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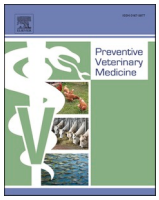

Survey of perceptions and attitudes of an international group of veterinarians regarding antibiotic use and resistance on dairy cattle farms

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ABSTRACT

Veterinarians are the main source of information for farmers regarding the responsible use of antibiotics in farm animals and how to reduce the risk of antibiotic resistance. Consequently, understanding how veterinarians perceive their clients' and colleagues' antibiotic use and their own beliefs about the development of antibiotic resistance is essential to determining areas in which antibiotic use practices can be improved to minimize the emergence of antibiotic resistance. An international cross-sectional study was carried out using a questionnaire designed to elucidate perceptions, attitudes, and concerns of dairy veterinarians regarding antibiotic use and the emergence of antibiotic resistance in dairy farming. The questionnaire was initially administered to veterinarians attending the International Bovine Mastitis Conference in Milano, Italy, 2018, followed by veterinarian members of the National Mastitis Council, and all conference registrants. A total of 71 participants from 21 countries participated in the survey, the majority were from the United States and member countries of the European Union. Logistic regression analysis was conducted to identify predictors of veterinarians' level of concern about the development of antibiotic resistance on their clients' farms. Associations were described with odds ratios (ORs) and the associated 95 % confidence intervals (95 % CIs). Free text responses where participants shared their views on the reason for overprescribing antibiotics by veterinarians were analyzed using thematic analysis. Participants perceived that nearly half of their clients overuse or inappropriately use antibiotics, and nearly half of their colleagues overprescribe or inappropriately prescribe antibiotics. After controlling for other factors, the odds of veterinarians being concerned about antibiotic resistance on dairy farms they served decreased by a factor of 0.91 for each additional year of participants' experience working with dairy cattle (OR = 0.91, 95 % CI = 0.84–0.99). Participants concerned about antibiotic resistance on clients' dairy farms were also more likely to consider better adherence to drug labelling as important for reducing farmers' antibiotic use (OR = 6.86, 95 % CI = 1.21–38.93). Thematic analysis revealed four themes surrounding the perceived reasons for veterinarians' overprescribing of antibiotics: (i) knowledge, (ii) attitudes, (iii) barriers, and (iv) rules and regulations. The study findings will aid in the development of strategies to improve antibiotic use in dairy farming and educational initiatives looking to enhance the communication between veterinarians and farmers about judicious use of antibiotics.

1. Introduction

Overuse and inappropriate antibiotic use in livestock have the potential to influence the emergence of antibiotic resistant commensals and pathogens in animals (Stanton, 2013; Prestinaci et al., 2015). Emergence of antibiotic resistant pathogens can increase the morbidity and mortality of infections, limiting veterinary treatment options (Oliver et al., 2011; Prestinaci et al., 2015; Lhermie et al., 2017). Resistant organisms spreading in the environment have been recognized for their role in human health risks (Manaia, 2017), while antibiotic residues promote the emergence of antibiotic resistant bacteria in the environment through selective pressure (Ben et al., 2019). Therefore, it is important that appropriate antibiotic use protocols are rigorously followed by farmers and veterinarians in order to prevent the

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development of antibiotic resistant bacteria on dairy farms and, through that, protect animals, humans, and the environment in the context of One Health (Robinson et al., 2016). This holds although the extent of adverse impacts on One Health from antibiotic use in dairy farming is currently unknown (Oliver et al., 2011).

Numerous national and international efforts by government and non-governmental organizations are underway to establish guidelines and recommendations aimed at preventing and reducing the occurrence of antibiotic resistant bacteria in animal production systems, including on dairy cattle farms (FDA, 2012; 2013; EC, 2015; 2018a; 2018b; FDA, 2015; WHO, 2017). Current regulations are not homogenous between countries. For example, antibiotic use regulations differ between two large geopolitical entities and major dairy milk producers, the United States (US) and European Union (EU). For instance, in January 2017, the US Food and Drug Administration (FDA) finished implementation of Guidance for Industry #213, bringing the use of medically important antibiotics in feed or water for the treatment, control, and prevention of diseases under veterinary oversight and eliminating the use of medically important antibiotics for growth promotion (FDA, 2013; 2015). Meanwhile, the EU has recently issued strict regulations to prohibit the administration of antibiotics as a preventive measure, limit their metaphylactic application, and establish a mandatory requirement for member countries to gather data about the sale and use of antibiotics (Europe Commission (EC, 2018a; 2018b). The differences in regulations and their timing might influence or be a reflection of the prevailing culture and beliefs among farmers and veterinarians working in these two economies. Thus, it is of interest to determine whether veterinarians from different countries, including from the US and EU, have different perceptions regarding the risk of antibiotic resistance emergence on dairy farms.

Veterinarians have a crucial role in promoting measures to reduce the risk of antibiotic resistance from emerging on dairy farms, as well as educating their clients regarding the judicious use of antibiotics. In fact, success of antibiotic resistance reduction programs has mostly relied on changing attitudes held by veterinarians and their clients about the prescription and administration of antibiotics (Oliver et al., 2011). For this reason, understanding how veterinarians perceive their clients' and colleagues' antibiotic use and their own beliefs about the development of antibiotic resistance is pivotal to identifying areas in which education and training efforts might improve antibiotic use and prescribing practices. Nonetheless, there is limited research assessing dairy veterinarians' perceptions regarding antibiotic use and the risk of development of antibiotic resistance in animals and humans, including studies in Italy (Busani et al., 2004), New Zealand (McDougall et al., 2017), the Netherlands (Speksnijder et al., 2015a, 2015b), the United Kingdom (Higgins et al., 2017), and the US (Cattaneo et al., 2009); this is insufficient considering the continuous development of regulations and guidelines for the use of antibiotics. Knowledge is especially sparse regarding perceptions of dairy veterinarians in the US. The study by Cattaneo et al. (2009) was performed before the Veterinary Feed Directive (VFD) final rule entered into effect in early 2017, introducing relevant changes in the way in which farmers access some antibiotics (FDA, 2015). Information is even more limited regarding veterinarians' attitudes towards the application of diverse preventive and management measures to reduce antibiotic resistance on dairy farms (Cattaneo et al., 2009). Also, it is currently unknown how many veterinarians are even concerned about development of antibiotic resistant organisms on their dairy clients' farms, which are within the circle of their direct awareness and potential influence, and what distinguishes them from their colleagues. The objective of this study was to describe opinions and concerns of an international group of dairy veterinarians regarding antibiotic use and resistance in dairy farming and determine the associated sources of variability with regards to the level of concern they have about antibiotic resistance on the dairy farms they serve.

2. Materials and methods

2.1. Survey design

A cross-sectional study of dairy veterinarians from different countries was conducted using a questionnaire survey. The questionnaire was implemented using the online Qualtrics survey platform (Qualtrics, Provo, UT) and was also available in a paper-based format; Table 1 shows the survey questions considered in statistical and thematic analysis (the whole survey is included in the Supplementary Material). Veterinarians who have been working with dairy cattle in clinical practice over the past year were eligible to participate. The survey was piloted by two veterinarians in clinical dairy practice and revised based on their feedback. Considering the preliminary nature of the investigation, power-based sample size calculation could not be conducted.

2.2. Data collection and management

The study was approved by the Cornell University Institutional Review Board for Human Participants (IRB protocol #1805008010). Participants' responses were anonymous and confidentiality was assured. The survey was administered in three venues. First, veterinarians attending the International Bovine Mastitis Conference in Milano, Italy, 2018 (which was organized by the University of Milan), were invited to complete either a paper-based survey at the conference (June 11 and 12, 2018) or an online Qualtrics survey (from June 11 to July 12, 2018). As the second venue, a link to take the online version of the survey was distributed by the National Mastitis Council (NMC) via email to their 176 member veterinarians (from June 23 to July 20, 2018). The NMC is a not-for-profit professional organization, with international membership, devoted to reducing mastitis and enhancing milk quality. As the third venue, the online version of the survey was distributed by the University of Milan via email to 623 people who registered for the conference and through this venue the survey was open from July 27 to September 6, 2018. Of those 623 registered, author P.M., who also served as a member of the conference organizing and scientific committees, approximated that two thirds (or roughly 400 participants) were dairy veterinarians. In addition to dairy veterinarians, the attendees of this annual conference have typically been dairy producers, researchers, extension specialists, industry suppliers, dairy processor field representatives, regulatory officials, teachers, and students. Though not possible to confirm, it is highly plausible that many of the NMC member veterinarians were also among the 623 people registered for the conference. In both paper and online formats, the survey was estimated to take 10−15 min to complete. An incentive was offered in the first administration venue; after completing the survey participants were offered to enter their e-mail address into a drawing to win one of 24 Cornell University T-shirts.

Information obtained from completed paper and online surveys, was organized into a datasheet in Microsoft Excel (Microsoft, Seattle, WA). Non-numeric responses to questions asking for a numeric response (i.e., participant did not respond with a number) were not utilized. Responses with numerical ranges in open-end questions were averaged, and answers "greater than" or "less than" were given as 1 integer above or below the provided value, respectively. If no proper response to a question was given, the corresponding response was left blank in the datasheet and considered as a missing observation. All surveys that were unfinished (i.e., participant did not finalize the questionnaire by submitting her/his answers, n = 50) and those answered by non-veterinarians (n = 7) were disregarded. Similarly, responses from which significant information regarding the subject matter could not be discerned were also excluded. For statistical analyses, all close-ended questions with offered responses, and the open-ended question asking for a country where the participants has practiced over the past year, were converted into categorical variables, while the remaining open-ended questions (which asked for a numerical response) were

Table 1
Survey questions and the associated variable names used in statistical and thematic analysis (answer choices for multiple choice questions are omitted for brevity; full questionnaire can be found in the Supplementary Material).

	Question	Variable
1	In the past year, approximately what fraction of your time in clinical practice did you spend working with dairy cows?	% of year in dairy
2	In what country did you practice veterinary medicine for most of the past year?	Country
3	Approximately how many years in total have you worked with dairy cows in clinical practice as a veterinarian?	Years in dairy
4	In a typical week over the past year, approximately what percentage of your time in clinical practice do you spend working with dairy cattle?	Time/week in dairy
5	Over the past year, approximately how many individual dairy farms have you personally provided veterinary services to?	No. farms served
6	Considering all the farms that you provided veterinary services to over the past year, what is the approximate total number of lactating dairy cows that you oversaw as a veterinarian?	No. lact. cows served
7	Approximately how many of the dairy farms you provided veterinary services to over the past year were certified organic?	No. organic farms served
8	What is the smallest dairy farm size (in terms of the number of lactating cows) you provided veterinary services to over the past year? Please estimate if you are unsure.	Smallest farm served
9	What is the largest dairy farm size (in terms of the number of lactating cows) you provided veterinary services to over the past year? Please estimate if you are unsure.	Largest farm served
10	Approximately what percentage of your current dairy farmer clients have you ever assisted in developing protocols for antibiotic use over the past year?	% clients use AB protocol
11	Please state your level of agreement with the following statement: "I feel comfortable giving my dairy farmer clients advice about antibiotic use, even if it conflicts with/differs from their current practices."	Give AB advice
12	Please state your level of agreement with the following statement: "Most of my dairy farmer clients are (or would be) generally receptive to advice I provide regarding antibiotic use."	Clients take AB advice
13	In your opinion, approximately, what percentage of your dairy farmer clients overused or inappropriately used antibiotics in their dairy cattle over the past year?	% clients overuse AB
	A) Of those farmers overusing or inappropriately using antibiotics, in what treatment area do you think these dairy farmers could improve their antibiotic use the most? You may make multiple selections.	AB improvement area
	B) What might deter or prevent those farmers who are using more antibiotics than needed from reducing antibiotic use? (Check all that apply.)	Barriers to AB reduction
14	In your opinion, considering all the farms you have served over the past year, how *important* are the following changes in reducing farmers' antibiotic use in dairy cattle?	
	- Improved environmental conditions for cattle (e.g. clean, well-ventilated, and adequately sized facilities that promote cow comfort)	Importance-environment
	- Improved herd health management (e.g. quality nutrition, vaccination, biosecurity, and hoof care) NOT including the environmental factors described in the first row	Importance-management
	- Better utilization of and/or adherence to antibiotic use protocols	Importance-AB protocols
	- Better adherence to labelling on drug packaging in regard to treatment regimen (dose, route, duration, and frequency)	Importance- drug packing/labelling
	- Improved record keeping	Importance-records
	- Increased utilization of diagnostics available for various diseases	Importance-diagnostics
	- Improved communication between farm owners, farm staff, and/or others	Importance-communication
15	In your opinion, considering all the farms you have served over the past year, how *easy* would the following changes be to implement in order to reduce farmers' antibiotic use in dairy cattle?	
	- Improved environmental conditions for cattle (e.g. clean, well-ventilated, and adequately sized facilities that promote cow comfort)	Difficulty-environment
	- Improved herd health management (e.g. quality nutrition, vaccination, biosecurity, and hoof care) NOT including the environmental factors described in the first row	Difficulty- management
	- Better utilization of and/or adherence to antibiotic use protocols	Difficulty-AB protocols
	- Better adherence to labelling on drug packaging in regard to treatment regimen (dose, route, duration, and frequency)	Difficulty- drug packing/labelling
	- Improved record keeping	Difficulty-records
	- Increased utilization of diagnostics available for various diseases	Difficulty-diagnostics
	- Improved communication between farm owners, farm staff, and/or others	Difficulty-communication
16	In your opinion, approximately, what percentage of veterinarians you know overprescribed or inappropriately prescribed antibiotics for use in dairy cattle over the past year?	% vets overprescribe AB
	[a,c]A) If your answer in question 16 is not 0%: Why do you think these veterinarians overprescribe or inappropriately prescribe antibiotics to their clients?	Vet overprescribing reasons
17	Over the past year, how many times have you experienced pressure or influence from your dairy farmer clients to prescribe antibiotics when they were unnecessary in your opinion?	Times pressured to prescribe AB
18	Please complete the following statement with one of the choices below: "I _____ discuss antibiotic resistance with my clients."	Discuss ABR
19[b]	How concerned are you about antibiotic resistant organisms developing on your dairy clients' farms?	Concern-ABR on farms
20[c]	How concerned are you about antibiotic use on your clients' dairy farms potentially causing antibiotic resistant infections in people working on those farms?	Concern-ABR in people on farms
21[c]	How concerned are you about antibiotic use on your clients' dairy farms potentially causing antibiotic resistant infections in the general public?	Concern-ABR in general public
22	Please state your level of agreement with the following statement: "In your country, antibiotic resistance due to antibiotic overuse and inappropriate use in dairy farming contributes to antibiotic resistant infections in dairy cattle."	AB overuse-ABR in dairy
23	Please state your level of agreement with the following statement: "In your country, antibiotic resistance due to antibiotic overuse and inappropriate use in dairy farming contributes to antibiotic resistant infections in the general public."	AB overuse-ABR in humans
24	Please state your level of agreement with the following statement: "In your country, antibiotic overuse and inappropriate use in dairy farming negatively impacts the environment."	AB overuse-ABR in environment
25	On a global scale, how do you rate antibiotic use in dairy farming as a threat to human health in terms of contribution to antibiotic resistant infections in humans?	ABR threat from AB in dairy
26	On a global scale, how do you rate antibiotic use in human medicine as a threat to human health in terms of contribution to antibiotic resistant infections in humans?	ABR threat from AB in humans
27	Approximately what percentage of your income over the past year was generated by antibiotic sales to your dairy farm clients?	% income from AB sale

Notations: AB = antibiotic; ABR: antibiotic resistance; Vet(s): veterinarian(s).
[a] This question was considered in qualitative (thematic) analysis.
[b] This question was considered as the outcome of interest in logistic regression analysis.
[c] These variables were no included in the logistic regression analysis.

converted into continuous variables.

2.3. Statistical analysis

All statistical analyses were performed in R Studio using R v. 3.5.1 (R Core Team, 2017). R packages "lme4", "exact2x2", "ggplot2", "rcompanion", and "epiDisplay" were employed for analysis. Responses obtained for every question in Table 1 were summarized and organized in tables (Tables 2 and 3) and/or visualized using plots. The outcome of interest was derived from the survey question "How concerned are you about antibiotic resistant organisms developing on your dairy clients' farms?" (question 19, Table 1). This question was converted into a binary variable "Concern-ABR on farms" with levels "Unconcerned" (including original levels: "Not at all concerned", "Slightly concerned", and "Somewhat concerned") and "Concerned" (including: "Moderately concerned" and "Extremely concerned"). The open-ended survey question "In what country did you practice veterinary medicine for most of the past year?" (question 2, Table 1) was converted into a categorical variable "Country" by grouping responses into "United States", "European Union", and "Other countries". However, because of a small number of responses under "Other countries" (n = 9), this level was dropped after initial descriptive analyses; the resulting binary variable was used as an explanatory variable (predictor) for the outcome of interest. Other predictor variables derived from the survey questions are listed in Table 1.

Potential associations between the outcome and categorical predictor variables were first visually assessed by generating balloon plots, while boxplots were used to visually evaluate relationships between the outcomes and continuous predictor variables. Logistic regression was used to evaluate associations between the outcome of interest and predictors. Associations between two categorical predictors were assessed by the Chi-square (or as applicable by the Blaker's exact test (Fay, 2010)) and associations between a categorical and continuous variable were assessed using the Mann-Whitney test. Correlations between two continuous predictor variables were tested using the Spearman's test. All categorical predictors were dichotomized (as explained in Table 3) to reduce the number of levels included in the models to improve study power. Variables "No. farms served", "No. lact. cows served", "Smallest farm served", and "Largest farm served" were highly skewed and so were log10-transformed for logistic regression analysis. An association between the outcome and a statistically significant predictor was expressed as odds ratio (OR) and the associated 95 % confidence interval (95 % CI). Predictor variables displaying significant associations ($p < 0.1$) with the outcomes at the bivariable level were tested in multivariable logistic regression models. For both bivariable and multivariable logistic regression analyses, *p*-values and the associated OR 95 % CI were based on the Wald test. Variables with more than 10 missing observations were evaluated at the bivariable level and were considered in multivariable analysis initially but were eventually excluded due to data loss. When multiple continuous variables were found to be highly correlated (at $r > 0.7$), only one was considered at a time in the multivariable analysis. Based on the Cramer's Phi tests of association, responses to questions 20 ("Concern-ABR in people on farms") and 21 ("Concern-ABR in general public") were very similar to those responded to question 19 ("Concern-ABR on farms"), which was used as the outcome of interest (Cramer's Phi = 0.5); thus, questions 20 and 21 were excluded from consideration in the multivariable logistic regression analysis. Question 16A ("Vet overprescribing reasons") was considered in thematic analysis. Other than questions 20, 21, and 16A, all other variables shown in Table 1 were considered as predictors in the bivariable logistic regression.

The final logistic regression model was selected through the stepwise backward elimination process using likelihood ratio test and the Akaike information criterion (AIC). Box-Tidwell test was used to determine if the assumption of linearity holds between the logit transformation of the outcome and the continuous predictor variables in the final logistic regression model (Box and Tidwell, 1962). Receiver operating characteristic (ROC) curves were built to determine to which extent the final model properly fitted the data. Confounding among variables was identified by evaluating changes of ≥30 % in the ln(OR) between the estimate calculated in the bivariable logistic regression (crude estimate) and estimate obtained after including the potential confounder in the multivariable model (adjusted estimate) (Dohoo et al., 2003). Two and three-way interactions between variables included in the final multivariable model were also assessed for. Except when otherwise stated, statistical significance was established at *p*-value < 0.05.

The "Country" variable was additionally evaluated as a dependent variable using logistic regression analysis to identify any systematic differences between study participants from the US and EU (this is further described in the Supplementary Material).

2.4. Thematic analysis

Answers to the open-ended question "Why do you think … veterinarians [you know] overprescribe or inappropriately prescribe antibiotics to their clients?" (Question 16 A, Table 1) were analyzed using thematic analysis (Braun and Clarke, 2006). All participants' responses were read by S.L.-S. to develop a preliminary codebook based on

Table 2
Summary statistics for continuous variables describing the responses provided by dairy veterinarians (n = 71) enrolled in the context of the International Bovine Mastitis Conference held in Italy in 2018.

Variable (unit)	Mean	Median	IQR	Range	Missing
% of year in dairy (%)	83.5	90	70–100	20–100	3
Years in dairy (year)	18.9	17	8–27	1–47	0
Time/week in dairy (%)	84.5	90	70–100	20–100	1
No. farms served (farm)	74.1	40	25–100	1–550	0
No. lact. cows served (cow)	19,273	5,000	2,500–11,000	20–350,000	0
No. organic farms served (farm)	2.6	1	0–3	0–25	0
Smallest farm served (cow)	120.6	30	20–50	2–2,600	0
Largest farm served (cow)	4,669	800	380–1,500	120–200,000	0
% clients use AB protocol (%)	59.3	60.5	30–90	0–100	1
% clients overuse AB (%)	47.1	40	30–70.5	0–100	3
% vets overprescribe AB (%)	42.9	47.5	17.5–61	0–100	3
Times pressured to prescribe AB (times pressured)	16.6	8.75	2.4–20	0–80	19
% income from AB sale (%)	13.2	6.5	0–25	0–65	17

Notation: IQR = Interquartile range; AB = antibiotic.

Table 3
Summary statistics of categorical variables describing the responses provided by dairy veterinarians (n = 71) enrolled in the context of the International Bovine Mastitis Conference held in Italy in 2018.

Variable[a]	Response	Number	%[b]
Country	European Union	45	64
	United States	16	23
	Other countries	9	13
Discuss ABR[c]	Never	0	0
	Very rarely	0	0
	Rarely	4	6
	Occasionally	23	32
	Frequently	30	42
	Very frequently	14	20
Concern-ABR on farms[d]	Not at all concerned	1	1
	Slightly concerned	12	17
	Somewhat concerned	13	18
	Moderately concerned	28	39
	Extremely concerned	17	24
Concern-ABR in people on farms[d]	Not at all concerned	4	6
	Slightly concerned	22	31
	Somewhat concerned	19	27
	Moderately concerned	15	21
	Extremely concerned	11	16
Concern-ABR in general public[d]	Not at all concerned	9	13
	Slightly concerned	18	25
	Somewhat concerned	17	24
	Moderately concerned	18	25
	Extremely concerned	9	13
Give AB advice[e]	Strongly disagree	2	3
	Disagree	0	0
	Neither agree nor disagree	6	9
	Agree	28	39
	Strongly agree	35	49
Clients take AB advice[e]	Strongly disagree	2	3
	Disagree	0	0
	Neither agree nor disagree	4	6
	Agree	49	69
	Strongly agree	16	23
AB overuse-ABR in dairy[e]	Strongly disagree	2	3
	Disagree	13	18
	Neither agree nor disagree	16	23
	Agree	29	41
	Strongly agree	11	16
AB overuse-ABR in humans[e]	Strongly disagree	7	10
	Disagree	27	39
	Neither agree nor disagree	26	37
	Agree	8	11
	Strongly agree	2	3
AB overuse-ABR in environment[e]	Strongly disagree	3	4
	Disagree	14	20
	Neither agree nor disagree	19	27
	Agree	26	37
	Strongly agree	8	11
ABR threat from AB in dairy[f]	No threat	2	3
	Low threat	40	57
	Moderate threat	22	31
	High threat	6	9
ABR threat from AB in humans[f]	No threat	5	7
	Low threat	12	17
	Moderate threat	51	73
	High threat	2	3

Notations: ABR = antibiotic resistance; AB = antibiotic.

[a] One observation is missing in each of the variables: "Country", "AB overuse-ABR in humans", "AB overuse-ABR in environment", "ABR threat from AB in dairy", and "ABR threat from AB in humans".

[b] Percentages were rounded to two decimal places. This caused some numbers to not add up to 100 %.

[c] Responses were dichotomized for logistic regression analysis: Levels "Never", "Very rarely", and "Rarely" were grouped into "Rarely", while levels "Occasionally", "Frequently", and "Very Frequently" were grouped into "Frequently".

[d] Responses were dichotomized for logistic regression analysis: Levels "Not at all concerned", "Slightly concerned", and "Somewhat concerned" were grouped into "Unconcerned", while levels "Moderately concerned" and "Extremely concerned" were grouped into "Concerned".

[e] Responses were dichotomized for logistic regression analysis: Levels "Strongly disagree", "Disagree", and "Neither agree nor disagree" were grouped into "Disagree", while levels "Agree" and "Strongly agree" were grouped into "Agree".

[f] Responses were dichotomized for logistic regression analysis: Levels "No threat" and "Low threat" were grouped into "No threat", while levels "Moderate threat" and "High threat" were grouped into "Threat".

emergent themes. Responses and the codebook were then also reviewed by A.G.S., M.W., and R.I. The codebook was revised until an agreement was reached between S.L.-S., A.G.S., M.W., and R.I. Next, S.L.-S. applied the topic-level codes to the responses in consultation with A.G.S. This method of coding allowed the participants' exact responses to be captured and organized for qualitative analysis. All quotes within a topic were then analyzed by S.L.-S. to identify higher-order trends and themes, which were then reviewed, discussed, refined accordingly, and agreed on by A.G.S., M.W., and R.I.

3. Results

The survey was completed by 71 dairy veterinarians. Of these, 34 were obtained through the administration venue 1 (offered on paper and online at the International Bovine Mastitis Conference in Milano), 24 through the administration venue 2 (online version distributed to NMC member veterinarians), and 13 through the administration venue 3 (online version distributed to all conference attendees post conference). Therefore, the response rate was between (i) 9 % (71/(623 + 176)) and (ii) 18 % (71/400) depending on how conservative or liberal denominator is used in calculation. In (i) the denominator is a sum of the 623 people registered to attend the conference and 176 NMC member veterinarians assuming that all 623 registrants were dairy veterinarians and that none of the NMC's 176 member veterinarians was registered to attend the conference. In (ii) the denominator is comprised of 400 dairy veterinarians (approximated by P.M. to have been among people registered to attend the conference) and it is assumed that this number already includes the NMC's member veterinarians. There was a total of 80 missing observations distributed among 14 questions (with the largest number of missing observations for the variables "Times pressured to prescribe AB" and "% income from AB sale"; Table 2).

3.1. Descriptive analysis

Responses to the questionnaire are summarized in Tables 2 and 3, and in Figs. 1–4. Participants represented 21 countries from the continents of South America, North America, Europe, Asia, and Oceania: Australia (n = 1), Austria (n = 1), Belgium (n = 1), Canada (n = 2), China (n = 2), Denmark (n = 1), Finland (n = 1), France (n = 4), Germany (n = 7), Hungary (n = 2), Ireland (n = 2), Italy (n = 21), New Zealand (n = 2), Portugal (n = 1), Spain (n = 1), the Netherlands (n = 2), Ukraine (n = 1), United Kingdom (n = 1), Uruguay (n = 1), the US (n = 16), and there was a single veterinarian working in three countries (Canada, the US, and Mexico). Among these, 45 (64 %) veterinarians were from countries members of the EU, 16 (23 %) from the US, and 9 (13 %) came from other countries (counting in the veterinarian working in Canada, the US, and Mexico), while one participant did not specify their country of work. Furthermore, veterinarians indicated that they worked a median of 17 (interquartile range (IQR) = 8–27) years with dairy cows and spent a median of 90 % (IQR = 70 %–100 %) of their time in a typical week over the past year working with dairy cattle in clinical practice. Additionally, participants served a median of about 40 (IQR = 25–100) individual farms and 5,000 (IQR = 2,500–11,000) lactating dairy cows in the past year, with the smallest and largest farms having a median size of 30 (IQR = 20–50) and 800 (IQR = 380–1,500) lactating cows, respectively.

Overall, veterinarians indicated that they have assisted a median of 61 % (IQR = 30 %–90 %) of their dairy farmer clients in developing

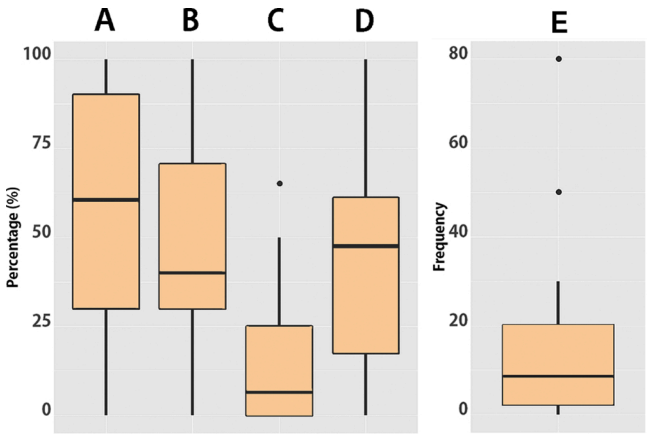

Fig. 1. Boxplots describing responses of participating dairy veterinarians enrolled in the context of the International Bovine Mastitis Conference held in Italy in 2018 regarding the (A) percentage of clients they assisted to in developing antibiotic use protocols, (B) perceived percentage of their dairy farmer clients overusing or inappropriately using antibiotics in their dairy cattle over the past year, (C) percentage of their income over the past year generated by antibiotic sales to dairy farm clients, (D) perceived percentage of their veterinarian colleagues overprescribing or inappropriately prescribing antibiotics for use in dairy cattle over the past year, and (E) number of times that they have experienced pressure or influence from their dairy farmer clients to prescribe antibiotics when they were considered unnecessary.

protocols for antibiotic use in the past year (Fig. 1A) and perceived that a median of 40 % (IQR = 30 %–71 %) of their clients overused or inappropriately used antibiotics in their dairy cows over the past year (Fig. 1B). Additionally, participants pointed out that a median of 7 % (IQR = 0 %–25 %) of their income comes from the sale of antibiotics to dairy farm clients (Fig. 1C). When asked about the use of antibiotics by their colleagues over the past year, participants responded that a median of 48 % (IQR = 18 %–61 %) of veterinarians they know are overprescribing or inappropriately prescribing these drugs (Fig. 1D). Furthermore, participants perceived pressure from their clients to prescribe antibiotics when they deemed it unnecessary a median of 9 (IQR = 2–20) times over the past year (Fig. 1E).

Among proposed strategies to reduce dairy farmers' antibiotic use, most veterinarians categorized them as "Very important" or "Extremely important", with the exception of "Importance- drug packing/labelling" which was mostly perceived as being "Moderately important" (Fig. 2A). Veterinarians perceived that improved environmental conditions for cattle and improved herd health management practices were the most important strategies. Conversely, the opinions of veterinarians about how difficult is to implement these same strategies were more centered around the neutral response. Most of the answers were classified as

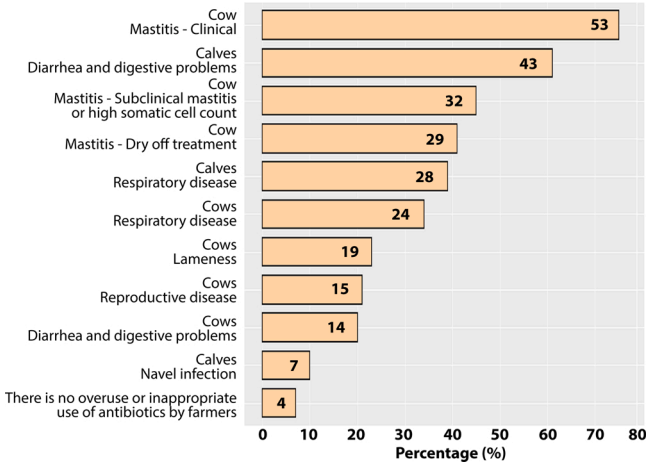

Fig. 3. Responses of participating dairy veterinarians to the question "Of those farmers overusing or inappropriately using antibiotics, in what treatment area do you think these dairy farmers could improve their antibiotic use the most? You may make multiple selections." x-axis indicates the percentage of veterinarians out of 71 participants who selected each response (the number within each bar represents frequency).

A.

Variable	Missing responses	Response				
		Not important	Slightly important	Moderately important	Very important	Extremely important
Importance-environment	0	0	2	7	22	40
Importance-management	0	0	3	9	20	39
Importance-AB protocols	0	1	4	23	27	16
Importance-drug packing/labelling	1	5	12	26	12	15
Importance-records	2	3	10	8	27	21
Importance-diagnostics	1	1	7	16	26	20
Importance-communication	1	0	4	14	25	25

B.

Variable	Missing responses	Response				
		Very easy	Easy	Neither easy nor difficult	Difficult	Very difficult
Difficulty-environment	1	3	7	18	34	8
Difficulty-management	0	5	21	21	23	1
Difficulty-AB protocols	0	12	25	15	17	2
Difficulty-drug packing/labelling	0	9	23	22	13	4
Difficulty-records	2	3	19	15	22	10
Difficulty-diagnostics	0	1	23	15	27	5
Difficulty-communication	1	3	21	26	19	1

Fig. 2. Heat map of the response frequencies for the perceived importance (panel A) and difficulty (panel B) of different strategies to reduce farmers' use of antibiotics in dairy cattle responded by the participating dairy veterinarians. Notation: AB = antibiotic.

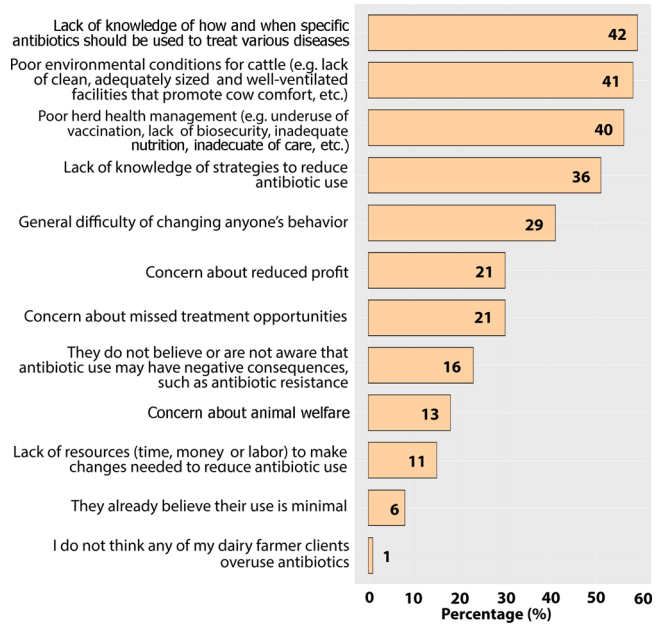

Fig. 4. Responses of participating dairy veterinarians to the question "What might deter or prevent those farmers who are using more antibiotics than needed from reducing antibiotic use? (Check all that apply.)" x-axis indicates the percentage of veterinarians out of 71 participants who selected each response (the number within or beside each bar represents frequency).

"Easy", "Neither easy nor difficult", or "Difficult" and only a few veterinarians perceiving these strategies as "Very easy" or "Extremely difficult" (Fig. 2B).

Regarding clinical treatment areas in which antibiotic use could be improved the most, the majority of veterinarians expressed that clinical mastitis (53/71, 75 %) and diarrhea and digestive problems in calves (43/71, 61 %) requires the most attention, followed by subclinical mastitis or high somatic cell count in cows (32/71, 45 %), while only a few perceived that navel infection in calves (7/71, 10 %) and diarrhea and digestive problems in cows (14/71, 20 %) are relevant (Fig. 3). In addition, veterinarians indicated that the main barriers to reducing antibiotic use by dairy farmers who use antibiotics more than needed are a lack of knowledge of how and when specific antibiotic should be used to treat various diseases (42/71, 59 %), poor environmental conditions for cattle (41/71, 58 %), poor herd management (40/71, 56 %), and lack of knowledge of strategies to reduce antibiotic use (36/71, 51 %). Only one of 71 (1 %) participating veterinarians perceived that dairy farmers are not overusing antibiotics and 6 of 71 (8 %) believed that their use is already minimal (Fig. 4).

3.2. *Variables associated with veterinarians' concern about the emergence of antibiotic resistant infections on their clients' dairy farms*

Statistically significant associations (at the *p*-value = 10 % level) between the outcome of interest, namely expressed concerns of participating veterinarians about the emergence of antibiotic resistant infections in dairy cattle on their clients' farms, and several predictors were identified (Table 4). Namely, the veterinarians' concern about antibiotic resistance on clients' farms was weakly negatively associated with the proportion of the last year spent in dairy cattle clinical practice, veterinarians' years of experience working with dairy cows in clinical practice, the proportion of dairy farmers they assisted in the development of antibiotic protocols, and the proportion of veterinarians' income obtained from antibiotic sales. Also, concern about antibiotic resistance on clients' farms was positively associated with the perceptions that better adherence to labelling on drug packaging was an important but difficult to implement strategy to reduce antibiotic resistant infections in dairy cattle, the perceived importance of increased utilization of diagnostics for various diseases, the perceived difficulty of better utilization of and/or adherence to antibiotic use protocols, the perception that overuse and inappropriate use of antibiotics in dairy farming contributes to antibiotic resistant infections in dairy cattle, and veterinarian's concerns regarding antibiotic resistance emergence in people working on the farms they serve and in the general public.

Results from the multivariable logistic regression model are shown in Table 5. They indicated that participants thought that better adherence to labelling on drug packaging is an important strategy to implement in

Table 4
Variables associated[a] with veterinarians' expressed concern (Concerned vs. Unconcerned as the baseline level) about the development of antibiotic resistant organisms on their dairy clients' farms.

Variable	Levels/Unit	Unconcerned (%)	Concerned (%)	OR[b]	95 % CI[c]	*p*-value
Importance-drug packing/labelling	Unimportant	7 (54 %)	10 (18 %)	1.00		
	Important	6 (46 %)	47 (82 %)	5.48	1.51 – 19.85	0.01
Importance-diagnostics	Unimportant	5 (38 %)	3 (5 %)	1.00		
	Important	8 (62 %)	54 (95 %)	10.63	2.07 – 60.56	0.004
Difficulty-AB protocols	Easy	11 (85 %)	26 (45 %)	1.00		
	Difficult	2 (15 %)	32 (55 %)	6.60	1.34 – 44.00	0.01
Difficulty-drug packing/labelling	Easy	9 (69 %)	23 (40 %)	1.00		
	Difficult	4 (31 %)	35 (60 %)	3.36	0.86 – 13.08	0.07
Concern-ABR in people on farms	Unconcerned	12 (92 %)	14 (24 %)	1.00		
	Concerned	1 (8%)	44 (76 %)	35.60	5.10 – 811.36	<0.0001
Concern-ABR in general public	Unconcerned	11 (85 %)	16 (28 %)	1.00		
	Concerned	2 (15 %)	42 (72 %)	13.83	2.71 – 95.90	<0.001
AB overuse-ABR in dairy	Disagree	11 (85 %)	20 (34 %)	1.00		
	Agree	2 (15 %)	38 (66 %)	10.10	2.02 – 69.32	0.001
% of year in dairy[d]	%	NA[e]	NA	0.96	0.91 – 1.01	0.08
Years in dairy[d]	Year	NA	NA	0.95	0.91 – 1.00	0.04
% clients use AB protocol[d]	%	NA	NA	0.98	0.96 – 1.00	0.07
% income from AB sale[d]	%	NA	NA	0.96	0.93 – 1.00	0.05

[a] Variables associated with the outcome at the *p*-value = 10 % level are shown.
[b] OR: Odds ratio.
[c] 95 % CI: 95 % confidence interval.
[d] Among participants who were Unconcerned and Concerned about the development of antibiotic resistant organisms on their dairy clients' farms the median and interquartile range (IQR) were respectively: for "% of year in dairy" 98 % (90%–100%) and 90 % (70%–100%); for "Years in dairy" 26 (18–30) and 15 (6–25) years; for "% clients use AB protocol" 90 % (80%–90%) and 58 % (30 %–90 %); and for "% income from AB sale" 20 % (5%–41%) and 0% (0%–20%).
[e] NA: not applicable for a continuous variable.

Table 5
Final multivariable logistic regression model for veterinarians' expressed concern (Concerned vs. Unconcerned as the baseline level) about the development of antibiotic resistant organisms on their dairy clients' farms.

Variable	Levels/Unit	OR[a]	95 % CI[b]	*p*-value
Importance-drug packing/ labelling	Unimportant	1.00		
	Important	6.86	1.21 – 38.93	0.03
AB overuse-ABR in dairy	Disagree	1.00		
	Agree	11.70	1.76 – 77.76	0.01
Years in dairy	Year	0.91	0.84 – 0.99	0.03
% clients use AB protocol	%	0.97	0.94 – 1.00	0.03

[a] OR: Odds ratio.
[b] 95 % CI: 95 % confidence interval.

order to reduce client's antibiotic use (OR = 6.86, 95 % CI = 1.21–38.93) and agreed that overuse of antibiotics contributes to the emergence of antibiotic resistance on farms (OR = 11.70, 95 % CI = 1.76–77.76). For every one-unit increase in participants' years of experience and the proportion of clients being assisted by veterinarians in the development of antibiotic protocols, the odds of veterinarians being concerned about the emergence of antibiotic resistant infections on the dairy farms they served decreased by a factor of 0.91 (OR = 0.91, 95 % CI = 0.84−0.99) and 0.97 (OR = 0.97, 95 % CI = 0.94–1.00; Table 5), respectively. The Box-Tidwell test indicated that the assumption of linearity held for both continuous predictors included in the model (i.e., "Years in dairy" and "% clients use AB protocol"). This model presented an AIC of 50.76 and a residual standard deviation of 40.76 on 64 degrees of freedom, while the null model had an AIC of 68.78 and a residual standard deviation of 66.78 on 68 degrees of freedom. Results from the likelihood ratio test indicated that models differed significantly (p-value $< 3.13 \times 10^{-5}$) and diagnostics with ROC (area under curve [AUC] = 0.91) also suggested a good fit. No interactions nor meaningful confounding were identified.

3.3. Thematic analysis

Among the 71 study participants, 52 responded to the open-ended question about reasons why veterinarians overprescribe or inappropriately prescribe antibiotics to their dairy farmer clients. Their responses were classified into four key themes: 1) knowledge, 2) attitudes, 3) barriers, and 4) rules and regulations (Table 6). Themes "attitudes" and "barriers" were further classified into groups concerning veterinarians and farmers, while the theme "knowledge" only concerned veterinarians. The distinction between attitudes and barriers for this is as follows. Attitudes refer to overprescription or inappropriate prescription by veterinarians' colleagues based on their experiences, beliefs, interests, and traditions or those imposed by their farmer clients, whereas barriers were understood as limitations of veterinarians or farmers that were caused by a lack of appropriate tools or opportunities to reduce/avoid injudicious antibiotic prescription. Finally, the rules and regulations theme included veterinarian's perception of limitations in the way proper antibiotic use is enforced or overseen by responsible organizations. Participants were not provided with a definition of "inappropriate" antibiotic use, so their responses reflected their own understanding of this concept.

Approximately one in every three participants mentioned lack of knowledge to explain veterinarian's overprescription of antibiotics. According to the participants, there were different reasons why insufficient knowledge was relevant, with the most mentioned reason being the lack of understanding about the way in which particular antibiotics work (i.e., duration, dose). Other common reasons were insufficient knowledge about the appropriate antibiotic treatment, lack of education about pathologies in dairy cattle (e.g., mastitis), and poor understanding of diagnostics. Less commonly mentioned motives were insufficient knowledge about alternative treatments or unawareness of the issue of antibiotic resistance emergence. Nonetheless, most participants provided a much more general answer by only stating that lack of knowledge was the main reason for antibiotic overprescription, without providing specific reasons.

In most responses, veterinarians described their colleagues' attitudes towards prescribing antibiotics. Reported motives that contributed to the overprescription of antibiotics included: profit (mentioned by approximately one in every six participants) and bad habit or tradition (mentioned by approximately one in every three participants), as well as less commonly mentioned: lack of concern, easiness on the veterinarian to continue their current practices, and fear of conflict with farmer or losing business. Among farmer attitudes, participants also indicated that antibiotic overprescription might result from increased pressure on veterinarians to comply with their client's demands (mentioned by approximately one in every five participants) and several participants mentioned farmers' unwillingness to change their own incorrect beliefs about the proper use of antibiotics.

Veterinarians' barriers were mentioned by several participants and they included problems with diagnosis and availability of diagnostic tests, and lack of time. Similarly, only a few mentioned farmers' barriers, which were related with the lack of infection prevention or good environmental conditions. Finally, a few participants expressed concern about the lack of oversight and regulation of antibiotic use.

4. Discussion

Elucidating whether and how veterinarians' antibiotic prescribing practices need to improve and whether veterinarians are concerned about antibiotic resistance emergence is a crucial step for developing solutions to these challenges. Furthermore, understanding the reasons behind veterinarians' and farmers' attitudes and behaviors towards antibiotic use helps to put these practices into context, which is important to consider when planning and implementing strategies to reduce antibiotic use. Veterinarians' knowledge, behavior, and attitudes regarding antibiotic use greatly influences those of their farmer clients (Sawant et al., 2005; Jones et al., 2015; McDougall et al., 2017). For example, veterinarians are frequently tasked with developing antibiotic use protocols to reduce their clients' antibiotic use. In fact, a little more than half of veterinarians participating in this study assisted their clients with developing antibiotic use protocols. Similarly, a study by Habing et al. (2016) found that close to 43 % (176/419) of surveyed dairy farmers from Ohio and Michigan, US, had written protocols to treat cattle against common pathologies in dairy provided to them by veterinarians. Contrary to that, a study assessing a similar question among veterinarians from Ohio State, reported that only 23 % of veterinarians (10/43) always assisted farmers with antibiotic protocols (Cattaneo et al., 2009). The difference in findings between Cattaneo et al. (2009) and our study may be due to the question wording. In Cattaneo et al. (2009), the question asked if veterinarians supply their clients with antibiotic use protocols 100 % of the time. Thus, the participants' negative response to that question might have meant that they did assist their clients, just not 100 % of the times. Another potential explanation for the higher proportion in our study may be a trend for veterinarians to become more involved in the antibiotic use protocol development in recent years. Associated with this, we found that dairy veterinarians who assist their farmers in developing antibiotic use protocols are less likely to be concerned about antibiotic resistance emergence on their clients' dairy farms. This finding could be a consequence of veterinarians' confidence that their clients' will follow their instructions in antibiotic use, therefore limiting opportunities for antibiotic resistance emergence.

Participants perceived that nearly half of their clients use antibiotics injudiciously, and that nearly half of their colleagues overprescribe/

Table 6
Themes identified in responses given by veterinarians to the question "Why do you think … veterinarians [you know] overprescribe or inappropriately prescribe antibiotics to their clients?" (52 participants provided responses for analysis).

Theme	Category	Subtheme	Country, experience[a]	Participant's ID	Quote
Knowledge	Veterinarians	Lack of knowledge	United States, 6 years	45	"They [veterinarians] do not think it is causing a problem and are unwilling to do what needs to be done to change it. In many cases, I see veterinarians that are not even aware or involved in how drugs are actually used on a day-to-day basis. Taking a stand would necessitate becoming more integrally involved in day-to-day operations and actually training on diagnosis and prognosis"
			China, 3 years	15	"In China, each dairy [farm] has its own vets, who are normally not well-educated and don't have enough knowledge to understand how to scientifically use antibiotics"
			Germany, 18 years	40	"Lack of knowledge: duration, dose, alternative treatment protocols"
Attitudes	Veterinarians	Profit motive	Ireland, 3 years	27	"In one case, fluoroquinolones were prescribed repeatedly as they are more profitable"
			Germany, 20 years	18	"The fact that Ab [antibiotics] are responsible for a considerable part of the income"
			Portugal, 15 years	24	"Market pressure on veterinarians"
		Bad habit/tradition	United States, 6 years	45	"They [veterinarians] do not think [overprescription of antibiotics] is causing a problem and are unwilling to do what needs to be done to change it"
			United States, 1 year	25	"Old school mentality of treating animals"
		Lack of concern	Italy, 35 years	1	"Lack of sensibility to the problem (AMR) [antibiotic resistance]"
			Italy, 4 years	33	"[Veterinarians] are not interested in preventing in the right way the disease"
		Easier on the veterinarian	Italy, 7 years	8	"They just follow the *needs* of the farm"
			Italy, 15 years	20	"Because the use of lot of antibiotics in a therapy procedure helps the vet mental peace and keeps the farmer quiet"
		Fear of conflict/losing business	Uruguay 10 years	22	"Farmers want to use atb [antibiotics], so they [veterinarians] prefer to not *fight*"[b]
	Farmers	Unwillingness to change/ habit and autonomy	Germany, 20 years	18	"There are certain habits that are very difficult to change (both vets and farmers)"[c]
			Australia, 12 years	35	"It's more because the client refuses to change their treatment practices"
		Pressure on veterinarians to meet client's demands	France, 5 years	6	"The producer did not perceive a clinical result, so they [veterinarians] have to make longer treatments or provide bigger doses"
Barriers	Veterinarians	Problems with diagnosis and availability of diagnostic tests	Ireland, 26 years	2	"Limitations in diagnostics"
		Lack of time	Finland, 8 years	66	"Lack of time and knowledge of the current protocols and needs for antimicrobials. No knowledge nor time for appropriate consulting"[d]
	Farmers	Lack of infection prevention/ good environmental conditions	Italy, 8 years	32	"Lack of prevention resources"
			Germany, 21 years	23	"Lack of appropriate environmental conditions, farmer is not willing to change that (or able)"
Rules and regulations		Lack of regulations/oversight	Portugal, 15 years	24	"Absence of mandatory regulation and supervision by local authorities"
			United States, 47 years	49	"Not enough oversight"

[a] Years of clinical experience working with dairy cattle.
[b] Considered as both the "Easier on the veterinarian" and "Fear of conflict/losing business" subthemes.
[c] Considered as both the farmers' and veterinarians' attitudes.
[d] Considered in both the "Knowledge" and "Attitude" themes.

inappropriately prescribe antibiotics (Table 2; Fig. 1B, D). Overprescribing of antibiotics by veterinarians may be the result of the pressure being exerted by their clients, as participants expressed being pressured to prescribe an antibiotic when they deemed it unnecessary a median of 9 times during the past year (Table 2, Fig. 1E). These results are similar to those in other studies, indicating that veterinarians might feel the need to comply with the request of their clients to avoid deteriorating their business relationship (McIntosh et al., 2009; Speksnijder et al., 2015b; Coyne et al., 2016). However, research has shown that more experienced veterinarians might be less concerned about the consequences of declining their clients' requests for an antibiotic prescription (Speksnijder et al., 2015b).

Veterinarians in this study believed that there is room for improvement of antibiotic use in several clinical domains. Among treatment areas, veterinarians pointed out clinical mastitis as well as diarrhea and digestive problems in calves as their primary targets for optimization of antibiotic use. These findings are consistent with a previous study assessing veterinarians' perceptions in Ohio, US (Cattaneo et al., 2009), antibiotic use information published by the USDA (2008) and Walker et al. (2012), and even perceptions of dairy farmers (Wemette et al., 2020). Consequently, it is more than likely that the importance of mastitis, diarrhea and digestive problems for dairy cattle production is a major factor influencing the perceptions of veterinarians regarding clinical treatment areas for antibiotic use improvement. Despite the widespread use of antibiotics to treat mastitis in dairy cattle, there is no compelling evidence that antibiotic resistance is currently emerging in mastitis-associated pathogens in dairy cattle (Oliver et al., 2011). Nonetheless, a judicious use of antibiotics by veterinarians in the treatment of clinical mastitis could assist in reducing the risk of antibiotic residues in milk (and the associated fines for farmers) and reduce

the cost of mastitis treatment.

Veterinarians' perceptions about their clients' behavior can provide valuable insight into barriers that prevent dairy farmers from reducing antibiotic use. Veterinarians are in an excellent position to identify barriers and attitudes of their clients in regards to antibiotic treatment and can provide valuable information that might not be obtained by surveying farmers. In our study, veterinarians expressed the belief that their clients are lacking in knowledge about the proper use of antibiotics and awareness regarding strategies for antibiotic use reduction, supporting the possibility that antibiotic use by farmers should be further optimized. Additionally, nearly half of veterinarians indicated that deficient environmental conditions and poor herd management prevented farmers from reducing their antibiotic use (Fig. 4). These perceptions could be related to the understanding that dairy farm environments can host opportunistic and pathogenic bacteria that can be transmitted through contaminated milk equipment and pens, particularly when established hygiene practices are precarious or insufficient (Munoz et al., 2007). Meanwhile, inappropriate herd management practices might increase dairy cattle susceptibility to bacterial infections and disease (Vasseur et al., 2010). In this sense, veterinarians believe that improving key elements involved in dairy farm herd and environmental management, such as farm infrastructure, cleaning of equipment and sheds, vaccination and feeding protocols, and animal care, could contribute to minimizing the need for antibiotic treatment through disease prevention (Fig. 4). This finding matches those reported by other veterinarians working in agricultural settings (Coyne et al., 2016).

We found that veterinarians with fewer years in clinical practice were more concerned about antibiotic resistant infections on the dairy farms they serve. These findings are consistent with studies conducted both in the Netherlands (Speksnijder et al., 2015b) and US (Cattaneo et al., 2009). Increased concern about antibiotic resistance among veterinarians with fewer years of experience could be a consequence of their training and education or the continuous increase in information regarding the adequate use of antibiotics made available by governmental and non-governmental institutions to communicate this issue to human and animal health professional students (Minen et al., 2010; Gordoncillo et al., 2011; World Health Organization (WHO, 2017). The finding that longer serving veterinarians are less concerned about antibiotic resistance emergence in dairy farming is worrisome because they are likely less willing to change their already adopted behaviors and attitudes regarding antibiotic use. For example, others have reported that changing veterinarians' behavior is challenging when veterinarians are unaware of the consequences of overusing antibiotics, they feel no responsibility for contributing to the antibiotic resistance issue, show no interest in improving their practices, or their practices have become routine (Speksnijder and Wagenaar, 2018).

Additionally, more recently trained veterinarians might be more receptive to new ideas and regulations regarding judicious antibiotic use. Research in the United Kingdom has shown that health students, including veterinarians, recognize antibiotic resistance as a matter of upmost importance for their future (Castro-Sánchez et al., 2016; Dyar et al., 2018). Veterinary students from Australian universities were knowledgeable about antibiotic resistance and how to properly combat it (Hardefeldt et al., 2018a). There is still a perceived need for improvement as 61 % (38/62) of veterinarians working in a veterinary teaching hospital in the US perceived that students are not receiving appropriate education about the rational use of antibiotics, or that the amount of training is too little or moderate (Ekakoro and Okafor, 2019). However, the scenario could be different for developing countries, as a survey in Nigeria found that more than a half of the surveyed students showed lower than average knowledge scores in this matter, indicating an urgent need for improved training of veterinarians on antibiotic use (Odetokun et al., 2019). As veterinarians have a fundamental role in preventing antibiotic resistance development in animals, it is important for veterinary students to be educated in the responsible use of antibiotics and for them to receive training on how to properly advise their clients' and deal with potential conflicts regarding antibiotic use that veterinarians might come across during their clinical practice.

Interestingly, veterinarians worried about the risk of antibiotic resistance emergence on dairy farms they serve believed that better adherence to drug labeling was important for reducing farmers' antibiotic use; though this variable ("Importance- drug packing/labelling") displayed a wide confidence interval (95 % CI: 1.21–38.93), indicating the uncertainty of how relevant this measure really is for veterinarians. Although not directly related to our findings, a study by Cattaneo et al. (2009) on dairy veterinarians from the US indicates that hand-outs with good management practices, diagnosis descriptions, and appropriate dosages are effective ways to assist farmers in improving their knowledge of antibiotic resistance (Cattaneo et al., 2009). It is important to consider that the study by Cattaneo et al. (2009) represents the beliefs and opinions of veterinarians from a decade ago, something that may be outdated given the rapidly growing attention that antibiotic resistance and antibiotic use are receiving and how the legislations have changed in the US. Further research is necessary to determine if education of farmers on good management practices and antibiotic use would improve their compliance with instructions in drug labels.

When asked about the possible reasons why their colleagues might overprescribe or inappropriately prescribe antibiotics in dairy farms, veterinarians provided answers that were grouped into themes associated with veterinarians' and farmers' attitudes. In addition, they mentioned barriers and lack of regulation and oversight regarding antibiotic prescription in dairy farms (Table 6). Limitations in knowledge about antibiotic treatment, pathologies in dairy cattle, diagnostics, alternative treatments, and the consequences of antibiotic misuse were pointed out as important factors preventing judicious antibiotic use by veterinarians. This is of no surprise, as insufficient knowledge regarding the use of antibiotics is considered one of the main drivers of antibiotic resistance and can have an effect in how antibiotics are prescribed (e.g., preference for prescription of broad-spectrum antibiotics) (Lee et al., 2013, 2015). Logically, understanding antibiotic pharmacokinetics, pharmacodynamics, toxicity, alternative treatments, and the circumstances in which they are required is essential for antibiotic use reduction in veterinary practice. Furthermore, New Zealand dairy veterinarians indicated the main source of information they took into account when prescribing antibiotics for mastitis or dry off treatment was their own veterinary training (McDougall et al., 2017). This highlights what should be the obvious that knowledge is crucial for decision making in antibiotic use. Similarly, knowledge about availability and suitability of diagnostic methods is also a major factor for veterinarians in identifying pathogenic agents and applying an adequate antibiotic treatment for a particular disease.

Veterinarians' time limitations and farmers' lack of interest in improving behaviors were also factors considered relevant by participating veterinarians. This corroborates previous findings (Friedman et al., 2007), where authors noted that lack of time dedicated to seeking out information from veterinarians was a contributing factor driving farmers' to inappropriately use antibiotics. In other study, veterinarians have experienced resistance from their clients in regards to responsible antibiotic practices (Higgins et al., 2017). The combined effects of veterinarians' reluctance or inability to dedicate time to advise their farmers and farmers' interest in receiving such advice might be leading to ineffective communication between veterinarians and their clients. In addition, convincing farmers about the importance of antibiotic use reduction in dairy farms might be a time-consuming activity for veterinarians, even more in cases where farmers are stiff defenders of their own incorrect beliefs.

Opinions regarding the influence of profit in veterinarians' antibiotic prescription behavior are conflicting, with some reports indicating it as a relevant factor (World Health Organization (WHO, 2001; Grave and Wegener, 2006), while most recent evidence support the opposite (De Briyne et al., 2013; Coyne et al., 2014, 2016). Veterinarians are an

important source of antibiotics for farmers and therefore have an ethical responsibility to appropriately prescribe these drugs to their clients and advise them on their correct administration. Opportunity to make a profit from antibiotic sale could therefore create a conflict of interest and a potential for overuse or overprescription of antibiotics (as also suggested by our results in Table 6). Whether or not this was the case among veterinarians in our study could not be determined since our study was not designed to compare the income from antibiotics sale and the actual antibiotic use by a veterinarian.

Participants expressed that their clients exerted pressure on them to prescribe antibiotics when deemed unnecessary. Farmers often expect veterinarians to include antibiotics in the treatment given to their animals, a factor that has been frequently mentioned to influence veterinarians to take the inappropriate decision to overprescribe antibiotics (McIntosh et al., 2009; Speksnijder et al., 2015a, 2015b; Higgins et al., 2017; Hardefeldt et al., 2018b). Indeed, dairy veterinarians from the Netherlands have expressed the importance of satisfying their clients in maintaining their business and that actions to dissuade farmers from inappropriately using antibiotics could be detrimental in this regard (Speksnijder et al., 2015b). Additionally, veterinarians also believe that some farmers display a lack of interest in changing their beliefs about antibiotic use, which might create a situation in which veterinarians' and farmers' views do not align, thus leading veterinarians to feel the need to meet clients' expectations. In these cases, it is much easier for the veterinarians to prevent conflict with their clients and avoid the risk of losing their business.

Some veterinarians also perceived that there are missed opportunities for antibiotic use reduction due to limitations in availability and training for current diagnostic techniques (Table 6). Although this perception is shared by small animal veterinarians (King et al., 2018), the existence of such barrier in the context of large animal medicine needs to be further addressed in future studies. Moreover, farmers' lack of adoption of preventive measures to reduce the occurrence of disease and poor environmental conditions in dairy farms were identified as important factors leading to overprescription of antibiotics by veterinarians. The reason for lack of adoption of such preventative measures could be related to farmers' budget constraints. Non-dairy farm animal veterinarians from the Netherlands have agreed that economic considerations are a major factor in adopting preventive measures to reduce disease occurrence in livestock animals (Speksnijder et al., 2015a). In this study, veterinarians indicated certain situations in which farmers might be unwilling to reduce antibiotic use through investment in alternative preventive measures (i.e., vaccination), therefore forcing veterinarians to increase antibiotic prescription in order to control disease outbreaks on farms.

Participants from the US and EU also mentioned the absence of mandatory regulations and oversight by local authorities as a relevant factor contributing to the overprescribing of antibiotics (Table 6). This is somewhat surprising considering that the majority of participants were from the US and EU where more strict regulations have recently taken place. The EU member countries, for instance, have strict regulations to eliminate the use of antibiotics for prevention and restrict their metaphylactic application (Europe Commission (EC, 2018a; 2018b). This also suggests that there is still room for tighter regulatory framework.

In summary, veterinarians participating in this study believed that injudicious antibiotic prescription is a prevalent behavior among their colleagues, with many reasons being centered around veterinarian-client interactions, as revealed by the thematic analysis. This study did not assess the thought process behind veterinarians' judgement about their colleagues (i.e., what factors contributed to their perceptions of overprescribing behavior), something that would be interesting to know to better understand what veterinarians deem as "injudicious". These findings also highlight the need for actions to improve antibiotic prescription practices by dairy cattle veterinarians, which can be achieved through strategic educational efforts. For instance, opportunities for continuing education should be provided for veterinarians working in dairy cattle clinics, especially for problematic treatment areas, such as mastitis and diarrhea and digestive problems in cows and calves, respectively. In addition, veterinary students should receive training in communication strategies to effectively discuss antibiotic use. Although some countries provide training to veterinary students aimed to improve communication skills (Castro-Sánchez et al., 2016; Ritter et al., 2018), this is not the rule for most countries, even in the developed world (Cipolla and Zecconi, 2015). Most notably, continuous educational programs focused in improving veterinarians' communication with their dairy clients are almost non-existent (Moore et al., 2016). These programs could not only provide a mechanism for improvement of communication skills in previously untrained veterinarians, but also serve as a review and/or update for those who received this kind of instruction before (Cipolla and Zecconi, 2015). Better communication between veterinarians and farmers could also serve to improve dairy farmers' antibiotic use and promote certain attitudes that might factor into veterinarians' decision-making on antibiotic treatment (i.e., pressure to prescribe antibiotics). It is important for veterinarians and farmers to share a similar idea about antibiotic use practices to better prevent antibiotic resistance emergence in dairy farms and achieve the appropriate antibiotic treatment (Reyher et al., 2017).

4.1. Study limitations

It is important to consider that the number of participants included in this study was limited to veterinarians that are active members of the NMC and those attending the International Bovine Mastitis Conference in Milano, Italy, 2018. Therefore, it is possible that bias was introduced by selecting a non-random sample of veterinarians. The study participants may represent a more affluent and educated subgroup of veterinarians, given their interest in continuing education through the conference and their ability to travel to Italy. Also, the study population had an overrepresentation of dairy veterinarians from Italy. Selection bias might have been further compounded through the relatively low response rate. The direction in which the selection bias could have influenced the results is difficult to predict. However, considering the participation by veterinarians from 21 countries with a wide range of years of experience and who served diverse dairy farms, the study is expected to provide useful information about dairy veterinarians, particularly in countries/regions with the largest representation (the US, Italy, and the EU as a whole). The study relied on participants' self-reporting of practices and perceptions, which could have introduced information bias if participants under or over-reported certain perceptions, due to social desirability bias. However, we do not expect that self-reporting would have systematically affected some groups of participants more than others (e.g., those who are concerned about the emergence of antibiotic resistance and believe that better labeling of drugs is important to reduce antibiotic use). Therefore, if present, the information bias would be expected to be non-differential and so would underestimate the strengths of associations. Participants were not provided with a definition of "overprescription" during the survey, meaning that their answers include their own understanding of this concept. For instance, some veterinarians might understand "overprescription" as prescribing larger doses than those indicated on the drug label, prescription of antibiotics when infection may not be bacterial, unnecessary prolongation of antibiotic treatment, and/or antibiotic prescription based entirely on farmers' demand. As this term might be understood differently by different people, we strongly believe that reaching a consensus on the definition of the term would assist in addressing the issue of antibiotic resistance in the context of large animal medicine. Confounding bias was controlled through multivariable modeling, however, potential confounding from unmeasured variables could not be controlled. One such unmeasured variable was the participant's gender, which unfortunately was not inquired about in the questionnaire. There was no evidence of participants from the US and EU being different with respect to the concern for the emergence of antibiotic

resistance on their clients' farms (the outcome of interest in logistic regression). Having said that, we acknowledge that grouping participants from the EU countries into a single category in this study may have oversimplified the diversity among the EU member countries and this diversity should be subject of future research. Interestingly, further comparison of the US and EU participants indicated that the US participants had an overrepresentation of senior veterinarians and veterinarians serving larger dairy farms compared to their EU counterparts (Supplementary Material, Tables S1 and S2). These discrepancies may be at least partly explained by how unattainable attendance to a conference in Italy may be for a junior US veterinarian and the generally larger dairy farms in the US than in the EU (United States Department of Agriculture (USDA, 2014; European Parliament (EUP, 2018). While seemingly they had no effect on the participants' concern about antibiotic resistance on their clients' farms, these characteristics of the study group need to be considered when generalizing results.

5. Conclusions

This study attempts to fill a gap in the understanding of perceptions of an international group of dairy veterinarians regarding antibiotic use and resistance. The participating veterinarians perceived that overprescription and inappropriate prescription of antibiotics occur in dairy farming, which is of great concern considering the potential implications for emergence of antibiotic resistance on dairy farms. Treatment of clinical mastitis in cows and diarrhea and digestive problems in calves were perceived as areas needing most improvement in terms of antibiotic use by farmers. Additionally, dairy veterinarians with more years in practice were more likely to be unconcerned about the issue of antibiotic resistance emergence, and therefore age-focused initiatives might be an adequate way to improve knowledge about this concept in the veterinary medicine. This study also supports that improving the knowledge about antibiotic use among veterinarians would be a potential way to reduce or optimize antibiotic use in farm animals. Meanwhile, farmers appear to be an important source of pressure for veterinarians, driving them to prescribe antibiotics when deemed unnecessary. It is therefore important to provide appropriate training for veterinarians in how to deal with this kind of situations. It is expected that findings reported here will provide the baseline for future research in this matter and aid in the development of strategies to optimize antibiotic use in dairy farming. Information contained here may be useful in preparing educational initiatives for farmers and veterinarians about the appropriate and responsible use of antibiotics.

Author's roles

M.W., R.I., A.G.S., P.M., and M.S. designed the study and developed the questionnaire survey. M.W. administrated the survey. N.V. and M.W. conducted data cleaning and preliminary analysis and interpretation of results. Statistical analysis and drafting of the manuscript were conducted by S.L.-S. under supervision of R.I. Thematic analysis was conducted by S.L.-S. under supervision of A.G.S.; M.W. assisted with interpretation of findings of thematic analysis. All authors contributed to interpretation of results and final manuscript revisions.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.prevetmed.2020.105253.

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