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Antimicrobial use practices, attitudes and responsibilities in UK farm animal veterinary surgeons

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ABSTRACT

Increasing levels of antimicrobial resistance in human and veterinary medicine have raised concerns around the issue of overprescribing and the indiscriminate use of antimicrobials. Their use in food producing animals is under scrutiny due to the perceived risk from the zoonotic transfer of resistant pathogens from animals to humans. This study aimed to explore UK veterinary surgeons antimicrobial prescribing behaviours, their attitudes to antimicrobial resistance and their perceptions of responsibility of antimicrobial use in pigs through a questionnaire study on a census sample of 261 veterinary surgeons in England, Wales and Scotland who had a clinical caseload which included commercial pigs. The questionnaire had a useable response rate of 34.1% (n = 61/179) in eligible veterinary surgeons.

Overall, veterinary surgeons reported personal confidence that their prescribing decisions were responsible however, there was concern that the prescribing behaviours of other veterinary surgeons and physicians in human medicine may be less responsible; a sociological concept known as 'othering'. In parallel, veterinary surgeons seldom identified that treatment failure was a consequence of antimicrobial resistance in their own clinical caseload, however they considered it an issue for other veterinary surgeons and for human prescribers. Veterinary surgeons consulted a wide spectrum of resources on antimicrobial use in pigs which, on occasion, contained conflicting guidance on what was defined as responsible prescribing. The decision over whether or not to prescribe an antimicrobial was influenced by numerous factors relating to the veterinary surgeons' experience and the clinical situation presented, but maintaining pig welfare was a high priority. There was a shared desire to seek alternative methods to prevent disease to antimicrobial use, however the use of diagnostics to support prescribing decisions was an infrequently reported behaviour and could play a more significant role in prescriber decisions if more cost effective and rapid tests were available.

Future interventions to optimise antimicrobial use in pigs needs to focus on the evolution of antimicrobial use practices in a changing political and scientific landscape whilst also considering individual motivations and justifications for use.

1. Introduction

The emergence of resistant bacteria in human and veterinary medicine has highlighted the need to ensure that antimicrobial use is minimal and prudent (Burow et al., 2014; Peeters et al., 2015; Tang et al., 2017). Whilst it is not possible to quantify the risk to human health, from antimicrobial use in livestock, there is growing concern over the potential public health risks (O'Neill, 2016; Tang et al., 2017; Aidara-Kane et al., 2018). Antimicrobial use characteristics in the pig sector, such as the comparatively high sales of products, the administration of in-feed antimicrobials (European Medicines Agency, 2017; VMD, 2017) and frequent prophylactic use (Callens et al., 2012), have highlighted pigs as a priority species for gaining understanding of antimicrobial use behaviours and seeking ways in which use can be reduced (Postma and Stärk, 2015; Visschers et al., 2015, 2016). Consequently, there is increased political pressure for policy measures to

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reduce antimicrobial use in pigs (O'Neill, 2016; RUMA, 2017), as well as other livestock species.

Guidelines on the use of antimicrobials in pigs have been produced by both the Pig Veterinary Society (PVS) and Responsible Use of Medicines in Agriculture Alliance (RUMA), to promote prudent prescribing practices and advise on alternative methods to treat and prevent disease (RUMA, 2013; PVS, 2014). However, at present there are currently no guidelines available in the UK which advise on appropriate antimicrobial choices for different disease conditions in pigs. For example, the PVS guidelines recommend that the use of antimicrobials classified as critically important to human health are only used if other antimicrobial classes are not available or effective. These guidelines follow the European Medicines Agency antimicrobial expert group (AMEG) definition of critically important antimicrobials and include the fluoroquinolones, third and fourth generation cephalosporins and colistin (PVS, 2014; NOAH, 2016). At the time of dissemination of the questionnaire the authors adopted the current World Health Organisation's (WHO)definition of highest priority critically important antimicrobials (HP-CIAs) from the fourth edition of the 'Critically Important Antimicrobials for Human Medicine' which included the fluoroquinolones, third and fourth generation cephalosorins and the macrolide antimicrobials. However, it did not include colistin (WHO, 2013).

Clinical factors such as the pharmacological characteristics of antimicrobials, antimicrobial susceptibility testing (AST) results, clinical disease signs and predicted outcomes have been found to motivate antimicrobial use decisions in both human (Coenen et al., 2002; Teixeira Rodrigues et al., 2013) and veterinary medicine (Busani et al., 2004; Speksnijder et al., 2015a; Coyne et al., 2016). Non-clinical factors also influence antimicrobial use decisions in both humans and animals such as a practitioners' perception of responsible prescribing behaviours, fear of clinical signs worsening should antimicrobials not be prescribed, professional stress and client compliance (Busani et al., 2004; Gibbons et al., 2013; Teixeira Rodrigues et al., 2013; Coyne et al., 2016). Studies have attempted to quantify antimicrobial use and investigate the influences behind antimicrobial use practices in food producing animal species (Dunlop et al., 1998; Busani et al., 2004; Stevens et al., 2007; Gibbons et al., 2013; Visschers et al., 2015, 2016), however there has been little research investigating prescribing practices in the UK pig industry. The aim of this study was to determine the behavioural influences and attitudes surrounding antimicrobial use practices and responsibility in veterinary surgeons working with pigs in the UK using a questionnaire survey.

2. Materials and methods

2.1. Questionnaire

The questionnaire design was guided by results from qualitative interviews and focus groups with veterinary surgeons working in UK pig practice (Coyne et al., 2014, 2016). The questionnaire was created using the Adobe FormsCentral (Adobe Systems Incorporated, USA) software and was available as both an electronic and paper format. The questionnaire consisted of closed questions, 5 point likert scale statements and open questions exploring antimicrobial prescribing behaviours, perceptions on antimicrobial resistance and participant perceptions of what antimicrobial use behaviours are considered to be responsible.

The questionnaire also included three common clinical disease scenarios encountered in commercial pig veterinary practice. Questions assessed the likelihood of respondents prescribing antimicrobials using a 5-point likert scale and requested the first and second antimicrobial choices using an open question for each scenario. An open question was used to ensure that respondents volunteered antimicrobial choices. Any antimicrobial products reported by the trade name were reported in the results as the appropriate antimicrobial active ingredient class.

Scenario one described *Escherichia coli. (E. coli)* scour in piglets on a 150 sow farrow-to-finish indoor slatted unit. The pathogen (*E. coli)* was chosen for the scenario as it has been identified as a significant cause of diarrhoea in neonatal piglets and is associated with significant morbidity within affected herds (Luppi, 2017). Widespread resistance to *E. coli* isolates have been identified across the UK including resistance to spectinomycin, tetracyclines and trimethoprim sulphonamide antimicrobials (VMD, 2015).

Scenario two described the observation of clinical signs of respiratory disease in finishers on an indoor slatted unit. Respiratory disease is a common driver for the use of antimicrobials in finishing pigs (Stevens et al., 2007) and many outbreaks are identified as disease syndromes commonly consisting of mixed viral and bacterial pathogens (Holko et al., 2004; Haimi-Hakala et al., 2017).

Scenario three described neurological signs and meningitis associated with *Streptococcus suis (S.suis)* in weaners on an indoor slatted unit. *S. suis* is a common cause of meningitis, septicaemia and sudden death in pigs and is widespread in much of the UK pig herd (Jackson and Cockcroft, 2007; Goyette-Desjardins et al., 2014). Widespread antimicrobial resistance has been observed in the *S. suis* pig isolates identified at UK government laboratories in 2014; high levels of resistance were observed to tetracyclines, lincomycin, tylosin and trimethoprim/sulphonamide. However, all of these isolates were found to be sensitive to penicillins (VMD, 2015).

The questionnaire content referred to the fourth revision of the WHO 'Critically Important Antimicrobials for Human Medicine' conducted in 2014 (WHO, 2013) which defined the fluoroquinolones, third and fourth generation cephalosporins and macrolide antimicrobial classes as HP-CIAs. However, it is worth noting that in the 2017 fifth revision of these guidelines that the polymixin class, which includes colistin, was added to the list of HP-CIA classes (WHO, 2017). In addition to the HP-CIAs colistin use was specifically assessed in the questionnaire content due to its reported frequent use in pigs (Timmerman et al., 2006; Callens et al., 2012), its increasing importance in human medicine as an antimicrobial of last resort and the concerns of the European Medicines Agency (EMA) who undertook a review on colistin use in animals in 2013 (EMA, 2013).

The questionnaire was piloted on veterinary surgeons working within the farm animal practice at the University of Liverpool. Ethical approval was granted for the study from the University of Liverpool Veterinary Science Research Ethics Committee and the Department for the Environment Food and Rural Affairs (Defra) prior to the piloting of the questionnaire.

The target population was all veterinary surgeons who conducted commercial pig veterinary work in England, Wales and Scotland. All veterinary practices on the Royal College of Veterinary Surgeons (RCVS) veterinary practice database (RCVS, 2014) which indicated they undertook pig work were contacted by telephone to confirm that their caseload included some pig work and to obtain the names of veterinary surgeons who saw commercial pigs which were then entered into a database. The final sample consisted of 261 veterinary surgeons across 104 veterinary practices.

An electronic version of the questionnaire was disseminated through the PVS mailing list on the 4th September 2014 and a paper questionnaire was sent to all veterinary surgeons in the sample who had not already completed the questionnaire online on the 24th October 2014. A second copy of the questionnaire and covering letter was then sent to non-responders on the 1 st December 2014.

2.2. Statistical analysis

Data analyses were completed using Microsoft Excel 2010 (Microsoft Corporation, Redmond, Washington, USA) and SPSS Statistics 22.0 (IBM SPSS Statistics for Windows Version 22.0. Armonk, NY: IBM Corp). Descriptive statistics including percentages for the response categories and likert scale questions were produced for each

section of the questionnaire. Where numbers in outlying likert scale categories were small, 5 point scale question categories were combined to produce a 3 point scale response. For example, never, rarely, sometimes, often, always condensed to give the following categories; never or rarely, sometimes, often or always. Chi-squared or Fishers Exact tests (fewer than 5 expected responses in one or more categories) were used to determine significant differences in responses between specialist pig practitioners (100% pig caseload) or mixed species veterinary surgeons; P values < 0.05 were deemed significant.

3. Results

3.1. Demographic information on respondent veterinary surgeons

In total 148 (56.7%) of 261 questionnaires were returned and, of these, 61 were completed (7 electronically; 54 postal). The 87 non-useable responses included being incomplete (n = 2), in which the respondent only completed the background information on themselves and their practice and did not respond to any questions about antimicrobial use, the veterinary surgeon reporting that they no longer had a sufficient pig caseload (n = 70), the veterinary surgeon no longer working at the practice (n = 12) and the respondent wishing to opt out of the study (n = 3). The useable response calculated after removing these non-eligible responses (veterinary surgeons that no longer treated pigs) was 34.1% (n = 61/179).

The clinical pig caseload of veterinary surgeons varied between respondents with 32.7% (n = 20) spending 100% of their time undertaking pig work whilst 57.5% (n = 29) of respondents spent less than 25% of their time working with pigs and the remainder between 26–99% (9.8%, n = 12). The greatest percentage of respondents were located in the Yorkshire and Humber region (23.6%, n = 17/61), the North East (11.1%, n = 8/61) and Eastern regions (11.1%, n = 8/61); reflecting the underlying population of pig veterinary surgeons in the sample database.

The majority of veterinary surgeons were male (70.5%, n = 43), 27.9% (n = 17) were female and n = 1 chose not to disclose their gender. The number of years of experience of veterinary surgeons varied although 50.0% (n = 30) had qualified over 26 years ago. Over half of the participants were senior veterinary surgeons (55.0%, n = 33), whilst 36.7% (n = 22) were assistants and 8.3% (n = 5) classified themselves as consultants specialising in pig medicine. A senior veterinary surgeon is classified by the RCVS as having a role overseeing the management of the veterinary practice or company, including having a managerial role for assistant veterinary surgeons employed (RCVS, 2012). Conversely, a consultant veterinary surgeon works independently from a veterinary practice or company giving veterinary advice on a self-employed basis. A minority of respondents (14.7%, n = 9) had completed postgraduate study relating to pig medicine, whilst 85.3% (n = 52) did not hold any relevant postgraduate qualifications. A large proportion of respondents, 74.2% (n = 46/61), were members of the PVS.

3.2. Antimicrobial prescribing decisions

The most frequently volunteered sources of information by respondents on antimicrobial use in pigs (Table 1) were the National Office of Animal Health (NOAH) compendium (64%) and pharmaceutical companies, others included the PVS and advice from colleagues. 35.1% (n = 20/57) of respondents stated that their practice currently had written prescribing guidelines for antimicrobial use in pigs.

The decision over whether or not to prescribe an antimicrobial was influenced by a number of different factors relating to the veterinary surgeons' experience and the clinical situation presented (Fig. 1). The majority of respondents identified that maintaining pig welfare, personal confidence in their diagnosis of a bacterial pathogen, advice from senior colleagues and confidence that the farm staff will use antimicrobials responsibly would be a positive driver towards the use of an antimicrobial. Mixed species veterinary surgeons more frequently held the opinion that a good relationship with the farmer ($P = < 0.001$), the farmer wanting antimicrobials ($P = 0.035$) and confidence that the farm staff would use antimicrobials responsibly ($P = 0.011$) would make them more likely to prescribe when compared with specialist pig practitioners.

Table 1
The information sources on antimicrobial use in pigs cited by UK veterinary surgeons respondents (n = 59).

	% of volunteered responses	n
NOAH Compendium	63.9	39
Pharmaceutical company	50.8	31
PVS	27.9	17
Veterinary press	26.2	16
Colleagues	23.0	14
Veterinary pig medicine textbooks	19.7	12
Academic journals	14.8	9
Internet	11.5	7
Own experience	11.5	7
VMD	9.8	6
CPD	8.2	5
RUMA guidelines	8.2	5
AASV	3.3	2
AHDB Pork	3.3	2
APHA	1.6	1
IPVS	1.6	1
Red Tractor Farm Assurance	1.6	1

NOAH Compendium –National Office of Animal Health Compendium, PVS – Pig Veterinary Society VMD – Veterinary Medicines Directorate, CPD – Continuing Professional Development, RUMA – Responsible use of Medicines in Agriculture Alliance guidelines, CPD – continuing professional development, AASV – American Association of Swine Veterinarians, AHDB Pork- UK levy board representing pig production, APHA – Animal and Plant Health Agency, IPVS – International Pig Veterinary Society.

Antimicrobial prescribing choices were explored in the respondent population through clinical disease scenarios (Table 2). There are presently no UK prescribing guidelines available which advise appropriate antimicrobial choices for different clinical disease conditions in pigs. Therefore, it was not possible to evaluate the appropriateness of prescribing decisions described in these scenarios against any guidelines. In scenario 1 (E.coli in piglets) 98% (n = 56/57) of participants were either likely or very likely to prescribe antimicrobials. Aminoglycosides were the most commonly described class of antimicrobials for use as a first line therapeutic option whilst fluoroquinolones were the most frequent second line choice. Overall, 16.7% (n = 10/60) of the first line and 42.2% (n = 19/45) second line antimicrobial choices in this scenario were categorised as HP-CIAs.

In scenario 2 (respiratory disease syndrome in finishers) around two thirds of respondents (67%, n = 36/54) were likely to prescribe antimicrobials in this scenario. Tetracyclines were the most frequent first line antimicrobial class chosen by participants whilst macrolides were the second most common. The only HP-CIA class chosen were macrolides and these represented 15% of first line (n = 5/33) and 44% of second line choices (n = 11/25).

In scenario 3 (*S. suis* in weaners) the majority of respondents (76%, n = 41/54) were likely to prescribe antimicrobials. Penicillins were the most commonly chosen antimicrobial class for both first and second line choices. The HP-CIA classes were only selected on 6.6% (n = 3/45) of occasions as a first and 10.3% (n = 3/31) as a second line option.

3.3. Antimicrobial resistance

Veterinary surgeons held contrasting opinions on the possible effects of antimicrobial use in pigs (Table 3). The majority of veterinary surgeons (67%) believed that antimicrobial use in pigs would increase

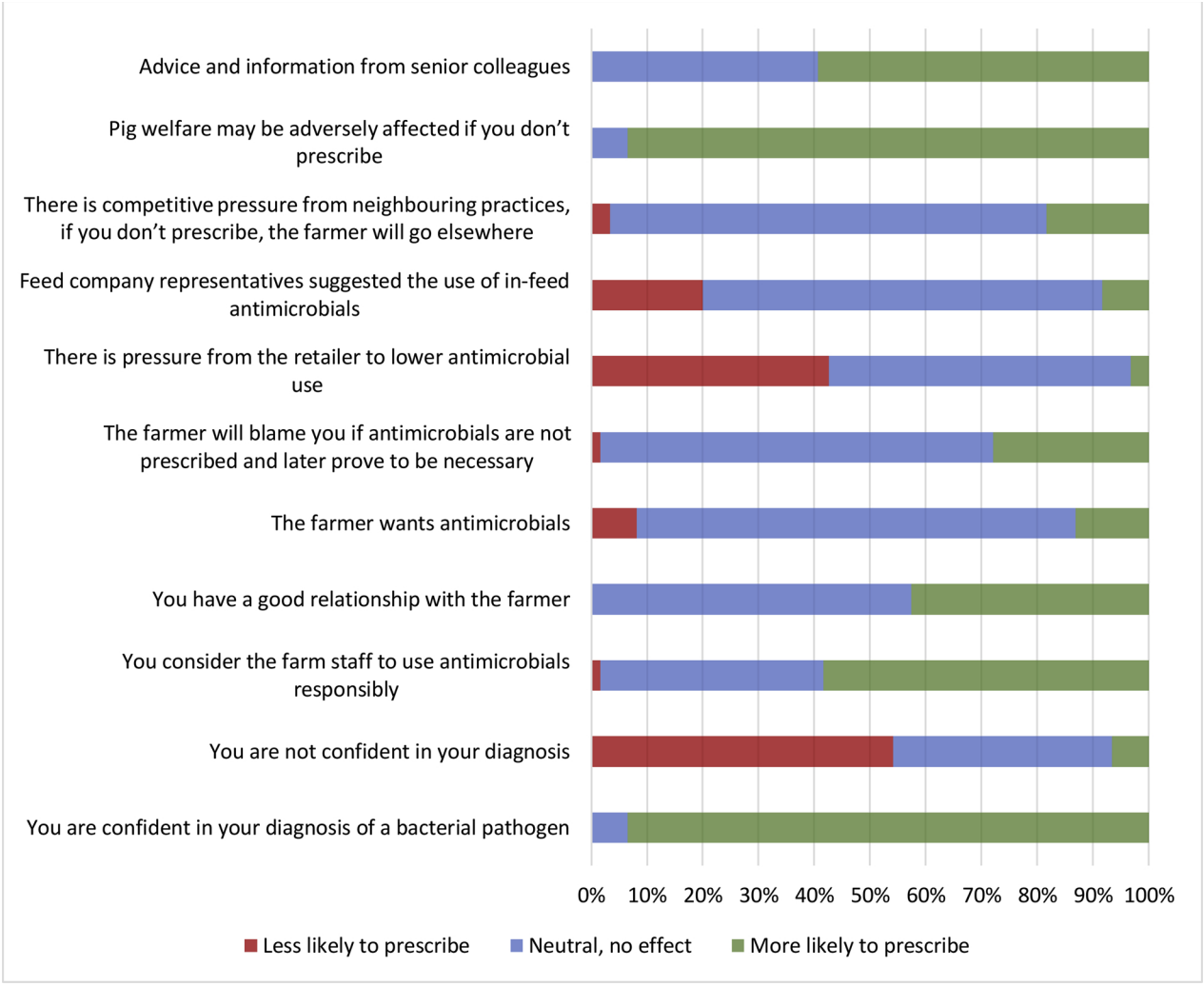

Fig. 1. UK pig veterinary surgeons opinion on factors likely to influence the decision of whether or not to prescribe an antimicrobial (n = 61).

resistance levels in pigs; however, the impact on human resistance levels divided opinion with only 45% rating it as important and 30% not considering it to be important.

Veterinary surgeons reported that AST was a more frequent behaviour following treatment failure (Fig. 2). For example, when a bacterial infection was initially suspected AST was described as being carried out frequently by under a fifth of veterinary surgeons; however, this figure doubled if it was carried out following treatment failure. Around half (51%) of respondents reported that they sometimes or often encountered a lack of response to antimicrobials. Similarly, around half of the respondents rarely or never considered that this lack of response was due to antimicrobial resistance.

3.4. Responsible antimicrobial use behaviours

The majority of veterinary surgeons felt that the use of antimicrobials for therapeutic or prophylactic reasons were either usually or always justified as being responsible (Table 3). Similarly, 87% of respondents felt that the use of in-feed antimicrobials were either usually or always justified. Despite a 2006 ban on the use of antimicrobials as growth promoters 4% felt this use was usually or always justified (Table 3). Respondents reported that the continual medication with antimicrobials from weaning until slaughter was less common in pigs under their care (15% stated sometimes or often, n = 9) compared to the UK pig industry in general (71% stated sometimes or often, n = 33).

Veterinary surgeon opinion on the use of the HP-CIAs and colistin varied. The majority of respondents perceived that the use of the macrolide class and colistin was justified whereas around half of respondents felt that the use of fluoroquinolones and third and fourth generation cephalosporins were either rarely or never justified. Specialist pig practitioners more frequently perceived that the use of the macrolide class and colistin were justified when compared with mixed species veterinary surgeons ($P = < 0.001$).

Veterinary surgeon opinion varied when comparing the responsibility of antimicrobial use in the pig sector with other veterinary sectors (Table 4). However, mixed species veterinary surgeons more frequently held the opinion that antimicrobial use in beef cattle ($P = 0.001$), dairy cattle ($P = 0.01$) and sheep ($P = 0.02$) were more responsible than in pigs when compared to specialist pig practitioners.

Veterinary surgeons rated the importance of different actors for monitoring and safeguarding the responsible use of antimicrobials in pigs (Fig. 3). All respondents considered that veterinary surgeons and farmers had an important role in ensuring that antimicrobial use was prudent, whilst the majority also believed that farm assurance schemes were important. However, opinion was divided on the role of the retailer and the UK and EU governments.

3.5. Beneficial measures and barriers to the reduction of antimicrobial use in pigs

Veterinary surgeon opinion on the potential effects of different

Table 2
UK veterinary surgeon antimicrobial prescribing decisions in 3 clinical disease scenarios.

	Scenario 1 - *E. coli* in piglets				Scenario 2 - Respiratory disease syndrome				Scenario 3 - *Streptococcus suis*			
Number of respondents that would prescribe an antimicrobial in the clinical disease scenarios												
	n		**%**		**n**		**%**		**n**		**%**	
Likely to prescribe an antimicrobial	56		98%		36		67%		41		76%	
Neutral opinion on whether an antimicrobial should be prescribed	1		2%		15		28%		6		11%	
Unlikely to prescribe an antimicrobial	0		0%		3		6%		7		13%	
Antimicrobial class choices in the clinical disease scenarios												
	1st choice		**2nd choice**		**1st choice**		**2nd choice**		**1st choice**		**2nd choice**	
	n	%	n	%	n	%	n	%	n	%	n	%
Penicillins	8	13.30%	3	6.70%	2	6.10%	7	28%	37	82.20%	15	51.70%
3rd and 4th generation cephalosporins*	1	1.70%	2	4.40%	-	-	-	-	1	2.20%	2	6.90%
Fluoroquinolones*	9	15%	16	35.60%	-	-	-	-	-	-	1	3.40%
Lincosamides	1	1.70%	1	2.20%	-	-	-	-	1	2.20%	-	-
Tetracyclines	2	3.30%	2	4.40%	25	75.80%	5	20%	-	-	2	6.90%
Trimethoprim-sulphonamides	6	10%	1	2.20%	-	-	1	4%	-	-	4	13.80%
Polymyxins**	3	5%	2	4.40%	-	-	-	-	-	-	1	3.40%
Aminoglycosides	26	43.30%	11	24.40%	-	-	-	-	-	-	-	-
Macrolides*	-	-	1	2.20%	5	15.20%	11	44%	1	2.20%	-	-
Florfenicol	-	-	-	-	1	3%	-	-	-	-	1	3.40%
Depends of diagnostic result	4	6.70%	6	13.30%	-	-	1	4%	5	11.10%	5	17.20%

[a]HP-CIA classes as defined by the fourth edition of the 'Critically Important Antimicrobials for Human Medicine' as was current at the time that the questionnaire was conducted (WHO, 2013).
[b]HP-CIA classes defined in the fifth edition of the Critically Important Antimicrobials for Human Medicine' published in 2017 which post-dates the questionnaire study.

measures on total antimicrobial use in the UK pig industry are shown in Table 5. The effects of policy measures produced mixed opinions. The majority of veterinary surgeons considered that the concept of a penalty system for high antimicrobial use farms and benchmarking antimicrobial use between pig units would be beneficial in reducing antimicrobial use in pigs. In contrast, the concept of 'decoupling' antimicrobial dispensing and prescribing, whereby the veterinary surgeon can prescribe but no longer dispense antimicrobials, was felt by the majority to have no effect on reducing antimicrobial use in pigs. However, banning in-feed premixed antimicrobials divided opinion with half of respondents considering it to be beneficial. Mixed species veterinary surgeons more frequently felt that a penalty system ($P = 0.01$) would be beneficial in reducing antimicrobial use in the UK pig herd when compared with specialist pig practitioners. Reducing imports of pig meat from high antimicrobial use countries divided opinion. However, mixed species veterinary surgeons more frequently identified this to be beneficial when compared with specialist pig practitioners ($p = 0.02$).

The perceived effect of banning HP-CIA classes also divided opinion. However, mixed species veterinary surgeons more frequently held the opinion that banning the use of fluoroquinolones and third andfourth generation cephalosporins would be beneficial in reducing antimicrobial use in pigs when compared with specialist pig practitioners ($p = 0.001$).

Over half of veterinary surgeons did not consider economic factors such as either increasing or decreasing the cost of antimicrobials for farmers would have any effect on the total amount of antimicrobials used in pigs. The impact of increasing the profitability of pig meat prices on total antimicrobial use in pigs divided opinion amongst respondents with some identifying it as a benefit whilst others identified it as having no effect or a barrier.

Overall, most respondents felt that modernising indoor pig accommodation and locating pig units in areas that are isolated from other pig farms were beneficial in minimising antimicrobial requirements. However, the consequences of increasing the use of outdoor breeding and straw-based finishing systems resulted in a spectrum of opinions amongst participants. The majority of participants considered alternative methods of preventing disease such the availability of more effective and a wider range of vaccinations, and de-populating and re-populating low health status pig herds with higher health status stock to

Table 3
UK pig veterinary surgeons' perceptions on the effects on antimicrobial resistance levels in production animals, humans and pigs from antimicrobial use in pigs and antimicrobial use behaviours that were considered to be justified and exemplify the responsible use of antimicrobials in pigs.

Veterinary surgeon perceptions on the effects on antimicrobial resistance levels in production animals, humans and pigs from the use of antimicrobials in pigs (n = 60)					
	Not important	Not very important	Neutral	Quite important	Very important
Increased antimicrobial resistance in other production animal species	3 (5%)	8 (13%)	18 (30%)	18 (30%)	13 (22%)
Reduced risk of disease transmission to human beings	6 (10%)	7 (12%)	16 (27%)	21 (35%)	10 (17%)
Increased antimicrobial resistance in human beings	5 (8%)	13 (22%)	15 (25%)	12 (20%)	15 (25%)
Increased antimicrobial resistance in pigs	3 (5%)	2 (3%)	15 (25%)	18 (30%)	22 (37%)
Antimicrobial use behaviours which were considered by veterinary surgeons to be justified and exemplify the responsible use in antimicrobials in pigs.					
	Never justified	Rarely justified	Usually justified	Always justified	Unsure
The use of the fluoroquinolones in pigs (n = 55)	1 (2%)	24 (44%)	22 (40%)	4 (7%)	4 (7%)
The use of the colistin in pigs (n = 53)	3 (6%)	9 (17%)	26 (49%)	7 (13%)	8 (15%)
The use of third and fourth generation cephalosporins in pigs (n = 56)	1 (2%)	25 (45%)	22 (39%)	4 (7%)	4 (7%)
Use of macrolides (n = 56)	0 (0%)	8 (14%)	34 (60%)	11 (20%)	3 (5%)
Antimicrobial use for therapeutic reasons (n = 58)	0 (0%)	0 (0%)	15 (36%)	42 (72%)	1 (2%)
Antimicrobial use for prophylactic reasons (n = 58)	2 (3%)	13 (22%)	36 (62%)	3 (5%)	4 (7%)
Antimicrobial use to increase growth rates or production (n = 58)	33 (57%)	20 (34%)	1 (2%)	1 (2%)	3 (5%)
The use of in-feed antimicrobials in pigs (n = 58)	0 (o%)	7 (12%)	44 (76%)	4 (7%)	3 (5%)

be beneficial in reducing overall antimicrobial use in pigs.

Farmer reluctance to change current practices was frequently identified as a barrier to reducing use; however, the majority of respondents felt that veterinary surgeons educating farmers on herd health improvements would be beneficial in reducing antimicrobial use in pigs. Mixed species practitioners identified farmer reluctance as a barrier significantly more commonly than specialist pig veterinary surgeons ($p = 0.001$).

4. Discussion

This study identified that veterinary surgeons' antimicrobial prescribing decisions were influenced by a range of factors. Factors identified such as the veterinary surgeons' confidence in their diagnosis, and a desire to avoid the negative welfare implications of disease, are also commonly described in human and veterinary medicine (Coenen et al., 2002; De Briyne et al., 2013), and are motivated by the prescribers'

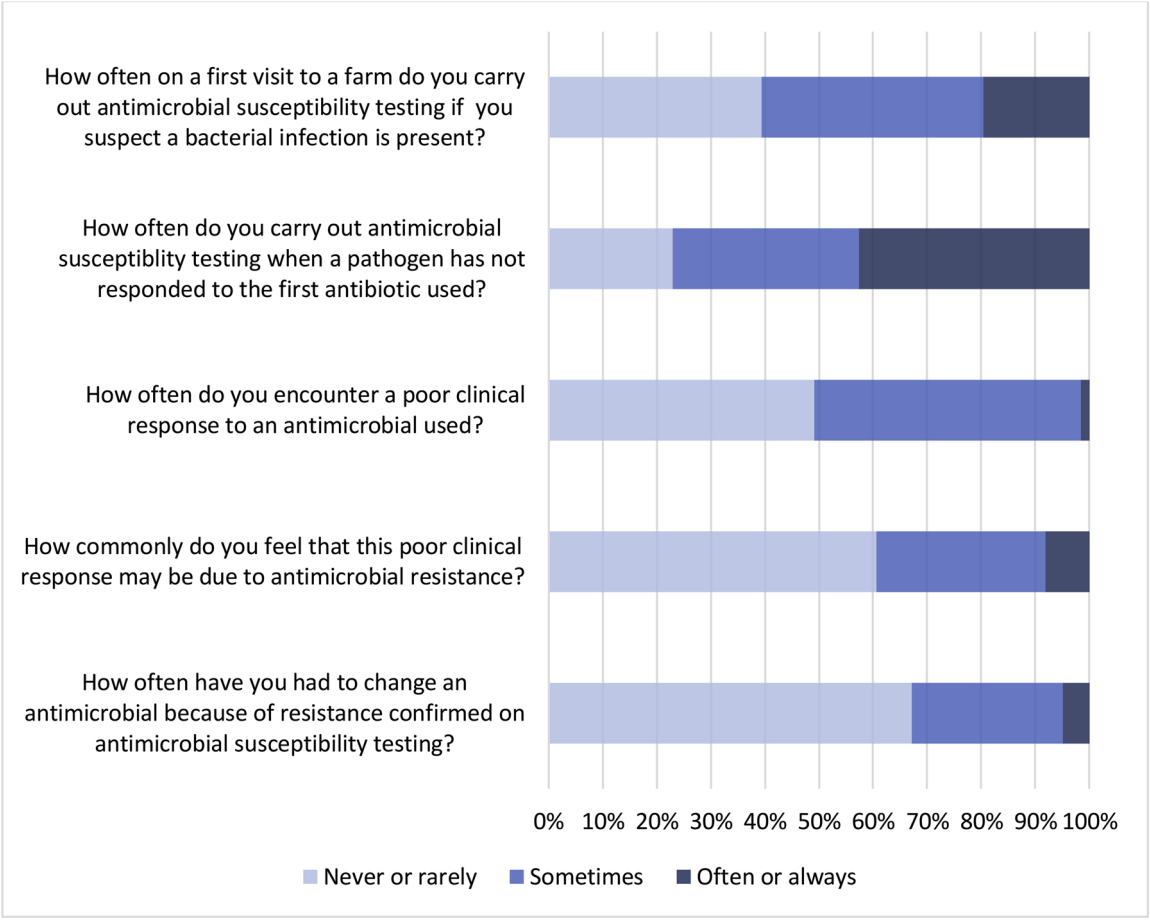

Fig. 2. Frequency of UK pig veterinary surgeon reported behaviour with regards to AST and treatment failure (n = 61).

Table 4
UK pig veterinary surgeon combined opinions on how responsibly antimicrobials are used in other veterinary sectors when compared with the pig sector.

	Less responsibly	Neutral	More responsibly
Beef cattle (n = 53)	7 (13%)	23 (43%)	23 (44%)
Dairy cattle (n = 54)	12 (22%)	22 (41%)	20 (37%)
Equine (n = 50)	14 (28%)	20 (40%)	16 (32%)
Poultry (n = 48)	14 (29%)	24 (50%)	10 (21%)
Sheep (n = 51)	11 (22%)	22 (43%)	18 (35%)
Small animals (n = 53)	23 (44%)	18 (33%)	12 (23%)

personal and professional responsibility (Busani et al., 2004, Mattick et al., 2014). Veterinary surgeons identified themselves and farmers to be the most important actors in monitoring responsible antimicrobial use in pigs identifying them as the most relevant target groups for interventions to promote prudent prescribing practices.

The veterinary surgeon-farmer relationship and confidence in the farmers' ability to administer antimicrobials responsibly were more commonly considered to be a factor that motivated prescribing by mixed species veterinary surgeons when compared with specialist pig practitioners. This may reflect that mixed species veterinary surgeons' livestock caseloads are likely to be predominantly ruminants, which typically require more individual veterinary visits when compared with pig herds which are managed at a population level (Kelliher et al., 2014). There are parallels with the human medicine definitions of 'patient-centred' and 'population-centred' care (Stiefel and Nolan, 2012), therefore, it may be that mixed species practitioners are utilising a more patient-centred approach, which could result in a closer veterinary surgeon-farmer relationship due to the more frequent farm visits and communication in ruminant species practice (Harwood et al., 2016). In addition, respondents working in mixed practice identified that they would be more likely to prescribe if they believed the farmer wanted antimicrobials compared with the specialist veterinary surgeon. However, this finding contrasts with the conclusions of Postma and Speksnijder, 2016 that veterinary surgeons specialised in intensive livestock species (pigs and poultry) felt a greater pressure from farmers to prescribe when compared with veterinary surgeons undertaking predominantly ruminant work (Speksnijder et al., 2015a).

Veterinary surgeons most frequently consulted the NOAH Compendium of Data Sheets for Animal Medicines and pharmaceutical companies for information on antimicrobial use in pigs. These sources offer guidance on the choice of an appropriate antimicrobial for the presenting condition, appropriate dosage and course length and the recommendation that HP-CIAs should be reserved for use when other antimicrobial classes are either ineffective or where clinical response is expected to be poor (Paskovaty et al., 2005; NOAH, 2014). However, they do not offer guidance on the potential over-use of broad-spectrum antimicrobials and do not advise on which specific antimicrobial classes should be used as first line options in pig practice (Paskovaty et al., 2005). The aforementioned guidance is included in the PVS prescribing principles, which were consulted by less than a third of respondents and offer advice on which classes of antimicrobial should be chosen as first, second and third line options and when AST should be conducted prior to the use of certain classes (PVS, 2014). Research in the cattle, horse and small animal sectors in the UK has also found that respondents consulted the NOAH Compendium and pharmaceutical companies more frequently than veterinary associations for information on antimicrobial prescribing (Hughes et al., 2012, 2013; Williams et al., 2012).

Veterinary surgeons frequently cited pharmaceutical companies as a source of information on antimicrobials in pigs. In agreement, a study into antimicrobial use behaviours in Flanders and the Netherlands showed that around half of veterinary surgeons considered pharmaceutical companies influenced their antimicrobial prescribing decisions in farm animal practice (Postma and Speksnijder, 2016). Evidence from human medicine demonstrates divided opinion on the influence of pharmaceutical companies on antimicrobial prescribing decisions with some sources identifying it as a pressure on prescribing practice (Paredes et al., 1996; Barden et al., 1998), whilst other studies considered them to have little or no effect on behaviours (Simpson et al., 2007; Lopez-Vazquez et al., 2012). The relationship between senior and assistant veterinary surgeons may also influence prescribing decisions. For example, respondents identified that advice from senior colleagues was a positive driver towards antimicrobial use decisions. Similarly, in human medicine it has been shown that senior physicians have a significant influence on junior doctors' antimicrobial prescribing behaviours (Sterkenburg et al., 2010; Santana et al., 2011).

The importance of diagnostic testing in identifying the pathogen responsible for clinical disease signs and ascertaining an appropriate antimicrobial are essential tools in ensuring that antimicrobial use is appropriate. However, AST was described by respondents as being utilised infrequently, although it was reported to be more frequent following initial treatment failure. Factors relating to the time delay in obtaining the results from such diagnostics and cost may be a hurdle to their frequent adoption (De Briyne et al., 2013; Speksnijder et al., 2015a; Coyne et al., 2016). Diagnostic testing has been identified as an underutilised tool in both veterinary (De Briyne et al., 2013; Coyne et al., 2016) and human medicine (Peterson and Dalhoff, 2004). There is a need for further research to identify cost effective, rapid pen-side tests to identify the pathogens responsible and their susceptibility profiles to determine the appropriate antimicrobial to use.

In parallel with other studies in human and veterinary medicine, veterinary surgeons seldom considered treatment failure as being a major issue in their clinical practice (Simpson et al., 2007; Buller et al., 2015; Speksnijder et al., 2015a). Additionally, when respondents

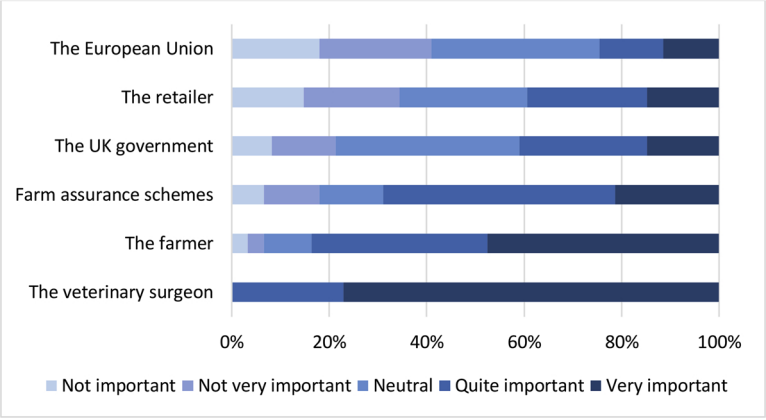

Fig. 3. UK Veterinary surgeons' ratings of which actors are important in monitoring responsible antimicrobial use in pigs (n = 61).

Table 5
Veterinary surgeon opinion on whether different measures would be considered to be a barrier, beneficial or have no effect on the total amount of antimicrobial used in pigs in the UK.

	Barrier	Neutral, no effect	Beneficial
Behavioural factors			
Farmer reluctance to change current practices (n = 60)	50 (83.3%)	8 (13.3%)	2 (3.3%)
Vet reluctance to change current practices (n = 60)	45 (75.0%)	14 (23.3%)	1 (1.7%)
Vets educating farmers on ways to improve herd health (n = 58)	0 (0.0%)	4 (6.9%)	54 (93.1%)
Factors relating to potential policy			
Banning in-feed antimicrobial formulations (n = 57)	13 (22.8%)	15 (26.3%)	29 (50.9%)
A 'penalty system' of penalties for high antimicrobial usage in pigs, such as the "yellow card" system in Denmark (n = 57)	7 (12.3%)	6 (10.5%)	44 (77.2%)
Banning the use of the fluoroquinolones and the third and fourth generation cephalosporins (n = 57)	11 (19.3%)	28 (49.1%)	18 (31.6%)
Banning the use of the macrolides (n = 57)	17 (29.8%)	23 (40.4%)	17 (29.8%)
A benchmarking system, whereby antibiotic usage is benchmarked between farms (n = 59)	3 (5.1%)	22 (37.7%)	34 (57.6%)
'Decoupling' the dispensing and prescribing of antimicrobials so that vets are no longer able to dispense antimicrobials directly and can only prescribe antimicrobials to clients (n = 58)	14 (24.1%)	40 (69.0%)	4 (6.9%)
Further controls on the licensing of cheaper generic antimicrobial products (n = 59)	3 (5.2%)	37 (63.8%)	18 (31.0%)
Reducing imports from other countries with high antimicrobial use (n = 59)	2 (3.4%)	23 (39.0%)	34 (57.6%)
Factors relating to management			
Eradicating swine dysentery from the UK (n = 58)	1 (1.7%)	9 (15.3%)	49 (83.1%)
Modernising indoor pig accommodation (n = 58)	0 (0.0%)	5 (8.5%)	54 (91.5%)
Increased use of straw-based finishing systems (n = 58)	10 (17.2%)	30 (51.7%)	18 (31.0%)
Increased use of outdoor breeding systems (n = 57)	5 (8.6%)	37 (63.8%)	16 (27.6%)
More effective vaccines (n = 61)	0 (0.0%)	2 (3.4%)	56 (96.6%)
A wider range of vaccines (n = 59)	0 (0.0%)	2 (3.5%)	55 (96.5%)
De-populating and re-populating low health status pig herds with higher health status stock (n = 59)	0 (0.0%)	6 (9.8%)	55 (90.2%)
Locating pig units in areas that are isolated from other units (n = 58)	0 (0.0%)	10 (16.9%)	49 (83.1%)
Factors relating to economics			
Increased profitability of pig meat price (n = 58)	5 (8.5%)	21 (35.6%)	33 (55.9%)
Increasing the cost of antimicrobials for farmers (n = 58)	7 (12.1%)	34 (58.6%)	17 (29.3%)
Decreasing the cost of antimicrobials for farmers (n = 59)	21 (36.2%)	36 (60.3%)	2 (3.4%)

encountered inefficacy of antimicrobials they rarely attributed this to antimicrobial resistance. Buller et al., (2015) described a similar phenomenon whereby veterinary surgeons generally did not consider antimicrobial resistance to be the primary cause of treatment failures, while studies in human medicine show that physicians do not consider antimicrobial resistance to have a major effect on their clinical work and it was infrequently considered in prescribing decisions (Simpson et al., 2007; Wood et al., 2013). Such beliefs that antimicrobial resistance is not a major issue in clinical pig practice, and that treatment failures are not a consequence of antimicrobial resistance, may act as a barrier to implementing policies advocating behaviour change to promote responsible antimicrobial use.

As is shown in the literature the majority of livestock veterinary surgeons acknowledged that increased antimicrobial resistance in humans is a potential consequence from the use of antimicrobials in pigs (Cattaneo et al., 2009; Speksnijder and Jaarsma, 2015; Visschers et al., 2016). However, Speksnijder et al. (2015b) identified that many of the farm animal practitioners in their study perceived indiscriminate prescribing in human medicine to be the most significant driver of antimicrobial resistance in humans. These respondents stated that they seldom saw treatment failure in everyday clinical practice and as such felt that overuse use by physicians was likely to be the most significant driver for antimicrobial resistance in human medicine.

The perception held by respondents that antimicrobial use in pigs may actually reduce the risk of disease transmission to humans is supported by the theory that antimicrobial use in livestock may reduce microbial load and shedding, and thus, may lead to a lower frequency of meat products and environmental contamination with zoonotic pathogens (Landers et al., 2012). However, such theories are poorly supported in published studies and the negative public health consequences from the zoonotic transfer of resistant bacteria from livestock to humans are well documented (Taylor et al., 2008; Burow et al., 2014; Liu et al., 2016; Tang et al., 2017). Thus, this shows a mismatch between scientific evidence and veterinary surgeon perceptions. Such perceptions may be driven by previous public health initiatives which focused on reducing microbial load in livestock species and meat; antimicrobial administration was one route through which *Salmonella* pathogen reduction was advocated for poultry (Van Immerseel et al., 2002).

Prescribing practices which have been highlighted through political and media pressure, such as the use of in-feed antimicrobials, prophylactic antimicrobial use, and the use of the HP-CIAs, were considered by the majority to be justifiable (O'Neill, 2015; Morris et al., 2016). In-feed antimicrobials are frequently used for disease prevention in pigs and whilst this use is generally perceived to be prudent by veterinary surgeons (Callens et al., 2012; Speksnijder and Jaarsma, 2015), there has been an increasing focus on research seeking alternative methods of preventing disease in pigs (EIP-AGRI, 2015; Postma and Stärk, 2015).

The literature identifies vaccination as a feasible alternative method of preventing disease to antimicrobial use in pigs (Buller et al., 2015; Postma and Stärk, 2015) and veterinary surgeons in this study identified that improvements in the efficacy and availability of vaccinations would be beneficial in reducing antimicrobial use. However, it is perhaps a simplistic view to consider vaccinations to be the answer to reducing antimicrobial use with a number of studies correlating more frequent vaccination use with higher antimicrobial use on farm (Stevens et al., 2007; Postma and Backhans, 2016; Temtem et al., 2016); these conclusions may reflect that pig herds with a greater prevalence of endemic disease and higher antimicrobial use are more likely to vaccinate. Another essential tool in minimising the antimicrobial requirement of a farm is ensuring that both internal and external farm biosecurity are optimal (Postma and Backhans, 2015, 2016; Collineau et al., 2017). Whilst biosecurity was not specifically covered in the questionnaire content it is major focus of recent efforts to reduce the burden of disease and antimicrobial use in UK pig production (RUMA, 2017).

Veterinary surgeons expressed concern that antimicrobial use may be less responsible by other practitioners within the pig industry. This concept in which such irresponsible prescribing behaviours are not identified in the prescribers' own behaviours, but are described as being more frequent in a distinct societal group, other pig veterinary surgeons or in other species sectors, is a social construct referred to as othering

(Sibley, 1998; Johnson et al., 2004); and is a recognised concept in human medicine (Barden et al., 1998; Butler et al., 1998; Teixeira Rodrigues et al., 2013). For example questionnaire respondents perceived that they themselves did not practice continual and long-term antimicrobial use but felt that such practices may be more common elsewhere in the UK pig industry; whilst such long-term and habitual use behaviours have been described in the pig industry (Visschers et al., 2014; Buller et al., 2015) they are not consistent with the current UK guidelines on the responsible use of antimicrobials in pigs (RUMA, 2013; PHWC, 2015).

There has been increasing pressure on the veterinary profession that use of the HP-CIAs should be restricted in livestock (O'Neill, 2016; WHO, 2017) and in agreement, the PVS prescribing principles recommend that these classes are not used as first line antimicrobial choices (PVS, 2014). However, the consensus opinion amongst respondents was that their use in pigs was responsible and justified. Additionally, HP-CIAs were seldom chosen as a treatment option in the clinical disease scenarios with the exception of *E.coli* scour in piglets whereby fluoroquinolones were a more frequent choice (15% of respondents as a first line choice and 36% as a second line choice). This may reflect the high resistance levels in *E. coli* to spectinomycin, an alternative authorised treatment option, described in national scanning surveillance and research studies (Österberg et al., 2016; VMD, 2017). Thus, any such restrictions on HP-CIA use are likely to have a significant impact on the pig industry. For example in the aforementioned example restricting fluoroquinolones will limit the number of effective treatment options for *E.coli* scour in piglets with potential negative health and welfare implications for piglets.

Specialist pig veterinary surgeons more frequently identified that the use of colistin was justified in pigs when compared with mixed species practitioners and its overall use was infrequently described in the clinical disease scenarios. This may reflect its comparatively common use in pigs when compared with other species (De Briyne et al., 2014; Benstetter, 2016). However, it should be noted that the discovery of the ability of the *mcr*-1 gene to transfer resistance via a plasmid-mediated polymyxin resistance mechanism occurred in 2015 after this study was completed (Liu et al., 2016; AbuOun et al., 2017; Hadjadj et al., 2017), and the use of colistin has since been voluntarily restricted by UK livestock industries (Anon, 2015), with the initiative resulting in an 83% reduction between 2015 and 2016 (VMD, 2017).

The policy approach taken by the UK to regulate antimicrobial use through voluntary initiatives and through farm assurance schemes (RUMA, 2017) contrasts to Sweden, Denmark and the Netherlands where antimicrobial use has been controlled through Government legislation (Dupont et al., 2015; Dorado-García et al., 2016; Begemann et al., 2017). Whilst it could be argued that the overall levels of veterinary antimicrobial sales and use reductions observed in these countries may suggest legislation is a more effective approach, this opinion does not consider the complexities of the different political environments and differences in livestock systems and animal demographics between countries (Begemann et al., 2017; European Medicines Agency, 2017). For example, the voluntary approach taken by the UK has already shown success with a 24% overall veterinary antimicrobial sales reduction from 2014 to 2016 (VMD, 2017). Additionally, in parallel to the UK, Belgium has adopted a voluntary approach to reducing antimicrobial use in livestock and has exhibited success in both reducing antimicrobial use and antimicrobial resistance in key food producing animal species (Postma and Speksnijder, 2016; AMCRA, 2017).

The view that a legislative approach to antimicrobial use reduction may not be appropriate for the UK is supported somewhat by the respondents' views which placed greater responsibility for monitoring the prudent use of antimicrobials on voluntary farm assurance schemes than on the UK or EU governments. Conversely, UK veterinary surgeons felt that policy banning in-feed antimicrobials, benchmarking farms on antimicrobial use and the use of a penalty system for high antimicrobial users were likely to have a beneficial effect on reducing the total amount of antimicrobials used in pigs. A penalty system whereby producers are penalised for prolonged high antimicrobial use has been successful in Denmark in reducing antimicrobial use in pigs (Aarestrup, 2012). This has been widely publicised and may have influenced the respondent opinions. However, it is worth noting that since this questionnaire was conducted there has been a voluntary initiative to collect antimicrobial use at pig farm level through the electronic medicines book. This has shown an overall reduction in use in the UK pig herd of 50% between 2015 and 2017, thus, agreeing with respondent opinion that benchmarking may be beneficial in reducing antimicrobial use (Driver, 2018).

Veterinary surgeon attitudes to the efficacy of policy measures on antimicrobials use in pigs may reflect underlying fears over potential regulatory changes rather than respondents' perceptions of actual effects from changes. For example, it could be considered that the negative respondent perception with regards to 'decoupling', as a policy measure to reduce antimicrobial use, simply reflects veterinary surgeons' underlying concerns over losing the ability to sell antimicrobials directly to farmers. This concept is shown in a study by Postma et al. (2016) which showed that the majority of veterinary surgeons in Flanders and the Netherlands identified that retaining the right to sell antimicrobials was a motivation to reducing antimicrobial use whilst over 80% disagreed with legislation to 'decouple' antimicrobial use. This uncertainty over the efficacy of 'decoupling' policy on the amount of antimicrobials used in pigs is supported somewhat by the wide spectrum of antimicrobial sales totals from across Europe in countries that have introduced such legislation; ranging from Norway and Sweden, with some of the lowest sales to Italy, with one of the highest (EMA, 2015).

This underlying fear of policy changes may also have driven veterinary surgeons opinion that restricting or banning the use of the HP-CIA classes would have no effect on the total amount of antimicrobials used in pigs in the UK. Contrary to this opinion evidence from Europe shows that restricting these classes may have no effect on the health and productivity of the national pig herd (EMA, 2014; Speksnijder and Mevius, 2015). Similarly, recent research into HP-CIA use in UK dairy cattle has shown that use can be discontinued whilst maintaining herd health and productivity (Turner et al., 2018).

Concerns over antimicrobial resistance and the potential public health effects from the use of antimicrobials in livestock, have continued to augment since this study was completed. These concerns have been accelerated since the 2016 conclusion of the government commissioned Review on Antimicrobial Resistance by Lord O'Neill (O'Neill, 2016). The review recommended setting an antimicrobial use reduction target for all livestock species to 50 mg/PCU by 2018 from the 2014 baseline of 62 mg/PCU (HM Government, 2016). Additionally, it recommended that species specific reduction targets were defined and in response, the UK pig industry described a baseline figure of 263.5 mg/PCU for use in pigs for 2015. Consequently, the industry agreed a voluntary reduction target to 99 mg/PCU by 2020 (RUMA, 2017). In addition to the pressure on livestock industries to reduce total antimicrobial use the O'Neill report also advised that the government should consider restrictions or bans on the use of the HP-CIA classes in agriculture (O'Neill, 2016). In response to these pressures the pig industry has taken a united approach to concerns over antimicrobial use and have already achieved an overall reduction of 34% in all antimicrobial classes and a reduction of 73% for fluoroquinolones, third and fourth generation cephalosporins and colistin from 2015 to 2016 (VMD, 2017).

The efforts to reduce antimicrobial use across the pig sector combined with the mounting pressures on the pig industry through negative media and public perceptions may have resulted in changes to veterinary surgeon opinion since the questionnaire study was undertaken. However, national and global concerns over antimicrobial resistance continue to grow whilst the policy priorities continually evolve and

change depending on the political and economic environment (Christley et al., 2017). For example, due to growing concerns over colistin resistance since the discovery of the *mcr*-1 gene the polymixin class of antimicrobials have been re-classified by the WHO as a HP-CIAs in the 2017 revision of the 'Critically Important Antimicrobials for Human Medicine' (Liu et al., 2016; WHO, 2017). Therefore, whilst some of the respondent beliefs and attitudes may have altered with time these results still present the most up to date insights into antimicrobial use practices by UK veterinary surgeons in pigs. Such detailed insights into antimicrobial use behaviours by pig veterinary surgeons will assist policy makers in identifying priority behaviours and areas to further address the global threat of antimicrobial resistance.

In total 148 (56.7%) of 261 questionnaires were returned and of these 61 were completed. The useable response calculated after removing incomplete responses, responses where the veterinary surgeon was no longer at the address or did not do sufficient pig work, was 34.1% (n = 61/179). In contrast, a questionnaire on antimicrobial use in UK pig farms had a response rate of 25.5% (Stevens et al., 2007), whilst a study on antimicrobial use by farm animal veterinary surgeons had a response rate of only 17.1% (Williams et al., 2012).

The low questionnaire response rate may be related to the increasing number of requests on veterinary surgeons to complete such questionnaires and the time pressures faced by practitioners. In addition public, political and media pressure relating to antimicrobial resistance have placed increasing pressure on the food producing animal sector and veterinary profession; such pressure may result in a reluctance to share opinions (McCullough et al., 2015; Morris et al., 2016). Both these factors indicate that future studies should aim for collaborative approaches between research organisations and key stakeholders, thereby ensuring stakeholder engagement from the outset. These pressures may also result in a potential bias in the respondent population as veterinary surgeons that completed the questionnaire may have a personal interest in antimicrobial use. In addition, there may be limitations in self-reported behaviours, whereby participants may respond to questions as they believe the authors expect them to, rather than reporting actual practices may occur (Bowling, 2005).

5. Conclusions

This study highlights some parallels between antimicrobial use practices in human and veterinary medicine, thus strengthening the necessity that antimicrobial resistance is approached from a One Health perspective. There is a need to reverse the current trend of human and veterinary medicine blaming each other and to reduce the mounting political and media pressure on the livestock sector. A One Health approach should encompass the health and welfare of humans and animals alike and consider the pressures currently facing the livestock sectors.

The drivers behind antimicrobial prescribing decisions by pig veterinary surgeons are multifactorial and complex. This study has identified the importance of non-clinical factors in influencing prescribing behaviours such as the veterinary surgeon-client relationship and the practitioners' personal sense of responsibility. It has highlighted that existing tools such as AST are underutilised and could play a more significant role in prescriber decisions if more cost effective and rapid tests were available. The wide range of information sources consulted on antimicrobial use in pigs, and the contrasts between the prescribing guidance contained in sources, highlight a need for uniform and comprehensive guidelines on the responsible antimicrobial use in pigs, which are readily available to both specialist and mixed species veterinary surgeons. Future work should explore antimicrobial use in pigs and needs to focus on the evolution of antimicrobial use practices in a changing political and scientific landscape. Such research will assist policy makers in targeting behaviours and areas to tackle the global threat of antimicrobial resistance.

Declarations of interest

None to declare.

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