Effect of health disorders on culling in dairy cows: a review and critical discussion

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Abstract

Risk of culling consequent to the main health disorders occurring in the current production systems are reviewed. Survival analysis models including health disorders as time-dependent variables are deemed to be the most appropriate to assess their effects because they allow a better description of the exact follow-up of disease history. Farmers preferentially consider health events in the current lactation and/or those occurring in early stages of lactation for making culling decisions. The unfavourable direct effects on culling of dystocia and udder disorders (mastitis and teat injuries) are clearly demonstrated, whereas there are discrepancies on the association between metabolic and reproductive disorders and culling. These discrepancies may be due to differences in study designs, populations involved and methods. Metabolic and reproductive disorders may act indirectly through a subsequent decrease in milk yield and reproductive performance. The impact of health disorders on longevity is on average weak, compared to the impact of low milk yield potential and poor reproductive performance. Herd characteristics (availability in heifers, quota, farmer's attitude towards risk and uncertainty…) modify the risk for a cow to be culled for a given health disorder. Consequences of including or not in the models descriptors on milk yield and/or reproductive performance from the last known lactation are discussed.

Aims of further studies in this area could be (1) to interpret the meaning and to analyse the reliability of culling reasons information, (2) to evaluate the relative effect on culling of health disorders and performance (milk yield and reproduction) in different parities, (3) to investigate the role of components of the herd effect on the risk of culling.

1. Introduction

Longevity is highly related to farm profit. Decisions to replace cows are mainly based on economic considerations; i.e., the farmer expects a higher profit by replacing the cow than by keeping her in the herd (van Arendonk, 1988). Reduction of production costs can allow profitability of dairy farms to be maintained. In the last decade, emphasis has been increasingly placed on health management in order to minimise losses that are due to health disorders. The contribution of cullings to disease-related losses is high. Half of the cullings occur involuntarily and are anticipated because of health disorders (Young et al., 1983; Dohoo & Martin, 1984; Sol et al., 1984; Anderson, 1985; Esslemont & Kossaibati, 1997; Seegers et al., 1998). Moreover, the possibilities of culling based on voluntary replacement and selection are limited in case of high incidence of involuntary disposals (Rogers et al., 1988).

Culling decision is completely embedded in the whole farming process. Whether or not to cull a cow for a given health disorder (except for the ones inducing emergency disposal) depends not only on individual factors (age, stage of lactation, performances), but also on herd factors (availability in replacement heifers, situation towards quotas, milk and beef market, farmers' attitude with respect to risk and uncertainty…). Previous studies showed a huge herd effect on the risk of being culled (Beaudeau et al., 1995; 1996; Emanuelson & Oltenacu, 1998; Gröhn et al., 1998). Thus studies trying to measure the relationships between health disorders and culling provide 'average' estimates of their impact. Herd factors can be considered as modulators of this information.

The objectives of this paper are to present the main approaches used to identify risk factors for culling, to summarise the reported effects of health disorders which are frequently met in current dairy production systems, and to discuss the different strategies to model the role of health events in the culling process.

2. Summary of methods used to identify risk factors for culling

Several methods have been used to study the effect of health disoders on culling.

2.1. Standard regression techniques

Health disorder-specific relative risks can be calculated (Milian-Suazo et al., 1988) with parity-adjustment (Bendixen, 1988; Bendixen & Åstrand, 1989). Cobo-Abreu et al. (1979) and Oltenacu et al. (1984) calculated parity-stratified odds ratios in order to quantify the associations.

Standard multivariate techniques, such as discriminant analyses (Martin et al., 1982; Dohoo & Martin, 1984), logistic regression (Gröhn and Saloniemi, 1986, Milian-Suazo et al., 1989 ; Beaudeau et al., 1994), logistic regression combined with path analysis (Erb et al., 1985; Oltenacu et al., 1990) allow to account for many possible risk factors in the same model, and therefore to adjust the effect of health disorders for that of other putative reasons, i.e. parity, milk production, reproductive performances.

A main drawback of the studies using these techniques is that all covariates are treated as time-independent variables. If a health disorder is treated as a time-independent covariate, its effect on culling is forced to be the same before and after its occurrence, which does not make sense unless the health disorder of concern occurs very early in lactation (e.g. peripartum health events). Conversely, a time-dependent covariate effect on the outcome can change over time. If a health disorder is modelled as a time-dependent covariate, its effect can be described after its occurrence only, which is more appropriate.

The strength of the association between a factor (e.g. exposure to disease) and the outcome (e.g. culling) can be measured by (1) a relative risk (RR), or (2) an odds ratio (OR) which is widely used because it is directly derived from the estimates of logistic regression. RR directly provides the relative increase in the probability of being culled in case of exposure. OR is often interpreted as a multiplicative factor of the risk of being culled when exposed, although it overestimates the RR especially when the outcome of interest is not rare (which is the case for culling).

2.2. Survival analysis with time-dependent covariates

Survival analysis is now considered as the most appropriate method for the analysis of survival data in dairy research (Ducrocq et al., 1988; Beaudeau et al., 1995; Gröhn et al., 1997; Essl, 1998). Length of productive life (LPL), defined as the number of days between date of first calving and date at culling or death, has been used as a suitable measure of longevity (Ducrocq et al., 1988).

The proportional hazards model (Cox, 1972) is based on the concept of hazard, defined as the probability of being culled at time t, given that the animal is still alive just prior to t. The Cox model has been described in details in previous papers in this workshop. Contrary to standard regression techniques which assume the cows to be classified as culled or not culled at the end of a time period (e.g. lactation), the proportional hazards model allows to use information from censored observations. Additionally, Kalbfleisch and Prentice (1980) showed that the proportional hazards model can be extended to cases for which variables are time-dependent. Therefore, with such an approach, the exact follow-up of health disorders with LPL is considered. At any time t, the model can be written as:

$$\lambda(t) = \lambda(t,z_1(t),z_2(t)) = \lambda_0(t) \exp\{\Sigma\, z_1(t)'\, \beta_1 + \Sigma z_2(t)'\, \beta_2\}$$

where $\lambda(t)$ is the hazard function at time t; $\lambda_0(t)$ is the unspecified hazard function; $z_1(t)'\beta_1$ describes the effect of covariates other than health disorders that influence culling risk; and $z_2(t)'\,\beta_2$ describes the effect of health disorders that possibly influence LPL of cows.

The vector $z_2(t)$ describes whether the cow was exposed or unexposed at time t to each health disorder of interest. For instance, clinical health disorders can be defined as time-dependent variables with their effect on the hazard assumed to be piecewise constant within lactation; with jumps occurring at date of first occurrence. At each date of calving, absence of any health disorder is often assumed, and health disorders are often assumed to influence hazard from the date of their first occurrence onward in the current lactation (Beaudeau et al., 1995 ; Gröhn et al., 1997).

A relative hazard ratio (HR) can be estimated for each covariate from the hazard function by taking the exponent of the estimate of βs. At each time point of LPL, the HR measures the instantaneous relative risk of a cow being culled, for example, when exposed versus unexposed to a given health disorder. In this case, the calculated HR is a measure of the impact of this health disorder on culling. Additionally, the effect of covariates on LPL can be measured by computing expected survivor curves, for instance, given the occurrence of a particular health disorder or of a combination of health disorders (Ducrocq et al., 1988; Ducrocq, 1994). The computation of these curves requires the assumption of a priori values of

all covariates over time (e.g. occurrence of health disorders at the median day postpartum of occurrence within lactation).

3. Health disorders as determinants of longevity

3.1. Relative incidences of health-related culling reasons

Description of the importance of health disorders in the culling process may rely on culling reasons stated by farmers. Certain reasons related to health disorders (reproductive problems, mastitis, foot disorders) are very often mentioned in the studies describing culling. Comparisons between studies are hardly feasible due to the various reasons given by the authors and the lack of homogeneity in their definition. Nevertheless, some general trends can be emphasized. As in most previous studies included in the review of Beaudeau et al. (1993), reproductive disorders are still the most frequent culling reasons in 3 recent studies (36.5% of all cullings for Esslemont & Kossaibati (1997); 28.5% for Seegers et al. (1998); 32.8% for Stevenson & Lean (1998)). Among other health-related culling reasons, those related to udder disorders are the second most frequent: mastitis-related culling reasons counted for 5 to 17% of all cullings (review of Beaudeau et al., 1993; Esslemont & Kossaibati, 1997; Seegers et al., 1998; Stevenson & Lean, 1998), and reached 28.5% when high SCC and teat injury were added (Stevenson & Lean, 1998). The proportion of cows culled for locomotor disorders and defects was low (below 6% in 80% of available studies). The proportion of cows culled for other health disorders (mainly peripartum health events) widely varied between studies, mainly depending on the definition of culling reasons.

Despite variations according to production systems studied, at least one-half of all cullings are primarily declared as related to health.

3.2. Health disorders as risk factors for culling

The role of health disorders as risk factors for culling has been investigated in a number of studies in the past 20 years. Two criteria were used to select papers for this review: (1) studies based on records only from commercial herds; (2) studies using discriminant analysis, logistic regression, or survival analysis, in order to prevent misinterpretation of unadjusted risks of culling associated to health disorders. Table 1 gives the main characteristics of samples in the 11 selected papers and a list of adjustment variables introduced in the analyses. Table 2 provides estimates of the effect of health disorders on culling.

3.2.1. Peripartum health disorders and events

There were discrepancies on the effect of metritis on culling. An unfavorable association was found in more than 50% of available studies. However, late metritis (diagnosed after 60 days post-partum) was found protective for early culling (before 150 days post-partum) (Dohoo & Martin, 1984). This could be explained by the combined effect of both the particular definition of this disorder and the time of culling in the lactation. In other words, only cows not destined to be culled were examined for this health disorder (Dohoo & Martin, 1984). Furthermore Erb et al. (1985) and Gröhn et al. (1998) found no direct association between metritis and risk of culling after adjusting for reproductive performance.

Again the effect of cystic ovaries as risk factor for culling remains unclear. Oltenacu et al. (1990) found an increased risk of culling among cows with cystic ovaries. However cystic ovaries were no longer a risk factor for culling when adjustment was made for reproductive performance (Beaudeau et al., 1994; Gröhn et al., 1998). Ovarian cysts probably act on culling through delayed conception. These results show the critical importance of the methodological choices (stage of lactation, definition of health disorder, inclusion of reproductive performances as risk factors in the analysis) for the investigation of health disorders as risk factors for culling.

As a general trend, dystocia was a direct risk factor for culling, regardless of the definition of the disorder.

The investigation of retained placenta as a risk factor for culling showed contrasting results. Five of the 8 available studies reported no significant effect, whereas Oltenacu et al. (1990) and Beaudeau et al. (1994) reported that cows with retained placenta had at least a 1.2 times higher risk. Gröhn et al. (1998) suggested that the putative effect of retained placenta may be indirect, through the mediation of poor reproductive performance.

3.2.2. Metabolic disorders

In two recent studies, cows with milk fever were found to be at greater risk of being culled within 45 days post-partum (Beaudeau et al., 1995; Gröhn et al., 1998). Most previous studies did not report any effect, maybe because the moment of culling within the lactation was not accounted for.

Displaced abomasum was a risk factor for culling in early lactation, and not later on (Geishauser et al., 1998; Gröhn et al., 1998). A possible explanation could be the decreased milk production following the occurrence of that event, that may indirectly lead to

an increased risk of being removed (Geishauser et al., 1998).

There was no conclusion on the effect of ketosis as a risk factor for culling. Papers from the eighties (Dohoo & Martin, 1984; Gröhn & Saloniemi, 1986) reported a protective effect of ketosis on culling, probably in relation to a positive association between ketosis and milk yield. Recent studies using survival analysis with adjustment on the milk yield reported an unfavourable effect (Beaudeau et al., 1995; Gröhn et al., 1998).

3.2.3. Udder disorders

An increased risk of culling in cows which have experienced a mastitis is a classical finding, regardless of the differences between breeds, study periods and designs. Main periods at risk of being culled in case of mastitis were early lactation (Beaudeau et al., 1994; Gröhn et al., 1998) and dry period (Beaudeau et al., 1995). Despite a very low incidence rate, the very high risk associated with mastitis during the dry period can be explained by its severity, possibly associated with a doubt on expected yield in the next lactation. However the risk of being culled after mastitis occurrence exists for all stages of lactation.

The high impact on culling of teat injuries found by Beaudeau et al. (1994; 1995) might be because they prevent milking and cause mastitis.

3.2.4. Locomotor disorders

A few studies investigated the effect of lameness on culling. Most reported no significant effect. A possible explanation is that many foot problems stay on a subclinical level and perhaps do not play a major role in the culling decision. Less of 3% of dairy cows are culled because of foot disorders (see above).

To summarise, the risk of being culled after dystocia and udder disorders (mastitis and teat injuries) appears clearly demonstrated in the literature, whereas discrepancies remain on the association between reproductive and metabolic disorders and culling. These discrepancies may be due to differences in study designs, population and period involved and methods. As already suggested, the impact of reproductive disorders highly depends upon whether or not the reproductive performance is included as an adjustment variable in models. Due to the known effect of some health disorders on reproductive performances and milk yield (reviews of Fourichon et al., 1999; Fourichon et al. (submitted); Hortet and Seegers, 1998a, b), the inclusion of reproductive performance and/or current milk yield (e.g. days to conception and/or mature equivalent 305d-milk yield of the lactation of concern) could lead to either the removal of the direct effect of health disorders, or the inclusion of an additional indirect effect. The direct and indirect effects of health disorders on culling will be elaborated in depth later on in this paper.

4. On the possible use of culling reasons in breeding strategies to improve longevity

In the context of breeding strategies to improve longevity, Strandberg (1997) argued that the aim should be to improve the overall breeding objective (e.g. expressed as lifetime profit) rather than to improve longevity in itself. Therefore he proposed that breeding programmes aiming at improving longevity combine two approaches (selection based on determinants - health events, reproduction - plus indicators - measures of stayability or length of productive life, conformation traits -).

However this strategy is heavily dependent on data recording. In countries where there is no systematic recording system of health events, culling reasons when available may partly compensate this lack of information. Compared to the costs induced by the collection, storage, and analysis of health disorders data, considering culling reasons data may be a cost-effective alternative.

Survival analysis could be used for the consideration of different types of longevity, (e.g. health-determined longevity, fertility-determined longevity) (Dürr, 1997; Strandberg et al., 1997). Using this approach, only cows culled for these specific reasons are considered uncensored, whereas cows alive or culled for other reasons are considered censored. However a main drawback of this option is the high proportion of censoring it induces, possibly leading to less precise estimation (Dürr, 1997). Second, it highly depends on the reliability of culling reasons stated by farmers. In other words, do culling reasons reflect the true importance of health determinants (occurrence of health disorders) in impaired longevity ?

The declared culling reasons are, per se, considered more or less subjective (Stewart et al., 1977; Ducrocq, 1987). Usually, culling reasons are grouped into two categories : involuntary and voluntary (Esslemont & Kossaibati, 1997). This classification shows numerous limits. In fact, except for emergency cullings, all other disposals are more or less decided and planned by the farmer. A large proportion of so-called 'involuntary' cullings might be used for adjusting herd size in order not to exceed milk quotas (Seegers et al., 1998). Furthermore

culling decisions are made taking into account the whole farming context (Lehenbauer & Oltjen, 1998). Taking into account both the first and the second declared culling reasons could help in better assessing the role of health in the culling decision process. Seegers et al. (1998) proposed to group culling reasons into eight main categories, five of them accounting for health or reproduction-related culling.

Regardless of the classification used, assessing the reliability of culling reasons requires health-related risk factors for specific culling reasons to be identified. The associations between health disorders and specific reasons for culling are poorly documented. Milian-Suazo et al. (1989), in a comprehensive study, found associations consistent with biological assumptions. Downer cow syndrome was associated with an increased risk of death, mastitis and teat problems with culling for udder disorders, cystic ovaries and abortion with culling for poor reproduction, foot and leg problems with culling for locomotor disorders and left abomasal displacement with culling for miscellaneous reasons. Martin et al. (1982) reported that a cow having experienced mastitis or lameness in the current lactation had a significantly increased risk of being culled for the culling reasons "mastitis" and "foot problems" respectively. However, occurrence of reproductive disorders did not significantly increase the risk of culling for reasons "reproductive problems". Oltenacu et al. (1984) investigated the relationships between the health status of cows and their reason for culling and concluded that there was no statistical significant association. These divergent results showed that, except for a few obvious and direct relationships, the associations between health disorders and specific culling reasons are complex. Owing to the huge herd effect on declared culling reasons, an on-farm check for plausibility of culling reasons should be the most relevant approach. However its feasibility is questionable. Further studies aiming at assessing the reliability and meaning of culling reasons declared by farmers are therefore necessary before considering culling reasons as relevant selection criteria to improve longevity.

5. On the different strategies to model the effect of health disorders on culling: methodological issues and associated results

5.1. Length of productive life or lactation as basis for making culling decision

Different time-frames for evaluating the impact of health disorders can be considered to check whether health-related cullings are decided taking into account particular events in the current lactation, or integrating the whole disease history of the cow. Several approaches are available: (1) one can evaluate the ability to start a new lactation based on events occurring within the current lactation of the cow (Martin et al., 1982; Dohoo & Martin, 1984; Erb et al., 1985; Gröhn and Saloniemi, 1986; Oltenacu et al, 1990; Beaudeau et al., 1994, 1995; Gröhn et al., 1998), (2) the possible effects of the health disorder on the whole productive life of the cows can be investigated (Beaudeau et al., 1995; Pasman et al., 1995). In Beaudeau et al., (1995), it appears that farmers essentially take into account current events for making decisions, whereas the contribution of health disorders from the previous lactation is low. For instance, mastitis occurring in a given lactation had no impact on the risk of culling in the subsequent one. This is in agreement with findings of Neerhof et al. (submitted) who reported that, among the models including different durations of mastitis effect (10, 100, 200, 400, 800 days or to the end of lactation), the one in which the mastitis occurrence affects the risk of being culled until the end of the lactation had the largest likelihood, meaning that it was the most relevant model among those studied.

5.2. Time of occurrence of health disorders during life and culling

Identification of early predictors for length of productive life (including health traits) is potentially of great interest in breeding strategies to improve longevity of dairy cows.

In a study involving 787 Holstein cows, Warnick et al. (1997) found that occurrence of dullness, respiratory health disorder or scour within the first 90 days of life had no impact on length of productive life, defined as in paragraph 2.2.

Furthermore, Pasman et al. (1995) reported no significant influence of any disorder recorded in the first lactation on length of productive life. This may be due to a 'masking' effect of 305-d milk yield and number of services in the last known lactation included in the models considered in this study. The fact that cows culled early (1^{st} parity) are more frequently eliminated for reasons such as 'low milk yield' and 'poor reproductive performance' than for health-related reasons supports this explanation. Elderly cows are often culled for health-related reasons (Seegers et al., 1998).

As a consequence, it can be assumed that the relative weights of health disorders and performance (milk yield and/or reproduction) on culling may vary across parities: compared to the impact of health disorders on culling, the impact of performance

would be higher in primiparous cows and less in later parities. Further analyses stratified by parity would allow to check this assumption.

5.3. Time of occurrence of health disorders within lactation and culling

Health disorders may have different effects on culling depending on when they occur, and when their effect on culling is observed (Beaudeau et al., 1994; Gröhn et al., 1998).

The analysis of the effect of health disorders on culling depending on their time of occurrence within lactation is intended to identify higher risk periods. The differential impact of mastitis and metritis, depending on their stage of lactation (higher risks associated with early occurrence of mastitis and late occurrence of metritis respectively (Beaudeau et al., 1995)) clearly demonstrates two key-times (peak of lactation and service period) in the farmers' decision to cull. It is reasonable to assume that conceiving cows at first AI and/or high yielding cows in early lactation are more likely to be kept. This could partly explain why mastitis occurring before the peak of lactation had a large impact on culling, and why late metritis, probably through an increase of days open, affects longevity.

Studies of possible interactions between occurrence of health disorders and time of culling may indicate in which delay farmers react.

Two categories of health disorders can be considered. The first one includes health disorders for which a culling decision is made very quickly, and for which the cow leaves the herd soon after. Teat injuries, non traumatic udder disorders other than mastitis (Beaudeau et al., 1994), mastitis occurring before the peak of lactation (Gröhn et al., 1998) may induce early cullings, in agreement with descriptive findings of Seegers et al. (1998) based on declared culling reasons. These health disorders are mainly related to the fact that they can prevent milking. Accident at calving and downer cow syndrome, because they induce a presumed vital prognosis and then are likely to be associated to immediate removals, can be included in this group (Beaudeau et al., 1994; Gröhn et al., 1998). The second group comprises other types of health disorders, which, in most cases, do not affect milking ability, and for which culling is generally delayed (Milian-Suazo et al., 1988; Seegers et al., 1998). These are mastitis after the peak of lactation, metabolic and reproductive disorders. There is a true choice given to farmers to decide to keep or to cull immediately the diseased cows. For mastitis and some metabolic disorders (e.g. ketosis), farmers may choose to treat first in order to allow the recovery of the cow. For reproductive disorders, farmers may postpone culling, since the reproductive performance (especially days open) is the key criterion for decision-making.

5.4. Direct and indirect effects of health disorders on culling

Owing to the known detrimental effects of some disorders on reproduction and milk yield (see reviews of Fourichon et al.; Hortet et al.,), two interrelated questions arise: (1) how to control properly for possible confounders when assessing the 'true' effect of health disorders on culling; (2) what is the relative impact of some health disorders as either predisposing risk factors (that is, which could not induce culling per se, but having a so-called indirect effect) or determining factor for culling (that is, having a so-called direct effect).

In all available studies, milk yield and reproductive performance, whenever included in models, had, on average, a higher impact on culling than most frequent health events, such as mastitis.

In this context, the reported effects of both health disorders and performance should be interpreted with caution, because they highly depend upon how milk yield and reproductive performance are described in the models. The advantages and drawbacks of the different strategies to deal with these covariates will be addressed separately below.

Gröhn et al. (1997) discussed some strategies for accounting for milk yield as an adjustment variable. The no inclusion option (strategy A1) does not appear as a correct choice since it does not correct for the fact that high yielding cows are more susceptible to mastitis (see for instance, Gröhn et al., 1990). Other strategies aim at both addressing the fact that milk yield is a risk factor for mastitis and at preventing overadjustment. Using previous milk yield (strategy A2) appears to be a relevant option since it partly avoids overadjustment. However, this strategy would exclude primiparous cows and previous lactation yield is not a perfect predictor of the milk production of the cow during the current lactation.

In the literature, the descriptors of milk yield are often a cumulative yield in the current lactation (305-d milk yield expressed in breed class units for Martin et al., 1982; Dohoo & Martin, 1984). It is reasonable to assume, even if it was not clearly stated in these studies, that a part of the effect of health disorders is included in the estimated effect of milk yield. Descriptors of current milk yield derived from measures at fixed stage of lactation after

interpolation from the nearest actual test day measurement (Gröhn et al., 1998) also reveal both direct and indirect (through decreased milk yield) effects on culling. For instance, the inclusion of current milk yield led to a decrease of the impact of mastitis. However the estimates of effect of mastitis remained large, that demonstrated that a direct impact subsisted.

Strategies including milk yield in the current lactation depend on the goal of the study. If one wants to study the effect of health disorders on culling after proper control for potential milk production (strategy A3), measures that express a phenotypic potential (e.g. best of the two monthly milk yield records derived from Wilmink (1987)) should be preferred to cumulative yield over the lactation: the former is assumed to be less affected by occurrence of most health disorders than the latter one (Beaudeau et al., 1994). Gröhn et al. (1997) proposed the first 60-d cumulative milk yield as a relevant descriptor to control for milk yield. Another option is to consider the phenotypic potential as the maximum class of milk yield reached by each cow within herd. For instance, Beaudeau et al. (1995) introduced in the models a variable based on the comparison, at date of new calving, of the 305-d mature equivalent milk production and the potential of 305-d mature equivalent milk production (extrapolated from the best of the first two monthly milk yield records) in the last known lactation. If the goal is to partition direct and indirect effects of a given health disorder (strategy A4), current milk yields (in the form of test day milk yields) may be used (Gröhn et al., 1998).

Few studies included poor reproductive performance in models for the assessment of health disorders as risk factors for culling (Erb et al. 1985; Beaudeau et al., 1994, 1995; Gröhn et al., 1998). Several strategies for the analysis can be used.

Erb et al. (1985) partitioned the influence of reproductive disorders on culling in direct and indirect effects using the path analysis method (strategy B1). In this paper, retained placenta, metritis and cystic ovaries were assumed to have both a direct impact and an indirect one through the mediation of increased days to first service and increased number of services. These authors reported that, in multiparous cows, retained placenta and metritis had only an impact on disposal through increased number of services, whereas cystic ovaries had both direct and indirect effects on culling through increased number of services.

Another strategy (strategy B2), which is *a priori* the simpliest, is to introduce in the models the conception status (pregnant vs. open), as a time-dependent variable, with the hypothesis that the detrimental effect of being open is large, regardless of the exact time of receiving this information (Gröhn et al., 1998). Using this option, the effect of reproductive disorders (retained placenta, cystic ovaries) become non significant, meaning that these health disorders have no direct impact on culling. Unfortunately, this option neglects that the effect of being open depends on when this information is available within the lactation (for a given cow to be bred, this effect is presumed null within the postpartum anoestrus). Another drawback is that it leads to possible overadjustement. The third one, which is maybe the most important, is the confusion made between biology-related and herd health management-related mechanisms (farmers' decision to cull). Disease affects conception (see above) and open cows are more likely to be culled. However, a farmer, because he/she has planned to cull a given cow anyway, may decide not to breed her, whether or not the cow experiences a given health disorder in the current lactation. Such an approach does not allow to partition these two mechanisms, if both are present.

To avoid confusion between biology and management-related factors, a strategy (strategy B3) is to built a reproductive status variable based on the sequence of AI a cow experiences and not on status at time of conception (Beaudeau et al., 1995). In a first step, the reproductive status was defined in four ordinal classes of numbers of days open postpartum. From one class to the next, the cow was supposed to be affected by more severe fertility problems. This variable was a time-dependent variable, and its effect was assumed piecewise constant; jumps occurred at date of calving and at the first date of any recorded AI occurring within the intervals 90 to 149, 150 to 209, and 210 d postpartum of each lactation. Thus, a cow not bred due the farmer's decision, is modelled to be at the lowest risk of being culled, in agreement with his/her decision.

To avoid the inclusion in the same model of covariates (reproductive health disorders and days open) that are often strongly related, a strategy (strategy B4) is to fit two separate models (one including reproductive health disorders, an alternative one including a reproductive status variable based on AI information but without reproductive health disorders) (Beaudeau et al., 1995). A drawback of such an option is that it does not allow per se the partition of the direct and indirect effects of a given health disorder.

To summarise, extreme caution is required for the interpretation of the effects of health disorders on culling when descriptors of milk yield and/or reproductive performances are included in models.

For the assessment of the 'true' effects of health disorders after a proper control for possible confounders, it may be advised either to express performances in terms of potential (use of real producing abilities) and not actual values, or to perform separate models, the former with descriptors of health disorders, the latter with descriptors of performances.

Conversely, whether or not farmers make culling decisions based on health disorders or only on current milk yield/reproduction is a specific question that requires the researcher to include performance from the current lactation. To assess the direct vs. indirect effect of health disorders on culling, the systematic strategy developped by Gröhn et al. (1998), which consists in performing four models (the first containing terms for health disorders only, the second containing terms for health disorders and reproductive performance only, the third containing terms for health disorders and milk yield only, the fourth containing terms for health disorders and both for reproductive performances and milk yield) can be advisable. Then the comparison of the effect of health disorders in the 4 models is of interest. In any case, conclusions remain highly dependent on the definition of descriptors of milk yield and/or reproductive performance.

5.5. Effect of a sequence of health disorders on culling

Several previous studies reported associations between health disorders throughout the lactation (Martin et al., 1982; Dohoo and Martin, 1984; Erb et al., 1985; Gröhn et al., 1990) or health profile throughout the whole lifespan of dairy cows (Faye et al., 1994). Whether or not the farmers account for sequences of health disorders to make culling decisions has not received a definite answer in the literature.

With proportional hazards or logistic regression models, when the effect of several health disorders are studied jointly, the risk associated with a sequence of two health disorders is assumed to be the product of the risk associated with each. In their study, Beaudeau et al. (1995) showed that estimates of effect associated with each health disorder remained almost unchanged when these health disorders were studied in separate models or jointly.

In case of non additive estimates on the log scale, considering interactions between health disorders may partly answer the methodological issue, but the interpretation of corresponding results is difficult and the lack of power often huge (Beaudeau et al., 1994). Another option is to introduce in the models synthetic variables describing diseases complexes, defined from preferential associations between health disorders.

6. Conclusions and areas for future research

The following conclusions and perspectives can be drawn from this review:

Survival analysis with time-dependent variables appears to be the most desirable technique for analyses of culling decisions. It provides time-specific probabilities of culling for health events to be used especially in simulation models.

Farmers mainly take into account the occurrence of udder and reproductive disorders through poor reproductive performance in the health-related culling of dairy cows.

On average, the calculated impact of health disorders on longevity is low, compared to those of low milk yield and poor reproductive performance. However, further studies aiming at assessing the relative impact on culling of health disorders and performance in different parities are needed.

Cows are culled after taking mainly into account events in the current lactation, rather than their whole disease history.

Culling decision-making process is dependent on the nature of health disorders. Farmers tend to cull cows with parturient events and/or udder disorders (other than mastitis) possibly affecting milking ability short after calving, whereas cows with mastitis and reproductive disorders leave the herd later within the lactation.

Culling decision-making process is also dependent on the moment of the health disorder occurrence. Farmers preferentially consider health events occurring in early stages of lactation.

The appeal of survival analysis with time-dependent covariates is that the effect of health disorders on the risk of culling can be determined at different stages of lactation. The interpretation of these effects requires extreme caution, especially when other time-dependent covariates, such as conception status are included in models.

Whether or not information on milk yield and/or reproductive performance from the last known lactation should be included depends on the goal of the study. In any case, attention should be paid to the consequences of overadjustment.

Owing to the poor reliability of culling reasons declared by farmers, caution is required when using this information to investigate health-determined longevity. If necessary, further studies to interpret their meaning and to analyse their reliability are needed.

There is a huge herd effect on the risk of being culled. Within-herd characteristics (availability in heifers, quota, farmer's attitude towards risk and uncertainty, milk and beef market…) modify the risk for a cow to be culled for a given health disorder. For a better understanding of the farmers' decision to cull, additional studies investigating the role of components of the herd effect on the risk of culling are needed.

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Table 1. Description of materials and methods (adjustment variables other than health disorders) used in selected papers

Studies				Adjustment variables[2]	Method[3]	Authors
Country	Study period	Sample size	Breed[1]			
Canada	1977-1978	18 herds	H	A, MY, H	DA	Martin et al. (1982)
Canada	1979-1981	32 herds 2,875 lactations	H	A, MY, H	DA	Dohoo & Martin (1984)
USA	1981-1983	33 herds 2,850 lactations	H	A, MY, RP, H	LR	Erb et al. (1985)
Finland	1983	73,368 lactations	Ayrshire	LN, HMY, S	LR	Gröhn & Saloniemi (1986)
Sweden	1983-1985	109,010 lactations	SRB, SLB	LN, HMY, S	LR	Oltenacu et al. (1990)
NL	1982-1990	35 herds 15,051 lactations	DF, MRY	LN, Y, MY, B, S, H	SA	Barkema et al. (1992)
France	1986-1990	47 herds 7,063 lactations	H	LN, MY, BVM, RP, H	LR	Beaudeau et al. (1994)
France	1986-1990	47 herds 3,589 cows	H	LN, ST, MY, FC, PC, RP, HS	SA	Beaudeau et al. (1995)
UK	1985-1987	42 herds 3,105 cows	BF	MY, RP	SA	Pasman et al. (1995)
USA	1984-1996	20 herds 508 cows	H	LN, MY, H	SA	Gieshauser et al. (1998)
USA	1994-1995	14 herds 7,523 cows	H	NL, ST, MY, RP, H	SA	Gröhn et al. (1998)

[1]H: Holstein, SRB: Swedish Red and White, SLB: Swedish Friesian, DF: Dutch Friesian, MRY: Meuse Rhine Yssel, BF: British Friesian

[2]A: age, LN: lactation number, ST: stage of lactation, MY: milk yield, FC: fat content, PC: protein content, BVM: breeding value for milk, RP: reproductive performance, B: breed, S: season, HMY: herd milk yield, HS: herd-season, H: herd

[3]DA: discriminant analysis ; LR: logistic regression ; SA: survival analysis

Table 2. Effect of health disorders on culling (literature review)

Health disorder	Risk of culling	Comments	Authors
Metritis	(+)[1]		Martin et al. (1982)
	(-)[1]	diagnosis >60d	Dohoo & Martin (1984)
	NS		Erb et al. (1985)
	1.4	primiparous	Oltenacu et al. (1990)
	0.3	diagnosis < 21d on early culling	Beaudeau et al. (1994)
	2.3	diagnosis > 50d on late culling	Beaudeau et al. (1994)
	1.5	diag. > 50d	Beaudeau et al. (1995)
	NS[2]		Gröhn et al. (1998) [3]
	(-)		Martin et al. (1982)
Cystic ovaries	NS		Dohoo & Martin (1984)
	NS	primiparous	Erb et al. (1985)
	1.5	multiparous	Erb et al. (1985)
	2.6	primiparous	Oltenacu et al. (1990)
	NS		Beaudeau et al. (1994)
	NS		Beaudeau et al. (1995)
	NS		Gröhn et al. (1998)
	(+)		Martin et al. (1982)
	NS		Dohoo & Martin (1984)
Dystocia	2.9	primiparous	Erb et al. (1985)
	3.7	multiparous	Erb et al. (1985)
	1.9		Gröhn & Saloniemi (1986)
	1.7	primiparous	Oltenacu et al. (1990)
	1.7	caeserean section	Barkema et al. (1992)
	NS		Beaudeau et al. (1994)
	1.7	accident at calving in L≥ 3	Beaudeau et al. (1995)
	1.2	calving provided with assistance	Beaudeau et al. (1995)
Retained placenta	NS		Martin et al. (1982)
	NS		Dohoo & Martin (1984)
	NS	primiparous	Erb et al. (1985)
	1.4	primiparous	Oltenacu et al. (1990)
	1.2	on late culling	Beaudeau et al. (1994)
	0.7	diagnosis in lactation 1	Beaudeau et al. (1995)
	NS	diagnosis in lactation 1	Pasman et al. (1995)
	NS		Gröhn et al. (1998)
Milk fever	NS		Martin et al. (1982)
	(+)	cow down	Dohoo & Martin (1984)
	NS		Erb et al. (1985)
	1.6	on early culling	Beaudeau et al. (1994)
	NS		Beaudeau et al. (1995)
	2.3	on culling <30d	Gröhn et al. (1998)
Abortion	NS		Dohoo & Martin (1984)
	6.2	diagnosis >180 d of gestation on late culling	Beaudeau et al. (1994)
	2.4	diagnosis >180 d of gestation	Beaudeau et al. (1995)
Stillbirth	1.3	primiparous	Oltenacu et al. (1990)

[1](+): increased risk ; (-): decreased risk - [2]NS: no significant association -
[3]results from a model containing terms for the interaction of health disorder and stage of lactation and terms for current milk yield and conception status

Table 2. Effect of health disorders on culling (literature review) (continued)

Health disorder	Risk of culling	Comments	Authors
Displaced	NS[2]		Martin et al. (1982)
abomasum	NS		Dohoo & Martin (1984)
	1.3		Geishauser et al. (1998)
	2.3	on culling <30d	Gröhn et al. (1998) [3]
Ketosis	(-)[1]	on culling <150d	Dohoo & Martin (1984)
	0.8		Gröhn & Saloniemi (1986)
	NS	primiparous	Oltenacu et al. (1990)
	1.9	diagnosis in lactation 1	Beaudeau et al. (1995)
	1.7	diagnosis in lactation 2	Beaudeau et al. (1995)
	1.9	on culling <30d	Gröhn et al. (1998)
	1.7	on 120<culling<180d	Gröhn et al. (1998)
Mastitis	NS		Martin et al. (1982)
	3.6	local therapy on culling<150d	Dohoo & Martin (1984)
	5.2	primiparous	Erb et al. (1985)
	2.1	multiparous	Erb et al. (1985)
	1.6		Gröhn & Saloniemi (1986)
	1.5	diagnosis <90d on late culling	Beaudeau et al. (1994)
	1.3	diagnosis <45d in lactation <3	Beaudeau et al. (1995)[4]
	4.0	diagnosis during dry period in lactation 1	Beaudeau et al. (1995) [4]
	NS	diagnosis in lactation 1	Pasman et al. (1995)
	1.9	diagnosis <30d on culling <30d	Gröhn et al. (1998) [4]
	3.0	60< diagnosis <150d on 120<culling<180d	Gröhn et al. (1998) [4]
Subclinical mastitis	(+)[1]	on culling >150d	Dohoo & Martin (1984)
High SCC	NS		Beaudeau et al. (1994)
SCC 300-800 c/ml	1.2	throughout lactation 1	Beaudeau et al. (1995)
SCC ≥800 c/ml	1.7	throughout lactation 1	Beaudeau et al. (1995)
Teat injuries	6.0	on early culling	Beaudeau et al. (1994)
	5.7	diagnosis in lactation 1	Beaudeau et al. (1995)
	1.7	diagnosis in lactation ≥2	Beaudeau et al. (1995)
Locomotor disorders	(+)	on culling <150d	Dohoo & Martin (1984)
	NS		Beaudeau et al. (1994)
	NS		Beaudeau et al. (1995)
	NS	diagnosis in lactation 1	Pasman et al. (1995)

[1](+): increased risk ; (-): decreased risk - [2]NS: no significant association -
[3]results from a model containing terms for the interaction of health disorder and stage of lactation and terms for current milk yield and conception status
[4]complete results are provided in corresponding papers