Review article

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

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Abstract — Risk of culling consequent to the main health disorders occurring in the current production systems is reviewed. Survival analysis including health disorders as time-dependent variables is considered to be the most appropriate method 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 variations between studies on the association between metabolic and reproductive disorders and culling. These variations may be due to differences in study designs, populations involved and methods. Consequences, in terms of estimated effect of health disorders, of methodological choices (e.g. whether or not including in the models descriptors for milk yield and/or reproductive performance) are discussed. 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 of heifers, quota, farmer's attitude towards risk and uncertainty...) modify the risk for a cow to be culled for a given health disorder. Aims of further studies 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.

dairy cow / culling / health disorders / risk factors / survival analysis

Résumé — Risque de réforme associé à la survenue de troubles de santé chez la vache laitière : revue et discussion critique. La revue porte sur le risque de réforme consécutif à la survenue des principaux troubles de santé dans les systèmes de production actuels. Pour estimer ce risque, les modèles

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d'analyse de survie dans lesquels les troubles de santé sont définis en tant que variables dépendantes du temps apparaissent les plus appropriés car ils permettent de tenir compte des variations de leurs effets au cours de la carrière des animaux. Pour décider la réforme, les éleveurs tiennent compte préférentiellement des évènements de santé survenant dans la lactation en cours et/ou en début de lactation. Dans l'ensemble des études, le risque de réforme après survenue d'une dystocie et/ou d'un trouble de la mamelle (mammites, blessures du trayon) est augmenté, alors que les travaux divergent quant aux effets des troubles métaboliques et de la reproduction. Les différences de populations d'étude, variables d'étude et méthodes utilisées peuvent expliquer ces différences de résultats. Les conséquences, en terme d'effets estimés, des choix méthodologiques effectués (par exemple, le choix d'inclure ou non dans les modèles des descripteurs des performances de production et de reproduction dans la lactation de réforme) sont discutées. L'effet des troubles métaboliques et de la reproduction sur le risque de réforme serait plutôt indirect, via la diminution des performances qu'ils peuvent induire. L'effet des troubles de santé est en moyenne plus faible que celui de faibles performances de production et de reproduction. Pour une vache donnée, le risque de réforme consécutif à la survenue d'un trouble de santé dépend fortement des caractéristiques de l'élevage (disponibilité en génisses de remplacement, situation par rapport au quota, ...). L'intérêt de nouveaux travaux (1) pour préciser le sens et analyser la fiabilité de l'information relative aux motifs de réforme, (2) pour évaluer l'impact relatif des troubles de santé et des performances sur la réforme dans les différentes parités, (3) pour identifier et quantifier le rôle des facteurs d'élevage sur le risque de réforme est souligné.

vache laitière / réforme / maladies / facteur de risque / analyse de survie

1. INTRODUCTION

Cow longevity is highly related to dairy farm profit. The decision to remove a cow from the herd is mainly based on economic considerations; the farmer expects a higher profit by replacing the cow than by keeping her in the herd [48]. Reduction of production costs maintains profitability of dairy farms. In the last decade, emphasis has been increasingly put on health management in order to minimise losses due to health disorders. The contribution of culling to disease-related losses is high. Half of the herd removals occur involuntarily and prematurely because of health disorders [1, 11, 19, 43, 44, 51]. Moreover, the possibilities of culling based on voluntary replacement and selection are limited in case of high incidence of involuntary disposals [42].

Culling decision is part of 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, performance), but also on herd factors (availability of replacement heifers, quota, 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 [5, 16, 27, 31]. Thus studies aiming at measuring 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 different strategies to model the role of health events in the culling process.

2. APPROACHES TO STUDY THE RELATIONSHIPS BETWEEN HEALTH DISORDERS AND CULLING

2.1. Description of culling reasons

In countries where there is no systematic recording system of health events, the description of the importance of health disorders in the culling process may rely on culling reasons stated by farmers. Descriptive studies aimed at assessing the relative incidence of culling reasons related to health, among all declared culling reasons [3, 19, 43, 45]. Compared to the costs induced by collection, storage, and analysis of health disorders data, the registration of culling reasons data is much cheaper and allows to give a first insight on the impact of health on culling. However, declared culling reasons are, per se, more or less subjective [12]. Furthermore, besides individual factors, culling decisions are made taking into account the whole farming context [31]. Therefore, using culling reasons alone is not sufficient to quantify the impact of health disorders on longevity.

2.2. Statistical analyses of risk factors for culling

2.2.1. Standard regression techniques

Health disorder-specific relative risks can be calculated [33] with parity-adjustment [7, 8]. Cobo-Abreu et al. [9] and Oltenacu et al. [36] calculated parity-stratified odds ratios in order to quantify the associations.

With standard multivariate techniques, such as discriminant analyses [11, 32], logistic regression [4, 24, 34], logistic regression combined with path analysis [17, 37], it is possible to account for many risk factors in the same model, and therefore to adjust the effect of health disorders on other putative reasons, like parity, milk production and reproductive performance.

The strength of an association between a factor (e.g. exposure to disease) and the outcome (e.g. culling) can be evaluated by relative risk (RR) measurement. The RR is the ratio between culling risk in the group exposed to the factor (p_1) and culling risk in the unexposed group (p_0) (RR = p_1/p_0). RR directly provides the relative increase in the probability of being culled in case of exposure. Another measure of association is the odds ratio, which is widely used because it is directly derived from the estimates of logistic regression. It is calculated as the ratio between the odds of culling in the exposed group and the odds of culling in the unexposed group (OR = $(p_1/(1–p_1))/(p_0/(1–p_0))$). 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).

An important drawback of the studies using these techniques is that all covariates are treated as time-independent variables. The effect on culling of a health disorder treated as a time-independent covariate 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). In contrast, a time-dependent covariate effect on the outcome can change over time. The effect of a health disorder modelled as a time-dependent covariate can be described after its occurrence only, which is more appropriate.

2.2.2. 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 [5, 12, 14, 18, 26]. 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 [14]. Measures of longevity such as LPL are most often characterised by presence of incomplete records, because some cows are still alive at the end of the study period. These cows generate censored data, for which only the lower bound of their LPL is known. Survival analysis [10] is based on the concept of hazard, defined as the limiting probability of being culled at time *t*, given that the animal is still alive just prior to it. Hence, the term hazard refers to the risk of culling. 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), survival analysis techniques allow to use information from censored observations. Furthermore, some cows can have a first calving occurring before the start point of the study. Information from these cows, generating left-truncated records, can also be analysed using such a technique.

Additionally, Kalbfleisch and Prentice [30] showed that survival analysis models can be extended to cases for which variables are time-dependent. Therefore, with such an approach, the exact follow-up of diseases with the LPL is considered.

In the proportional hazards model, the hazard $\lambda(t) = \lambda(t,z_i(t))$ is written as the product of a baseline hazard function $\lambda_0(t)$, representing the ageing process, and of a term $e^{z_i\beta}$, representing the vectors of covariates that influence the culling rate with time. This leads to an intuitive interpretation of the hazards ratio of two animals, which characterises the relative risk of being culled. For instance, if two cows have hazards of 0.001 and 0.002 at a given t respectively, the latter cow is twice more likely to be culled at t than the former one. Their hazards are proportional. The baseline hazard function can have parametric form or can be left completely arbitrary. In the latter case, the proportional hazards model becomes the so-called Cox model (1972): then, the effects of the covariates on the hazard are estimated independently from the baseline hazard function with a semi-parametric estimation procedure [10, 30], which involves the maximisation of a partial likelihood, representing the part of the full likelihood which does not depend on the baseline. At any time t, the model can be written as:

$$\lambda(t) = \lambda(t, z_1(t), z_2(t)) = \lambda_0(t) \exp\left[\sum z_1(t)\beta_1 + \sum z_2(t)\beta_2\right] \quad [1]$$

where $\lambda(t)$ is the hazard function at time t; $\lambda_0(t)$ is the unspecified hazard function; β_1 describes the effect associated with the covariates in vector $z_1(t)$ other than health disorders that influence culling risk; and β_2 describes the effect of health disorders that possibly influence LPL of cows and that are described through the incidence vector $z_2(t)$.

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. The hazard corresponding to the absence of any health disorder is assumed at each date of calving, and health disorders are assumed to influence hazard from the date of their first occurrence onward in the current lactation [5, 26].

Using a methodology based on (possibly partial) likelihoods, it is possible to draw inferences about the parameters β_1 and β_2 (tests of significance of each effect and potential interactions, point estimates, confidence intervals, predictions of future observations). A risk factor for culling is a factor for which the β estimate is significantly different from 0, at least for some levels.

A relative hazard ratio (HR) can be estimated for each covariate from the hazard function by taking the exponent of the difference between the estimates of β for the level of interest (e.g., "exposed" or "diseased") and a reference level (e.g., "not exposed" or "healthy"):

$$\mathrm{HR} = \frac{\lambda_0(t) \exp\left[\sum_i z_i(t)\beta_i + \gamma_{\text{exposed}}\right]}{\lambda_0(t) \exp\left[\sum_i z_i(t)\beta_i + \gamma_{\text{not exposed}}\right]} = \exp\left[\frac{\gamma_{\text{exposed}}}{\gamma_{\text{not exposed}}}\right] \quad [2]$$

At each time point of LPL, the HR measures the instantaneous relative risk for a cow of 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 [13, 14]. The computation of these curves requires the knowledge of the baseline hazard function $\lambda_0(t)$, which is estimated at the same time as the β in parametric models and assuming that the true value of the βs is equal to their estimate in the Cox model. Expected survivor curves also require the assumption of a priori values of all covariates *i* over time (e.g. occurrence of health disorders at the median day postpartum of occurrence within lactation). The expected survivor is computed as follows:

$$\hat{S}(t) = \exp\left[-\int_0^t \lambda(t)d(t)\right] = \exp\left[-\int_0^t \lambda_0(t)\exp\left[\sum_i z_i(t)\hat{\beta}_i\right]d(t)\right] \quad [3]$$

Theoretical survivor curves of a cow whether or not she is exposed to a given health disorder is given in Figure 1.

2.2.3. Definition of the outcome variable

In most studies aiming at investigating health disorders as risk factors for culling, culling of a cow is defined as her exit from the herd regardless the associated reason [4, 5, 17, 24, 27, 34, 37, 39–41]. However, it may be assumed that the effect of a given health disorder may differ depending on the culling reason. In other words, specific relationships may exist between a given health event and the reason for culling.

The consideration of culling reason as the outcome variable is poorly documented [15, 32, 34, 36, 46]. Most studies used standard regression techniques involving a binary dependent variable defined as culled for a specific culling reason vs. not culled for each cow [15, 32, 36]. Survival analysis may also be used for the consideration of different types of longevity, (e.g. health-determined longevity, fertility-determined longevity) especially in the context of breeding strategies to improve longevity [15, 46, 47]. Using this method, 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 [15].

3. HEALTH DISORDERS AS DETERMINANTS OF LONGEVITY

3.1. Relative incidences of health-related culling reasons

Some reasons related to health disorders (reproductive disorders, mastitis, foot

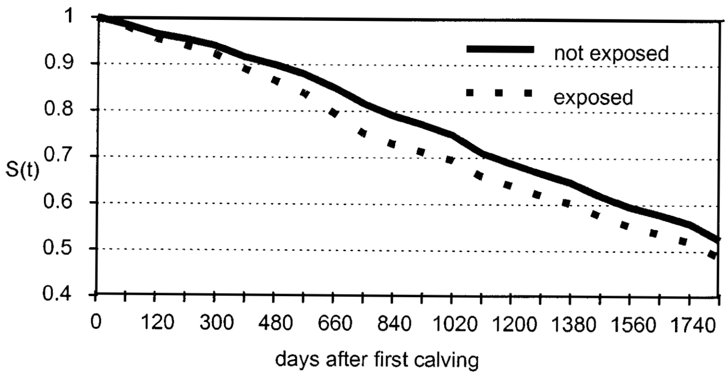

Figure 1. Theoretical survivor curves of a cow whether or not she is exposed to a given health disorder.

disorders) are very often mentioned in the studies describing culling. Comparisons between studies are hardly feasible due to variations in culling reasons studied by the authors and the lack of homogeneity in their definition. Nevertheless, some general trends can be emphasised. As in most previous studies included in the review of Beaudeau et al. [3], reproductive disorders are still the most frequent culling reasons in 3 recent studies (36.5% of all cullings for Esslemont and Kossaibati [19]; 28.5% for Seegers et al. [43]; 32.8% for Stevenson and Lean [45]). 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. [3]; Esslemont and Kossaibati [19]; Seegers et al. [43]; Stevenson and Lean [45]), and reached 28.5% when high SCC and teat injury were added [45]. 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) varied widely 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 health-related.

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 results included in this review: (1) studies based on records from commercial herds only; (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 I gives the main characteristics of samples in the 14 selected papers and a list of adjustment variables introduced in the analyses. Table II 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 unfavourable association was found in more than 50% of available studies. However, late metritis (diagnosed after 60 days postpartum) was found protective for early culling (before 150 days postpartum) [11]. 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 to be culled were examined for this health disorder [11]. Furthermore Erb et al. [17] and Gröhn et al. [27] found no direct association between metritis and risk of culling after adjusting for reproductive performance.

The effect of cystic ovaries as risk factor for culling remains unclear. Erb et al. [17] and Oltenacu et al. [37] found an increased risk of culling among cows with cystic ovaries, whereas Martin et al. [32] and Rajala-Schultz and Gröhn [39] reported that cysts protected against culling. In general, cystic ovaries were no longer associated with an increased risk of culling when adjustment was made for reproductive performance [4, 27, 40]. 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 performance as a risk factor 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

Table I. 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]			
NL	1982-1990	35 herds 15 051 lactations	DF, MRY	LN, Y, MY, B, S, H	SA	Barkema et al. (1992) [2]
France	1986-1990	47 herds 7 063 lactations	H	LN, MY, BVM, RP, H	LR	Beaudeau et al. (1994) [4]
France	1986-1990	47 herds 3 589 cows	H	LN, ST, MY, FC, PC, RP, HS	SA	Beaudeau et al. (1995) [5]
Canada	1979-1981	32 herds 2 875 lactations	H	A, MY, H	DA	Dohoo and Martin (1984) [11]
USA	1981-1983	33 herds 2 850 lactations	H	A, MY, RP, H	LR	Erb et al. (1985) [17]
USA	1984-1996	20 herds 508 cows	H	LN, MY, H	SA	Geishauser et al. (1998) [23]
Finland	1983	73 368 lactations	Ayrshire	LN, HMY, S	LR	Gröhn and Saloniemi (1986) [24]
USA	1994-1995	14 herds 7 523 cows	H	NL, ST, MY, RP, H	SA	Gröhn et al. (1998) [27]
Canada	1977-1978	18 herds	H	A, MY, H	DA	Martin et al. (1982) [32]
Sweden	1983-1985	109 010 lactations	SRB, SLB	LN, HMY, S	LR	Oltenacu et al. (1990) [37]
UK	1985-1987	42 herds 3 105 cows	BF	MY, RP	SA	Pasman et al. (1995) [38]
Finland	1993	2 338 herds 39 727 cows	Ayrshire	LN, ST, S, H, RP[4, 5], MY[5]	SA	Rajala-Schultz and Gröhn (1999) [39, 40, 41]

[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.
[4] Only in Rajala-Schultz and Gröhn (1999) [40].
[5] Only in Rajala-Schultz and Gröhn (1999) [41].

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

Health disorder	Risk of culling	Comments	Authors
Metritis	0.3	diagnosis < 21 d on early culling	Beaudeau et al. (1994) [4]
	2.3	diagnosis > 50 d on late culling	Beaudeau et al. (1994) [4]
	1.5	diagnosis > 50 d	Beaudeau et al. (1995) [5]
	(–)[1]	diagnosis > 60 d	Dohoo and Martin (1984) [11]
	NS		Erb et al. (1985) [17]
	NS[2]		Gröhn et al. (1998) [27][3]
	(+)[1]		Martin et al. (1982) [32]
	1.4	primiparous	Oltenacu et al. (1990) [37]
	2.2	diagnosis < 30 d on culling < 30 d	Rajala-Schultz and Gröhn (1999) [39][4, 5]
	1.4	diagnosis < 30 d on culling > 240 d	
Cystic ovaries	NS		Beaudeau et al. (1994) [4]
	NS		Beaudeau et al. (1995) [5]
	NS		Dohoo and Martin (1984) [11]
	NS	primiparous	Erb et al. (1985) [17]
	1.5	multiparous	Erb et al. (1985) [17]
	NS		Gröhn et al. (1998) [27]
	(-)		Martin et al. (1982) [32]
	2.6	primiparous	Oltenacu et al. (1990) [37]
	0.3	diag. < 150 d on culling < 150 d	Rajala-Schultz and Gröhn (1999a) [39][4, 5]
Dystocia	1.7	caeserean section	Barkema et al. (1992) [2]
	NS		Beaudeau et al. (1994) [4]
	1.7	accident at calving in L≥ 3	Beaudeau et al. (1995) [5]
	1.2	calving provided with assistance	Beaudeau et al. (1995) [5]
	NS		Dohoo and Martin (1984) [11]
	2.9	primiparous	Erb et al. (1985) [17]
	3.7	multiparous	Erb et al. (1985) [17]
	1.9		Gröhn and Saloniemi (1986) [24]
	(+)		Martin et al. (1982) [32]
	1.7	primiparous	Oltenacu et al. (1990) [37]
	2.4	on culling < 30 d	Rajala-Schultz and Gröhn (1999) [39][4, 5]
	1.2	on culling > 240 d	
Retained placenta	1.2	on late culling	Beaudeau et al. (1994) [4]
	0.7	diagnosis in lactation 1	Beaudeau et al. (1995) [5]
	NS		Dohoo and Martin (1984) [11]
	NS	primiparous	Erb et al. (1985) [17]
	NS		Gröhn et al. (1998) [27]
	NS		Martin et al. (1982) [32]
	1.4	primiparous	Oltenacu et al. (1990) [37]
	NS	diagnosis in lactation 1	Pasman et al. (1995) [38]
	NS		Rajala-Schultz and Gröhn (1999) [39][4]
Milk fever	1.6	on early culling	Beaudeau et al. (1994) [4]
	NS		Beaudeau et al. (1995) [5]
	(+)	cow down	Dohoo and Martin (1984) [11]
	NS		Erb et al. (1985) [17]
	2.3	on culling < 30 d	Gröhn et al. (1998) [27]
	NS		Martin et al. (1982) [32]
	2.5	on culling < 30 d	Rajala-Schultz and Gröhn (1999) [39][4,5]
Abortion	6.2	diagnosis > 180 d of gestation on late culling	Beaudeau et al. (1994) [4]

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

Health disorder	Risk of culling	Comments	Authors
Abortion	2.4	diagnosis > 180 d of gestation	Beaudeau et al. (1995) [5]
	NS		Dohoo and Martin (1984) [11]
Stillbirth	1.3	primiparous	Oltenacu et al. (1990) [37]
Displaced abomasum	NS		Dohoo and Martin (1984) [11]
	1.3		Geishauser et al. (1998) [23]
	2.3	on culling < 30 d	Gröhn et al. (1998) [27] [3, 5]
	NS[2]		Martin et al. (1982) [32]
	6.8	diagnosis <30 d on culling < 30 d	Rajala-Schultz and Gröhn (1999) [39][4, 5]
Ketosis	(–)[1]	on culling < 150 d	Dohoo and Martin (1984) [11]
	0.8		Gröhn and Saloniemi (1986) [24]
	NS	primiparous	Oltenacu et al. (1990) [37]
	1.9	diagnosis in lactation 1	Beaudeau et al. (1995) [5]
	1.7	diagnosis in lactation 2	Beaudeau et al. (1995) [5]
	1.9	on culling < 30 d	Gröhn et al. (1998) [27]
	1.7	on 120 < culling < 180 d	Gröhn et al. (1998) [27]
	2.1	diagnosis < 30 d on culling < 30 d	Rajala-Schultz and Gröhn (1999) [39][4, 5]
Mastitis	1.5	diagnosis < 90 d on late culling	Beaudeau et al. (1994) [4]
	4.0	diagnosis during dry period in lactation 1	Beaudeau et al. (1995) [5][5]
	1.3	diagnosis < 45 d in lactation < 3	Beaudeau et al. (1995) [5][5]
	3.6	local therapy on culling < 150 d	Dohoo and Martin (1984) [11]
	5.2	primiparous	Erb et al. (1985) [17]
	2.1	multiparous	Erb et al. (1985) [17]
	1.6		Gröhn and Saloniemi (1986) [24]
	1.9	diagnosis < 30 d on culling < 30 d	Gröhn et al. (1998) [27][3, 5]
	3.0	60 < diagnosis < 150 d on 120 < culling < 180 d	Gröhn et al. (1998) [27][3, 5]
	NS		Martin et al. (1982) [32]
	NS	diagnosis in lactation 1	Pasman et al. (1995) [38]
	1.4 to 2.6		Rajala-Schultz and Gröhn (1999) [39][4, 5]
High SCC	NS		Beaudeau et al. (1994) [4]
SCC 300-800 c·ml^{-1}	1.2	throughout lactation 1	Beaudeau et al. (1995) [5]
SCC ≥ 800 c·ml^{-1}	1.7	throughout lactation 1	Beaudeau et al. (1995) [5]
Subclin. mastitis	(+)[1]	on culling > 150 d	Dohoo and Martin (1984) [11]
Teat injuries	6.0	on early culling	Beaudeau et al. (1994) [4]
	5.7	diagnosis in lactation 1	Beaudeau et al. (1995) [5]
	1.7	diagnosis in lactation ≥ 2	Beaudeau et al. (1995) [5]
	1.5 to 3.0		Rajala-Schultz and Gröhn (1999) [39][4, 5]
Locomotor disorders	NS		Beaudeau et al. (1994) [4]
	NS		Beaudeau et al. (1995) [5]
	(+)	on culling < 150 d	Dohoo and Martin (1984) [11]
	NS	diagnosis in lactation 1	Pasman et al. (1995) [38]
	1.2 to 6.0		Rajala-Schultz and Gröhn (1999) [39][4, 5]

[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] results from a model containing terms for the interaction of health disorder and stage of lactation at culling; [5] complete results are provided in corresponding paper.

results. Six of the 9 available studies reported no significant effect, whereas Oltenacu et al. [37] and Beaudeau et al. [4] reported that cows with retained placenta were at least 1.2 times more at risk. Gröhn et al. [27] 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 postpartum [5, 27, 39]. 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 mainly in early lactation, mostly right after its occurrence [23, 27, 39]. 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 [23].

There were variations between studies on the effect of ketosis as a risk factor for culling. Papers from the eighties [11, 24] 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 [5, 27, 41].

3.2.3. Udder disorders

An increased risk of culling in cows which have experienced mastitis is a classical finding, regardless of breed, study period or design. For mastitis, the main risk periods for being culled were early lactation [4, 27] and dry period [5]. 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 [39].

The high impact of teat injuries on culling found by Beaudeau et al. [4, 5, 39] 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 than 3% of dairy cows were culled because of foot disorders (see above).

3.2.5. Health disorders as risk factors for specific culling reasons

Few studies have been done to investigate these specific relationships. Milian-Suazo et al. [34], 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. [32] 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. [36] 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 show 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.

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 or 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. [21, 22]; Hortet and Seegers [28, 29]), the inclusion of reproductive performance and/or current milk yield (e.g. days to conception and/or mature equivalent 305 d 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 in paragraph 4.4 of this paper.

4. ON THE DIFFERENT STRATEGIES TO MODEL THE EFFECT OF HEALTH DISORDERS ON CULLING: METHODOLOGICAL ISSUES AND ASSOCIATED RESULTS

4.1. Length of productive life or lactation as time frame for making culling decision

Different time-frames for evaluating the impact of health disorders can be considered to check whether health-related culling decisions are made with consideration of particular events in the current lactation, or integration of the whole disease history of the cow. Several approaches are available: one can evaluate (1) the ability to start a new lactation based on events occurring within the current lactation of the cow [4, 5, 11, 17, 24, 27, 32, 37, 39–41], or (2) the possible effects of the health disorder on the whole productive life of the cows [5, 38]. In Beaudeau et al. [5], 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. [35] 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.

4.2. 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. [49] 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, as defined in paragraph 2.2.

Furthermore, Pasman et al. [38] 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 current lactation included in the models considered in this study. The fact that cows culled early (1st 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 [43].

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.

4.3. 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 [4, 5, 27, 39–41].

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 [5]) clearly demonstrates two key-times (peak of lactation and service period) in the farmers’ decision to cull. It is reasonable to assume that cows conceiving 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 on possible interactions between occurrence of health disorders and time of culling may indicate in which delay farmers react. Rajala-Schultz and Gröhn [39] reported that mastitis, teat injuries and lameness had a significant effect on culling throughout the whole lactation, whereas other non reproductive disorders affected culling decisions mostly at the time of their occurrence.

From other studies, 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 [4], mastitis occurring before the peak of lactation [27] may induce early cullings, in agreement with descriptive findings of Seegers et al. [43] based on declared culling reasons. These health disorders are mainly related to the fact that they can prevent milking. Also, accident at calving and downer cow syndrome, because they induce a presumed vital prognosis, ketosis and displaced abomasum in early lactation, because they are often associated with a subsequent drop in milk yield, are all likely to lead to immediate removals [4, 23, 27]. 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 [33, 43]. These are mastitis after the peak of lactation, metabolic and reproductive disorders. For mastitis, reproductive disorders and some metabolic disorders, farmers may choose to treat first in order to allow the recovery of the cow, and therefore postpone her possible culling.

4.4. Direct and indirect effects of health disorders on culling

In regards of the known detrimental effects of some disorders on reproduction and milk yield [21, 22, 28, 29], 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

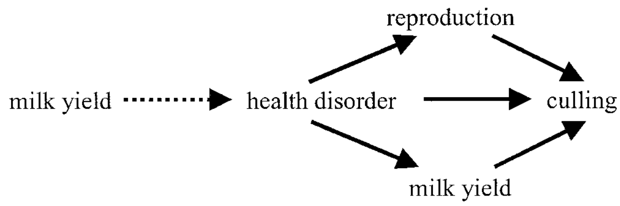

Figure 2. Illustration of the direct and indirect effect (through milk yield and reproduction) of health disorders on culling.

direct effect). The concept of direct vs indirect effect of a given health disorder on culling is illustrated in Figure 2.

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 different strategies to deal with these covariates will be addressed separately below.

Gröhn et al. [26] discussed some strategies for accounting for milk yield as an adjustment variable, taking the analysis of the effect of mastitis on culling as an example. 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. [25]). Other strategies aim at both addressing the fact that milk yield is a risk factor for mastitis and at preventing overadjustment (Fig. 2, dotted line). Using previous milk yield (strategy A2) appears to be a relevant option since it partly avoids overadjustment. However, this strategy excludes primiparous cows from the analysis. Furthermore, previous lactation yield is far from a perfect indicator of the milk production potential 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. [32], Dohoo and Martin [11]). It is reasonable to assume, even if it was not clearly stated in these studies, that 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 [27, 41] 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, demonstrating a direct impact [27, 41].

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 [50]) 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 [4]. Gröhn et al. [26] 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. [5] included in their models a variable based on the comparison, at date of new calving, of the class of 305 d mature equivalent milk production and the class of potential 305 d mature equivalent milk production (extrapolated from the best of the first two monthly milk yield records) in the current lactation. The best of these two classes was considered as representing the real phenotypic potential on production on which the farmer is likely to base his voluntary culling decisions. 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 [27, 41].

Few studies included poor reproductive performance in models for the assessment of health disorders as risk factors for culling [4, 5, 17, 27, 41]. Several strategies for the analysis can be used.

Erb et al. [17] partitioned the influence of reproductive disorders on culling in direct and indirect effects using the path analysis method (strategy B1). In their 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 simplest, 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 [27]. Using this option, the effect of reproductive disorders (retained placenta, cystic ovaries) becomes 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 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, if the producer has planned to cull a given cow anyway, he 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 account for the fact that a cow to be bred is per se not at risk of being culled for poor reproductive performance during her postpartum anoestrus, a strategy (strategy B3) is to design a variable describing the reproductive status of each cow, so that a given cow is modelled to be at the lowest risk of being culled in early lactation. Such a variable may be based on the sequence of AI a cow experiences and not on status at time of conception [5]. 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.

To avoid confusion between biology and management-related factors (as described above), Gröhn et al. [27] suggested to use AI information, in addition to the knowledge of pregnancy status (strategy B4). If a cow is bred at least once, it may be assumed that the absence of conception does not result from the farmer's decision. Therefore, by accounting for the number of AIs a cow experiences, it is possible to distinguish among cows that never conceived, those deliberately not inseminated, and those failed to conceive despite several inseminations [40]. Rajala-Schultz and Gröhn [40] reported that the earlier the farmer knew a cow had conceived, the smaller was her risk of culling (biology-related contribution), and also that a cow not inseminated at all had a 10 times higher risk than a cow inseminated once (management-related contribution).

To avoid the inclusion in the same model of covariates (reproductive health disorders and days open) that are often strongly related, a strategy (strategy B5) 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 [5]. 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 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 yield 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 [5, 39], the latter with descriptors of performance [5].

In contrast, whether or not the farmers make culling decisions based on health disorders or only on current milk yield/reproduction is a specific question requiring that the researcher includes performance from the current lactation. To assess the direct vs. indirect effect of health disorders on culling, it may be advisable to use the systematic strategy developed by Gröhn et al. [27], and partly used by Rajala-Schultz and Gröhn [39, 40, 41], which consists in performing four models: the first contains terms for health disorders only, the second contains terms for health disorders and reproductive performance only, the third contains terms for health disorders and milk yield only, the fourth contains terms for health disorders and both for reproductive performances and milk yield. Then the comparison of the effect of health disorders in the 4 models is of interest. Table III gives, as an example, values of relative risk of culling after occurrence of some health disorders estimated from the four models described in Gröhn et al. [27]. From the comparison of effects for each health disorder, ketosis appeared to have only a direct effect on culling, since relative risks of culling were almost the same among models. Mastitis occurring within 30 d postpartum and cystic

Table III. Risk of culling consequent to 4 health disorders depending on whether or not milk yield and reproductive performances in the current lactation were accounted for – from Gröhn et al. [27].

	Relative risk of culling[1]			
	Health disorders[2]	Health disorders[2] + milk yield	Health disorders[2] + reproduction	Health disorders[2] + milk yield + reproduction
Ketosis	2.4	2.4	2.4	2.3
Cystic ovaries	1.4	1.9	NS[3]	NS
Mastitis < 30 d pp	2.5	NS	2.5	NS
Mastitis > 60 d pp	4.9	4.4	4.0	3.6

[1] Reference: cow without the health disorder of concern.
[2] Model containing terms for.
[3] $P > 0.05$.

ovaries had only an indirect impact on culling through low milk yield and poor reproductive performance respectively: their effect was no longer significantly higher than unity in models containing terms for milk yield and reproductive performance respectively. Mastitis occurring after 60 d postpartum had both a direct and an indirect effect on culling: its effect decreased when a term for milk yield was accounted for in the models. In any case, conclusions remain highly dependent on the definition of descriptors of milk yield and/or reproductive performance.

4.5. Effect of a sequence of health disorders on culling

Several previous studies reported associations between health disorders throughout the lactation [11, 17, 24, 32] or health profile throughout the whole lifespan of dairy cows [20]. Whether or not the farmers account for sequences of health disorders to make culling decisions has only received a partial 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. [5] 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 constrast, Rajala-Schultz and Gröhn [39] reported that the effects of dystocia and metritis were slightly reduced when included simultaneously in the model, compared with a situation when they were modelled separately. This latter finding suggests interrelated effects of some diseases on culling [39].

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 [4]. Another option would be to introduce in the models synthetic variables describing diseases complexes, defined from preferential associations between health disorders.

5. 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 or udder disorders (other than mastitis) possibly affecting milking ability shortly 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 or reproductive performance from the current lactation should be included depends on the goal of the study. In any case, attention should be paid to the consequences of overadjustment.

There is a huge herd effect on the risk of being culled. Within-herd characteristics (availability of 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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