure 1).

The negative carryover effects of ODM on milk production only occur during the lactation in which the cows are milked once daily. Pomiès et al. (2008) reported that cows that had been milked once daily for

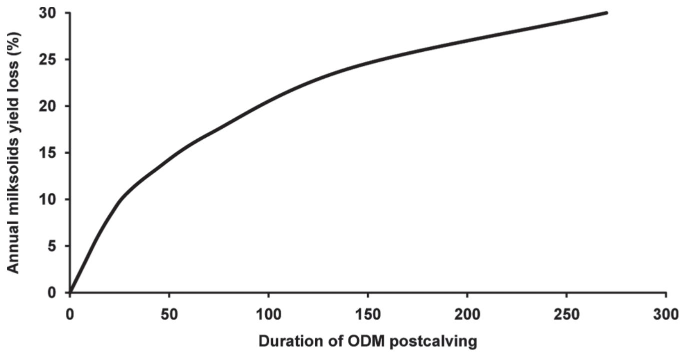

Figure 1. Schematic diagram of the predicted relationship between the duration of once-daily milking (ODM) starting at calving and the annual milksolids (fat and protein) yield loss (as percentage of twice-daily milking) in dairy cows (adapted using data from Phyn et al., 2010).

3 successive lactations produced a similar amount of milk during the fourth lactation when they were milked twice daily compared with cows that were milked twice daily continuously. This is also true for short periods of ODM. When cows were milked once daily for 8 wk before drying-off, milk production in the subsequent lactation did not differ compared with that in cows milked twice daily during the final 8 wk of lactation (Ferris et al., 2008). Additionally, although the negative effect of ODM can be greater in primiparous than multiparous cows, there is no evidence to indicate that ODM affects the lifetime productivity of primiparous cows. Milk production losses in multiparous ODM cows are not affected by whether they were milked once daily or twice daily as primiparous cows (Clark et al., 2006). Furthermore, in a twin cow study (Claesson et al., 1959), cows produced 50% less milk with ODM relative to TDM during their first lactation. This yield loss improved to 40% during the second lactation, and when all cows were milked twice daily for their third lactation, no differences were observed in milk production between cows previously on ODM or TDM (Claesson et al., 1959). Therefore, it appears that the dry period is able to restore the lactation potential of the mammary gland following either part- or full-lactation ODM.

MILK COMPOSITION AND PROCESSING

Reducing milking frequency alters milk composition. Davis et al. (1999) reviewed several mostly short-term ODM studies and reported that milk fat and protein content usually increase with ODM, whereas lactose content decreases. Similar results were reported in full-lactation studies (Rémond et al., 2004; Clark et al., 2006). However, the increased fat and protein content with ODM does not compensate for the decreased milk yield, resulting in decreased fat, protein, and lactose yields relative to those achieved with TDM (Lacy-Hulbert et al., 1999; Clark et al., 2006).

It is not clear why the fat content of milk increases with ODM, because both enzyme activity (Farr et al., 1995) and the expression of genes (Grala et al., 2011) involved in milk fat synthesis are downregulated in mammary tissue collected from cows milked once daily. In addition, the mammary extraction of certain precursors (i.e., glucose and acetate) is reduced with ODM (Guinard-Flament et al., 2007). Most likely, the increase in fat content with ODM is related to a concentration effect caused by the lower milk volume. The decrease in lactose content may be related to decreased gene expression of key enzymes regulating lactose synthesis (Grala et al., 2011), lower mammary uptake of glucose (Guinard-Flament et al., 2007), or increased "leakiness" of tight junctions between adjacent mammary epithelial cells, which results in elevated lactose concentrations in blood (Stelwagen, 2001). The increase in protein content of milk may be desirable, especially because ODM has been reported to increase total casein content (Claesson et al., 1959; Lacy-Hulbert et al., 1999; Rémond et al., 2004), although not in all studies (Auldist and Prosser, 1998). However, closer inspection of the detailed milk protein composition indicates that the effects of ODM on the processing quality of milk are less favorable. Milk protein gene expression decreases (Grala et al., 2011) and proteolytic activity in milk increases, due to activation of the plasmin-plasminogen system (Knutson et al., 1993; Stelwagen et al., 1994b; Kelly et al., 1998). These changes result in a breakdown of β-CN into the less desirable γ-CN (Prosser et al., 1995; Lacy-Hulbert et al., 1999). Furthermore, total whey protein content in milk is increased with ODM (Lacy-Hulbert et al., 1999; Rémond et al., 2004) in addition to the whey to casein ratio (Davis et al., 1999), which is likely the result of an influx of undesirable blood serum-derived proteins, such as serum albumin (Lacy-Hulbert et al., 1999), and proteolysis.

The changes in milk composition with ODM could affect the processing characteristics of the milk. Pomiès et al. (2007) reported that the lower level of free fatty acids in milk from cows on ODM may benefit butter and cream manufacturing. They also reported that rennet coagulation time and curd firmness, important factors in cheese manufacturing, were adversely affected when milk from cows on ODM was used; however, no such effects were observed (O'Brien et al., 2002) in another study. Moreover, using milk from cows on ODM does not appear to affect the sensory characteristics of cheese (Martin et al., 2009). To our knowledge, there are no published data on the possible adverse effects of increased serum proteins in milk from cows on ODM affecting fouling during the spray-drying process in the manufacture of milk powders. In practice, such effects, if they do exist, may be obscured by the pooling of ODM and TDM milk at the factory. Overall, more research on the processability of ODM milk is required to make any conclusive statements on its effect on the manufacturing of dairy products.

A positive effect of ODM is its ability to significantly increase the content of valuable bioactive molecules, such as lactoferrin, and other immune-related proteins in milk, such as acute phase proteins and RNases (Farr et al., 2002; Stelwagen et al., 2011). The increase in such factors appears to be the result of a mild, nonpathogenic, intramammary inflammatory response (Stelwagen et al., 2009). The possibility of marketing milk from ODM cows on the basis of the enhanced bioactive content and yield is an opportunity that remains to be explored (Stelwagen et al., 2009).

UNUSUAL AND EXTENDED MILKING INTERVALS

Many different options exist to address labor requirements. Some farmers opt to omit the afternoon milking on a Sunday, whereas others milk 3 times in 2 d in an attempt to reduce the milking frequency while minimizing adverse effects on production. O'Brien et al. (2002) reported that omitting 1 afternoon milking each week during late lactation had no detrimental effect on either milk composition or milk yield. Milking 3 times in 2 d for 3 wk in early and mid lactation (Rémond and Boit, 1997) or for the entire lactation (Woolford et al., 1985) reduced milk yield and altered composition similar to that observed with ODM. Consistent with ODM, a parity effect is observed, with a larger milk yield loss evident in primiparous compared with multiparous cows. Rémond et al. (2009) investigated the concept of having a short milking interval (≤5 h) followed by an extended milking interval (≥19 h) in the early part of the day to free up time during the remainder of the day. They reported that milking at 5- and 19-h intervals provided the most promise, with 10 and 4% milk yield losses during early and late lactation, respectively.

Milking intervals longer than 24 h are not common dairy practice; however, due to weather or other factors (e.g., power cuts), farmers may be unable to milk their cows for extended periods, sometimes for several days. Biologically, if milk removal ceases, the mammary gland starts to involute and milk secretion declines rapidly, with concomitant changes in milk composition (Singh et al., 2005). Morphologically, changes in mammary tissue occur within the first week of nonmilking, becoming more extensive by the third or fourth week, as part of the normal drying-off process. Yet, many alveolar structures are retained (Holst et al., 1987; Hurley, 1989), indicating that involution may be reversible following an extended nonmilking period. Indeed, Noble and Hurley (1999) reported a partial recovery of milk yield after 3 d of milking, following 11 d of milk stasis, and Dalley and Davis (2006) reported that milk yield was fully restored by remilking after 7 d of milk stasis. These results were confirmed in a recent study in which cows were remilked after not being milked for 7, 14, or 28 d (Singh et al., 2012). It was reported that even after 14 or 28 d of stasis, milk yield partially recovered, albeit increasingly to a lesser extent as the length of the nonmilking period increased. Furthermore, the recovery process may be accelerated with a brief period of subsequent frequent milking (Stelwagen et al., 2008).

NUTRITION

Effect of ODM on DMI

With cows on ODM consistently producing less milk and milk components than their TDM counterparts, it is tempting to speculate that they also have a lower DMI requirement, and therefore, lower feed costs. Unfortunately, there is very little information available on DMI in cows milked once daily, because ODM is often practiced in less intensive dairying systems, based on pasture grazing, where it is difficult to obtain routine and accurate individual DMI data. In a controlled full-lactation study, where pre- and postgrazing pasture mass was measured, no difference was found in DMI between ODM and TDM herds (Holmes et al., 1992). In addition, O'Driscoll et al. (2010b) reported no difference between ODM and TDM cows grazing pasture even when the plane of nutrition was altered, which is consistent with data from Kay et al. (2011). However, pre- and postgrazing mass measures are not sensitive enough to detect small differences in DMI. In the study by Holmes et al. (1992), an attempt was made to obtain periodic individual cow DMI data using an intraruminal slow-release chromium tracer method on a small subset of cows. Using this method to measure individual DMI, a tendency was observed for lower DMI in the ODM cows. The only studies in which accurate individual DMI data were recorded were those in which cows were kept indoors and fed a TMR. Rémond et al. (2004) collected DMI data from fully fed cows during the first 14 wk of lactation. No significant difference in DMI was observed between ODM and TDM cows during the first 6 wk of lactation; however, ODM cows ate 1.3 to 2 kg DM/d less between wk 7 and 14 of lactation, indicating that the lower production may slowly translate into a lower DMI, even during the most metabolically demanding phase of lactation. McNamara et al. (2008)

compared ODM and TDM during the first 4 wk of lactation and reported that ODM cows had a significantly lower DMI (1.4 kg DM/cow per day) than those on TDM. However, when comparing ODM to TrDM during the first 4 wk of lactation in fully fed, housed cows, Patton et al. (2006) could not detect a difference in DMI between the groups. Additionally, Ferris et al. (2008) reported no difference in DMI comparing ODM with TDM, but that study was conducted with cows in late lactation. Further research is therefore required to determine the effect of ODM on DMI during different stages of lactation and in different production systems (grazing vs. supplement-fed cows kept indoors).

Relationship Between ODM and Nutrition

In pasture-based systems, pasture quantity and quality can be reduced because of adverse weather events or poor pasture management. Sometimes ODM is used strategically during energy deficits in an attempt to off-set the decrease in energy intake and improve cow energy balance. However, when cows were underfed (i.e., 40% decrease in DMI) and milked once daily for short periods (2 to 21 d), milk production was reduced by more than that due to the underfeeding alone (Auldist and Prosser, 1998; Kay et al., 2011). Nonetheless, the milk yield loss due to ODM in the underfed cows was less than in cows that were adequately fed (e.g., 14 and 21% loss in underfed and adequately fed cows, respectively; Kay et al., 2011). Although such an interaction between DMI and milking frequency indicates the presence of a relationship between nutrition and milk yield loss with ODM, the overall relationship is much more complicated. Because of the reduced milk output as a result of ODM, a larger proportion of the available nutrients are available to maintain the lower level of milk synthesis, especially during energy deficits, whereas, in TDM cows with unrestricted DMI, the much greater milk output may be more limited by milk storage characteristics of the udder (Knight and Dewhurst, 1994; Stelwagen, 2001). Interestingly, during late lactation, when milk storage capacity may be less of an issue (Dewhurst and Knight, 1993), no interaction was found between feeding level and milking frequency, but overall feed restriction resulted in a greater milk yield loss (as a percentage) than ODM (Lacy-Hulbert et al., 1999). Similarly, in an Irish full-lactation study (O'Brien et al., 2005a), no interaction was observed between nutrition level and milking frequency, but overall the production loss due to ODM was greater than that due to feed restriction alone. Collectively, these studies indicate independent, but partially additive, regulatory effects of nutrition and milking frequency on milk production.

Effect of ODM on Energy Balance

Changes in BW and BCS, combined with plasma hormone and metabolite concentrations, may provide insight into the nutritional status of cows milked once daily in the absence of accurate DMI data. Holmes et al. (1992) reported that during an entire lactation of ODM, cows produced approximately 35% less milk, gained 40 kg of BW, and increased their BCS by 1.6 units (1 to 10 scale), whereas TDM cows lost 17 kg of BW and 0.2 BCS units. These results are in agreement with those from another full-lactation study (Clark et al., 2006). Similar results were obtained from cows exposed to short periods of ODM at the beginning of lactation (Rémond et al., 2002, 2004; Schlamberger et al., 2010; Phyn et al., 2011b), with cows on ODM having an improved energy balance compared with those on TDM or TrDM (Rémond et al., 2002; Patton et al., 2006; McNamara et al., 2008). Consistent with these results, cows on ODM have lower plasma NEFA and BHBA concentrations and greater plasma glucose concentrations (McNamara et al., 2008; Schlamberger et al., 2010; Phyn et al., 2011a; Kay et al., 2012). Taken together, these results indicate that cows on ODM are able to partition more of their available energy into body reserves and, furthermore, that any reduction in DMI relative to TDM is not as great as the reduction in milk yield.

As a practical management solution in response to pasture feed shortages, cows in less intensive systems are often switched to ODM in an attempt to conserve BCS and thus maintain and extend their lactation, albeit at a lower production level. However, ODM-enhanced mammary regression, combined with a reduced DMI, may actually shorten the lactation, because the reduction in both milking frequency and DMI downregulate galactopoietic drivers. This notion is supported by a drying-off study in which cows on ODM and feed restriction dried off earlier than those on ODM or TDM without feed restriction (Bushe and Oliver, 1987), and also by the fact that mammary cell proliferation is adversely affected by nutrient restriction (Nørgaard et al., 2005).

It would be interesting to investigate if the improved BW and BCS associated with longer periods of ODM in grazing situations translate into long-term benefits during subsequent lactations, through improved conception rates, increased longevity, and overall metabolic performance of such cows. To answer this, further research providing detailed information on individual cows over an extended experimental period is required.

REPRODUCTION

The modern dairy cow is able to sustain a high level of milk production over an extended period. During early lactation, when DMI is suboptimal and metabolic demands are at a peak, the dairy cow faces a tremendous metabolic challenge, and this is exacerbated in pasture-based dairy systems. Moreover, this is also the time during which the dairy cow is required to become pregnant again. Not surprisingly, nutrition and milk production are considered key factors affecting fertility of the modern dairy cow (Chagas et al., 2007). Thus, as ODM reduces milk production and improves overall energy balance, it may provide a management practice to improve reproductive performance.

Several ODM studies have measured reproductive parameters and, although data do not always indicate improved reproductive performance, it is important to note that no data indicate any adverse effects of ODM on reproduction. Some experiments indicate that ODM may improve the spontaneous resumption of estrus cycling following calving (Rhodes et al., 1998; Patton et al., 2006); however, ODM does not always improve the postpartum anestrus interval (McNamara et al., 2008). Patton et al. (2006) reported that cows on ODM during the first 4 wk of lactation resumed cycling 10 d earlier than cows on TrDM; however, interval to conception, conception rates to first or second service, and final pregnancy rate were not affected by milking frequency. An increase in the spontaneous resumption of estrus, but not in the intervals to conception or conception rates, was also reported in anestrus cows on commercial dairy farms milked once daily compared with twice daily for 4 wk around the planned start of mating (Rhodes et al., 1998). In contrast, McNamara et al. (2008) reported no differences in any measures of cyclicity and reproductive performance between cows on ODM, TDM, or TrDM for the first 4 wk of lactation. In 2 studies (Rémond et al., 2004; O'Brien et al., 2005b), final pregnancy rates increased when cows were milked once daily for a full lactation; however, Clark et al. (2006) reported no differences in final pregnancy rates between cows milked once daily compared with twice daily averaged across 4 consecutive lactations. In the latter study, the number of days from calving to conception were reduced in ODM cows (Clark et al., 2006), which is consistent with the reduced use of hormonal treatment for postpartum anestrus and improved 3-wk submission and 3-wk pregnancy rates (Clark et al., 2006). Although most data indicate improved reproductive performance with ODM, it must be emphasized that none of the studies were designed specifically to address the effect of ODM on reproductive performance and, moreover, they encompass a range of measured reproductive parameters, breeds, nutritional regimens, and farming systems and relatively low numbers of animals to measure reproductive performance. Therefore, further research is needed, specifically aimed at investigating the effect of reduced milking frequency, on reproductive parameters, hormonal intervention, and seasonal-calving patterns, all of which are important factors in a pasture-based dairy system.

HEALTH AND WELFARE

Metabolic Health

The overall energy balance of cows during early lactation is improved with ODM (Rémond et al., 2002; Patton et al., 2006; McNamara et al., 2008). However to date, no research indicates that this translates to a lower incidence of metabolic disorders, such as ketosis, hepatic lipidosis, or hypocalcemia.

Immune suppression in the periparturient dairy cow is a commonly observed phenomenon and has been linked to poor metabolic status and negative energy balance (Loiselle et al., 2009). Thus, given that ODM improves energy balance in early lactation, it may also improve the immune status of dairy cows during this challenging time. However, this notion is not supported by the results from a study in which cows were on ODM or TDM during the first week of lactation (Loiselle et al., 2009). Those authors found no effect of milking frequency on chemotaxis, phagocytosis, or respiratory burst (i.e., the production of reactive oxygen species), as measured in PMNL cells obtained from cows on ODM and TDM. Nor was there much of an effect of ODM on lymphocyte proliferation and proinflammatory cytokine (tumor necrosis factor-α, IL-4, IFN-γ) production. Only IFN-γ was increased, but only during d 5 (i.e., during ODM) and d 14 (i.e., cows were back on TDM). Llamas Moya et al. (2008) studied immune function in primi- and multiparous dairy cows, comparing ODM and TDM during the first 7 wk of lactation by measuring phagocytosis and oxidative burst in both polymorphic neutrophils (**PMN**) and monocytes. Phagocytotic activity in PMN was actually greater in TDM rather than ODM cows. Milking frequency had no effect on phagocytosis in monocytes and parity had no effect on either PMN or monocytes. Oxidative burst activity also tended to be greatest in TDM cows. Moreover, oxidative burst activity was higher in primi- than in multiparous cows. Interestingly, phagocytotic activity in PMN and monocytes increased as lactation progressed, with the lowest activity observed in the first week of lactation. This may explain why Loiselle et al. (2009) saw little effect of milking frequency on immune function, because their study looked only at ODM during the first week postpartum. Recently, O'Driscoll et al. (2012), using a factorial experimental design, studied the effect of feeding level and milking frequency on mammary immune function in cows during the first 7 wk of lactation.

Total white blood cell percentage, IFN-γ, and acute phase proteins (i.e., haptoglobin and serum amyloid A) were not affected by nutrition or milking frequency. However, with ODM, the percentage of lymphocytes increased, whereas those of monocytes and PMN decreased. This may suggest that the adaptive immune system is activated; however, overall, based on studies reported to date, it would appear that ODM during early lactation has no major effect on systemic immune function, but that timing and duration of ODM are factors to take into consideration with future research in this area.

Udder Health

Less frequent milk removal from the udder could adversely affect udder health because of increased milk leakage (Rémond et al., 2002; Gleeson et al., 2007), which provides pathogens access to the mammary gland across the teat barrier. Somatic cell counts were consistently elevated with ODM compared with TDM in both short- and long-term studies, even after correcting for the concentration effect of the lower milk yield (Holmes et al., 1992; Stelwagen and Lacy-Hulbert, 1996; Kelly et al., 1998; O'Brien et al., 2005; Clark et al., 2006). However, in one study with cows milked once daily from parturition, SCC only increased after 30 wk of lactation (Rémond et al., 2004); the reason for this delay is not clear. Importantly, however, the increase in SCC does not necessarily appear to be associated with an increase in mastitis. Lacy-Hulbert et al. (2005) and Rémond and Pomiès (2005) reported no increase in intramammary infections and clinical mastitis with ODM. Moreover, Holmes et al. (1992) reported no differences in the prevalence of the major mastitis-causing pathogens, despite a significantly higher SCC in the milk of ODM cows. Instead, the increase in SCC seems to be due to a mild inflammatory response, resulting in an increase in PMN in the milk (Stelwagen and Lacy-Hulbert, 1996) and activation of the innate mammary immune system (Stelwagen et al., 2011). In addition, SCC is significantly greater in cows that already have a high SCC before being switched to ODM (Kamote et al., 1994). Hence, the ODM-associated increase in milk SCC may be more of a management issue rather than an animal health problem, as it may lead to the bulk tank SCC level exceeding penalty thresholds, particularly if it is already close to the threshold level.

Lameness

Lameness can be a major health and welfare issue in dairy cows, particularly in pasture-based systems if cows are required to walk long distances across hilly terrain or on poor quality surfaces to and from the milking parlor. An indirect benefit of ODM is that cows spend less time walking on farm tracks and standing on concrete in holding yards, which may reduce hoof damage and the incidence of lameness (Chesterton et al., 1989). Consistent with this notion, Caixeta and Bicalho (2011) reported that the probability of lameness was significantly lower when milking frequency was reduced from TrDM to TDM. However, only a few studies have directly measured the effect of milking frequency on lameness. In those that have, hoof health is generally improved in ODM compared with TDM cows because of a lower incidence of sole lesion and white line disease, particularly as lactation progresses (Boyle et al., 2005; O'Driscoll et al., 2010a). However, O'Driscoll et al. (2010a) also reported that ODM cows had greater heel erosion, possibly due to more time spent standing in wet conditions at pasture, which has a softening effect on the sole. Alternatively, abnormal movement of the hind legs to swing around the more distended udder of ODM cows during early lactation (Gleeson et al., 2007) may cause mechanical stress and wear on parts of the heel that are not adapted to absorb the impact of walking. This impaired locomotion of ODM cows in early lactation caused by the greater abduction or adduction of the hind leg is only temporary, as locomotory ability in peak, mid, and late lactation was greater in ODM compared with TDM cows (O'Driscoll et al., 2010a). Although these data indicate improved overall hoof health and locomotory ability in ODM compared with TDM cows, further research is required to investigate the effect of ODM on the occurrence and severity of lameness in commercial dairy herds.

Animal Welfare and Behavior

Several studies have examined the effect of ODM on various indicators of animal welfare, particularly to address concerns that milking cows once daily during early to peak lactation may cause discomfort due to udder distension. Gleeson et al. (2007) compared cows on ODM and TDM at high and low levels of nutrition and reported no difference in milk let-down or peak milk flow. However, cows on ODM, particularly when fed the high energy diet, had firmer udders, greater milk leakage, greater adduction or abduction of the hind leg, and lower blood lymphocyte and higher blood PMN and monocyte counts at peak lactation, indicating that the cows experienced some stress associated with udder distension. The authors hypothesized that reducing the concentrate supplement may prevent such a possible adverse response to ODM. In agreement with this, in a grazing study without supplements, no differences were observed at peak lactation in udder firmness, milk leakage, walking stride, or kicking movements in the milking parlor with ODM cows compared with those on TDM (Tucker et al., 2007). Furthermore, ODM cows spent more time lying down each day and were more likely to lie with their hind legs touching their body compared with TDM cows during peak lactation, indicating that ODM cows did not alter lying behaviors or postures to reduce pressure on the mammary gland (Tucker et al., 2007). Even in the last few hours before the morning milking, when udder distension and potential discomfort would be greatest, no difference was found in lying times or postures between ODM and TDM cows at peak or mid lactation (Tucker et al., 2007). Hence, high-yielding cows milked once daily may experience some discomfort from udder distension, but there is no evidence to indicate that this occurs at peak or mid lactation in ODM cows managed in less-intensive grazing systems.

Switching cows to ODM during mid lactation also appears to have little effect on cow comfort. Increased milk leakage and greater udder firmness occur following a reduction in milking frequency from twice to once daily, but cows quickly adapt within the first week of transitioning to ODM (Tucker et al., 2007; O'Driscoll et al., 2012). Furthermore, Tucker et al. (2007) reported that cows switched to ODM did not have a negative behavioral response or physiological stress response, as they did not stand at the gate waiting to leave the paddock to be milked or vocalize during the afternoon milking time, alter their lying times or postures, or have increased concentrations of fecal glucocorticoid metabolites. Furthermore, when cows were milked once daily for 1 wk before drying-off, very little difference was observed in udder firmness and lying behavior compared with those milked twice daily (Tucker et al., 2009). Investigating the circadian rhythm of body temperature, Kendall et al. (2008) reported a lower body temperature at certain times of the day in cows milked once daily compared with twice daily, but concluded that these differences were related to differences in metabolic activity, rather than a consequence of physiological stress. Collectively, these studies indicate that ODM does not adversely affect the welfare or behavior of cows.

CONCLUSIONS

Once-daily milking, compared with the more commonly practiced TDM, reduces milk yield, with losses ranging from 7 to 40%, depending on factors such as parity, breed, and stage of lactation. However, the practice of ODM offers a viable management tool, with reduced farm working expenses and increased labor flexibility being the key benefits. In addition, ODM improves cow energy balance during early lactation and periods of energy restriction, increases BW and BCS, and may improve reproductive performance, without compromising animal welfare. Once-daily milking does not increase the prevalence of mastitis, but may cause an increase in the milk SCC of individual cows. Once-daily milking is a management practice that fits well into dairy systems that are not based on milk production per cow, and although it is possible to increase stocking rate to compensate for the individual cow production loss with ODM, this is only recommended if feed is not limiting. Once-daily milking, during the entire lactation or part of the lactation, may not suit every farm system, but it can offer a useful farm management tool during strategic periods of the lactation cycle to manage both labor and cow performance.

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