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Knowledge and perceptions of Australian postgraduate veterinary students prior to formal education of antimicrobial use and antimicrobial resistance

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ABSTRACT

Antimicrobial resistance (AMR) is widely perceived as a threat to human and animal health and a significant One Health issue with extensive and complex factors contributing to its occurrence and spread. Previous studies have surveyed human and animal health professionals to determine their perceptions regarding AMR and antimicrobial use (AMU). There are limited studies exploring the understanding of veterinary students despite their critical role as future antimicrobial prescribers. A cross-sectional survey was administered to an entire cohort of Doctor of Veterinary Medicine Year 2 (DVM2) students ($n = 136$) to investigate their knowledge and perceptions regarding AMR and AMU prior to formal education on this issue. Ninety students (66.2% of the cohort) completed the survey. There was overwhelming agreement regarding the immediacy of the problem, with 84.4% of students indicating that '*We must take action on AMR*'. Despite more than 94.4% of students correctly defining AMR, specific knowledge regarding AMR impact, contributory causes to AMR and strategies to solve the challenge of AMR was variable. Most students perceived livestock producers to have a significant role in the perpetuation of AMR due to AMU for prophylaxis (71.1% substantial/moderate contribution) and treatment (56.7% substantial/moderate contribution). Over a third of respondents (37.8%) were unsure if AMR could spread from animals to humans. Respondents perceived that various groups (dentists, doctors, veterinarians, professional organisations) are all important in ameliorating the issue of AMR. The implementation of restrictive measures to reduce veterinary prescription of antimicrobials was viewed as less important than strategies involving education, hygiene, surveillance, and guideline development/availability. To encourage the development of good antimicrobial stewardship (AMS) practices, professional veterinary education needs to foster an understanding of the scientific, behavioural and social issues that contribute to AMR and inappropriate AMU, as well as prescribers' personal contribution to AMR perpetuation and amelioration.

1. Introduction

Antimicrobial resistance (AMR) is a significant and expanding global health issue with considerable ramifications for human and animal health [1]. As antimicrobial prescribers, veterinarians are key partners in a One Health approach to AMR as suggested by the World Health Organisation [2]. For veterinarians, AMR is a multifaceted problem given its direct effects on animal treatment outcomes and the potential for zoonotic transfer of resistant microorganisms [3]. Previous research has investigated the practices and perceptions of Australian veterinarians concerning AMR and antimicrobial use (AMU) [4–9].

Understanding the knowledge and perceptions of students who will be future antimicrobial prescribers is equally important for guiding the development of curricula that fosters best practice in antimicrobial stewardship (AMS). There are a limited number of studies exploring the perceptions of veterinary students regarding AMR globally. A study involving Serbian and Croatian veterinary students at various stages of training revealed a lack of cognisance regarding the potential contribution of veterinary medicine to AMR with 42.8% perceiving it had minimal or no contribution [10]. Less than 25% of Nigerian veterinary students at various stages of their training were aware of global efforts to reduce AMR, but greater than 87% exhibited a strong willingness to

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understand the issue of AMR further [11]. A multicentred investigation of Australian veterinary students' attitudes in the final two years of their degrees, identified a disconnect between preclinical and clinical teaching around AMU [12]. Other studies have surveyed the perceptions of South African veterinary students in pre-final and final years of their veterinary program [13] and veterinary students in their first and final years of their veterinary degree in Bangladesh [14]. These studies concluded that knowledge regarding AMR and AMU increased as students progressed throughout their degree, however, strengthening the alignment between preclinical and clinical teaching was required. These findings highlight the impact of developing evidence-based foundations for prescribing during training and the essential nature of curriculum alignment [10–12].

Similarly, investigations into the knowledge and perceptions of final year Australian medical students regarding infectious diseases versus cardiovascular disease found they lacked confidence and knowledge in the diagnosis and management of infectious diseases compared with cardiovascular disease [15]. Given the range of non-clinical influences on antimicrobial prescribing such as reputation, professional hierarchies, and the pressures to align with clinical practice methods of peers rather than guidelines [16], embedding strong evidence-based foundations for prescribing during professional training is critical.

Australian tertiary programs to train registrable veterinarians have considerable demands on the curriculum to deliver day 1 competencies. Accreditation of these veterinary programs require that students are trained in the importance of antimicrobial stewardship (AMS) and the implications of AMR to animal *and* human health. However, for teachers to engage and expedite this learning, knowledge of veterinary students' perceptions of AMR issues, prior to formal veterinary training is important in addressing preconceptions. Therefore, the aims of this cross-sectional study were to assess the perceptions of second year veterinary students in the Doctor of Veterinary Medicine (DVM2) at The University of Sydney, prior to their formal training on the impact of AMR and their understanding of the groups/factors responsible for perpetuating and solving the problem. The results of this study will be used to inform the Australian national curriculum on AMR and AMS in veterinary training.

2. Methods

2.1. Study design

A cross-sectional survey was designed to collect information regarding students' perceptions about the impact of AMR and their understanding of the factors and stakeholders responsible for perpetuating and solving the problem. Questions were modified from previous surveys administered to doctors, dentists, and veterinarians [9,17]. The survey for the students was tested prior to administration, using experienced academics and third and fourth year DVM students with their feedback used to refine the final version. The survey used 76 Likert-type responses on a 4- or 5-point scale, with 'not sure' options provided. The survey is provided in Supplementary material. The survey was divided into five sections focusing on: '*antimicrobial resistance and you*'; '*factors influencing the development of antimicrobial resistance*'; '*the impact of antimicrobial resistance*'; '*management of antimicrobial resistance*'; and '*demographic information*'. The survey was administered via an online format using REDCap electronic data capture tools https://projectredcap.org/software. The survey was estimated to take 10 to 15 min to complete. This study was approved by the Human Research Ethics Committee of The University of Sydney [Protocol number 2019–1002].

2.2. Recruitment

The survey was administered on February 24th, 2020. A survey link was disseminated to the enrolled students in year 2 of the Doctor of Veterinary Medicine (DVM2) through their university email addresses using a cohort alias. The link was resent on March 2nd, 2020 to remind students to complete the survey. Participation was voluntary and respondents could abandon completing the survey at any stage without penalty.

2.3. Statistical analyses

Statistical analyses were performed using GraphPad Prism® version 8.4.3 (San Diego CA, US). If there was missing data on a single item, the respondent was excluded from the respective analysis. For Likert-type questions, responses were clustered into the following groups: 'agree / strongly agree' or 'disagree / strongly disagree'; 'substantial / moderate contribution' or 'small / no contribution'; 'moderately / very / extremely important' or 'slightly / not important'; and there was also an 'unsure' category for all items, as detailed in the result tables. These groups and the 'unsure' category for each statement were compared using the Mann-Whitney U test. The Kruskal-Wallis H test was used to compare the mean rank between questions, with Dunn's test used for post-hoc analysis of pairwise comparisons. For all tests, statistical significance was $p < 0.05$. Uncertainty in the students' response was nominally flagged as 'high' when >20% indicated they were 'unsure' of their response to the item. The open-ended question was analysed by determining the proportion of respondents providing a response broadly aligning with the WHO statement "*antimicrobial resistance happens when microorganisms (such as bacteria, fungi, viruses, and parasites) change when they are exposed to antimicrobial drugs*" [2].

3. Results

3.1. Sample population

Ninety out of 136 (66.2%) DVM2 students completed the survey. Most students identified as female (74.4%) consistent with the sample population demographics. Students' median age was 24 years (range 20 to 37 years). All respondents had completed an undergraduate degree before entering the DVM program. Three respondents held a Masters' degree, and none had undertaken a Doctor of Philosophy (PhD) or equivalent. Students intended to work across a variety of interest areas. These included small (53.3%), large (10%) and mixed (48.9%) animal practice, other private practice such as specialisation or exotic species (52.2%) and more broadly in industry (8.9%), diagnostic laboratories (7.8%), government (13.3%) and research/academia (13.3%). Students were able to select multiple checkboxes for this question.

Results have been categorised into the following sections: '*understanding AMR and its impact*', '*perceived contributions to AMR*', '*addressing the problem of AMR*' and '*strategies for addressing the challenge of AMR*'.

3.2. Understanding AMR and its impact

The majority of respondents (78.8%) recognised that the use of antibiotics could select for resistant microbes, which was broadly consistent with the WHO definition of AMR [2]. Conversely, five respondents (5.5%) were incorrect in their assessment that AMR referred to a failure of the patient's own physiological response to antimicrobials. Formal education related to AMR had been undertaken by one-third of respondents in their previous degree and two-thirds of respondents indicated that they wanted further education on the topic, with 37.8% indicating that their understanding was inadequate. Many respondents (67.4%) did not report any personal experience with AMR, while the remaining respondents (32.6%) reported experience with AMR themselves and/or via the medical experience of a family member, friend, or pet.

Respondents had various positions on AMR with most agreeing '*we must take action*' (84.4%) and that their actions could contribute to how AMR is managed (68.9%). None of the respondents believed that '*no action is required*' (Fig. 1). A small proportion of respondents agreed /

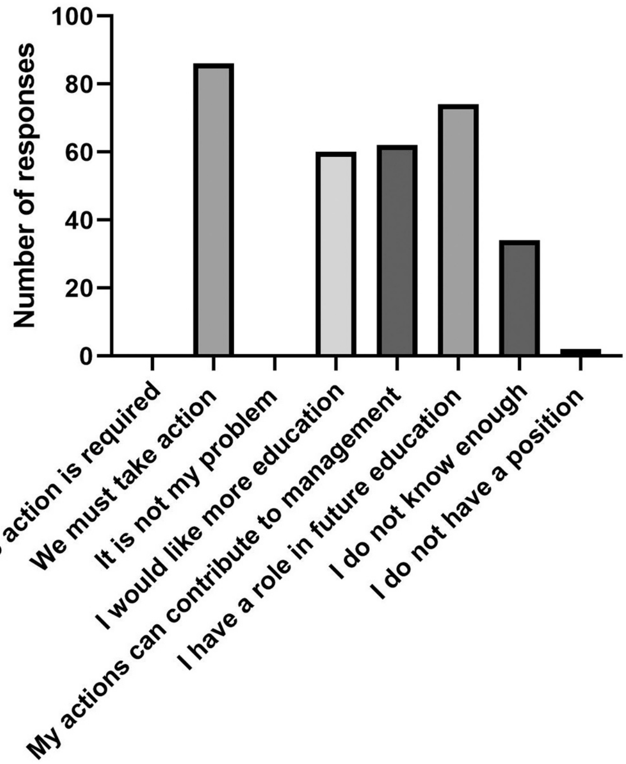

Fig. 1. Positions of participants regarding antimicrobial resistance and antimicrobial use (respondents could select multiple options).

strongly agreed [broadly agreed = A], that AMR is overdramatised as a public health problem (A = 4.5%) (Table 1). Respondents overwhelmingly agreed that '*unnecessary use of antimicrobials leads to reduced future treatment choice*' (A = 91.0%) and that "*antimicrobials can affect 'good' bacteria that normally live on the skin or in the gut*" (A = 92.3%), with a few respondents agreeing that '*taking antimicrobials has no effect on the bacteria that naturally live in the gut*' (A = 5.6%). While most respondents agreed that *the 'effectiveness of antimicrobials has decreased'* (A = 72.2%), 14.5% disagreed with this statement.

There was greater disparity between respondents and high levels of uncertainty (>20%) in response to statements that 'new *antimicrobials are constantly being discovered and developed to keep up with the problem of AMR*' (A = 51.2%; disagree / strongly disagree [D] = 25.6%; unsure [U] = 23.3%); '*the world is running out of effective antimicrobials*' (A = 61.1%; D = 18.9%; U = 20.0%); or that '*antimicrobial use in one patient may weaken its effectiveness for other patients in the future*' (A = 33.3%; D = 37.8%; U = 28.9%). Respondents were more likely to agree that '*antimicrobial use in one patient may weaken its effectiveness in the same individual in the future*' (A = 66.7%; D = 10.0%; U = 23.3%). There was a high level of uncertainty as to whether '*antimicrobial resistant bacteria could last a year in a patient after a single administration*' (U = 72.2%). Although some respondents agreed that AMR *'has spread from human to human'* (A = 54.4%), '*from animals to humans*' (A = 44.4%), and *'from humans to animals'* (A = 32.2%) there were high levels of uncertainty (U = 26.7%, 37.8% and 40%, respectively) and disagreement (18.9%, 17.8% and 27.7%, respectively) by students regarding these. Students were more certain that the '*emergence of AMR in animals will have a negative effect on human health*' (A = 80.1%) than the '*emergence of AMR in humans will have a negative effect on animal health*' (A = 64.1%) (p = 0.004), although 21.3% were unsure of the latter statement.

Table 1
Students' perceptions on the impact of antimicrobial resistance & antimicrobial use.

	Level of agreement			Statistical analyses between levels of agreement		
Statement	*A* (%)	*D* (%)	*U* (%)	*p* (A vs D)	*p* (A vs U)	*p* (D vs U)
The problem of AMR is overdramatised	4.5	84.3	11.2	<0.0001	ns	<0.0001
Unnecessary use of antimicrobials leads to reduced future treatment choice	91.0	2.3	6.7	<0.0001	<0.0001	ns
Antimicrobials can affect 'good' bacteria that normally live on the skin and in the gut	92.3	2.1	5.6	<0.0001	<0.0001	ns
Taking antimicrobials has no effect on the bacteria that naturally live in the gut	5.6	90.0	4.4	<0.0001	ns	<0.0001
The effectiveness of antimicrobials has decreased	72.2	14.5	13.3	<0.0001	<0.0001	ns
New antimicrobials are constantly being discovered and developed to keep up with the problem of antimicrobial resistance	51.2	25.5	**23.3**	0.0007	0.0002	ns
The world is running out of effective antimicrobials	61.1	18.9	**20**	<0.0001	<0.0001	ns
Antimicrobial use in one patient may weaken its effectiveness in the same individual in the future	66.7	10.0	**23.3**	<0.0001	<0.0001	0.03
Antimicrobial use in one patient may weaken its effectiveness for other patients in the future.	33.3	37.8	**28.9**	ns	ns	ns
Antimicrobial resistant bacteria may last a year in a patient after a single use of an antimicrobial	20	7.8	**72.2**	0.03	<0.0001	<0.0001
Resistance to antimicrobials has spread from human to human	54.4	18.9	**26.7**	<0.0001	0.0002	ns
Resistance to antimicrobials has spread from animals to humans	44.4	17.8	**37.8**	0.0002	ns	0.0044
Resistance to antimicrobials has spread from humans to animals	32.2	27.7	**40.0**	ns	ns	ns
Emergence of antimicrobial	80.1	4.3	15.6	<0.0001	<0.0001	0.02

(*continued on next page*)

Table 1 (*continued*)

Statement	Level of agreement			Statistical analyses between levels of agreement		
	A (%)	*D* (%)	*U* (%)	*p* (A vs D)	*p* (A vs U)	*p* (D vs U)
resistance in animals will have a negative effect on human health (1)						
Emergence of antimicrobial resistance in humans will have a negative effect on animal health (2)	64.1	14.6	**21.3**	<0.0001	<0.0001	ns

A = agree / strongly agree; D = disagree / strongly disagree; U = unsure; ns = not significant. Significance of (1) vs (2) $p = 0.04$; **Bolded signifies that over 20% of respondents were unsure.**

3.3. *Perceived contributors to AMR*

3.3.1. *Stakeholder groups implicated in contributing to AMR*

Students indicated that professional stakeholder groups that make a substantial / moderate contribution (C) to the issue of AMR include '*doctors prescribing antimicrobials*' (C = 73.3%), '*veterinarians prescribing antimicrobials*' (C = 60.0%), and '*livestock producers*', the latter through use in treatment (C = 71.1%) and metaphylaxis (C = 56.7%) (Table 2). Students attributed a significant contribution to '*transmission of antimicrobial resistance in human hospitals*' (C = 53.9%) and to a lesser extent, animal hospitals (C = 48.9%). However, there was no statistically significant difference between the perceived contribution of human versus animal hospitals to AMR.

3.3.2. *Factors contributing to AMR*

Table 2 documents that students believed that the following make a substantial / moderate contribution to AMR: '*using an antimicrobial when the benefit to the patient is uncertain*' (C = 84.1%), '*unnecessary use of broad-spectrum antimicrobials*' (C = 83.2%), and '*patients (human and animal) using antimicrobials from previously unfinished prescriptions*' (C = 77.8%). Students believed that '*human patients*' and '*owners of animals requesting antimicrobials*' from the respective health-care provider contributed to AMR (C = 71.1% and 67.4%, respectively).

Students perceived that the following also resulted in a substantial / moderate contribution (C) to AMR: '*use of over-the-counter antimicrobials in humans*' (C = 64.5%) and '*in animals*' (C = 58.6%); '*long durations of antimicrobial treatment*' (C = 57.7%); and '*too low a dose of antimicrobials used in treatment*' (C = 51.1%). A high proportion of respondents perceived that patients '*not finishing their prescribed course of antimicrobials*' (C = 82.1%) made a considerable contribution to AMR. Students believed that the '*slow development of new antimicrobials*' has a small / no contribution (N) to AMR (*N* = 60%).

There was moderate agreement by students regarding the need for antimicrobials for '*routine desexing of companion animals*' (C = 48.9%) or '*routine dental procedures in companion animals*' (C = 48.9%) and '*surgeries to fix a broken bone in companion animals*' (C = 56.7%). High levels of uncertainty were recorded for each question (24.4%, 21.1%, 32.2% respectively).

3.4. *Addressing the problem of AMR*

3.4.1. *Stakeholders responsible for addressing the problem of AMR*

Table 3 demonstrates that students perceived a moderately/very/extremely important role [I] in addressing AMR for most stakeholders including prescribers (such as doctors, veterinarians, and dentists), influential organisations and other groups such as farmers/producers

Table 2
Students' perceptions of stakeholder groups or factors contributing to antimicrobial resistance.

Groups / factors	Level of perceived contribution			Statistical analyses between levels of perceived contribution		
	C (%)	N (%)	U (%)	p (C vs N)	p (C vs U)	p (N vs U)
Doctors prescribing antimicrobials	73.3	26.7	0	<0.0001	<0.0001	<0.0001
Dentists prescribing antimicrobials	42.2	50.0	7.8	ns	<0.0001	<0.0001
Veterinarians prescribing antimicrobials	60.0	40.0	0	0.011	<0.0001	<0.0001
Pharmaceutical representatives marketing antimicrobials	38.9	53.3	7.8	0.011	<0.0001	<0.0001
Use of antimicrobials by livestock producers to prevent disease	71.1	22.2	6.7	<0.0001	<0.0001	0.0051
Use of antimicrobials by livestock producers to treat disease	56.7	32.2	11.1	0.0016	<0.0001	0.001
Transmission of AMR in human hospitals **(1)**	53.9	34.9	11.2	0.016	<0.0001	0.0003
Transmission of AMR in animal hospitals **(2)**	48.9	38.9	12.2	ns	<0.0001	<0.0001
Using an antimicrobial when benefit to the patient is uncertain	84.1	13.6	2.3	<0.0001	<0.0001	0.0097
Unnecessary use of broad-spectrum antimicrobials	83.2	13.4	3.4	<0.0001	<0.0001	0.028
Patients (human and animal) not finishing their prescribed course of antimicrobials	82.1	16.9	1.1	<0.0001	<0.0001	0.0003
Patients (human and animal) using antimicrobials from previously unfinished prescriptions	77.8	20.0	2.2	<0.0001	<0.0001	0.0002
Human patients requesting antimicrobials	71.1	25.6	3.3	<0.0001	<0.0001	<0.0001
Owners of animals requesting antimicrobials	67.4	29.2	3.4	<0.0001	<0.0001	<0.0001
Use of over-the-counter antimicrobials in humans	64.5	24.4	11.1	<0.0001	<0.0001	0.031
Use of over-the-counter antimicrobials in animals	58.6	31.3	10.1	0.0003	<0.0001	0.0007
Long durations of antimicrobial treatment	57.7	31.2	11.1	0.0005	<0.0001	0.0017
Too low a dose of antimicrobials used in treatment	51.1	37.8	11.1	ns	<0.0001	<0.0001
Slow development of new antimicrobials	27.8	60.0	12.2	<0.0001	0.015	<0.0001
	48.9	26.7	**24.4**	0.0033	0.0011	ns

(*continued on next page*)

Table 2 (*continued*)

Groups / factors	Level of perceived contribution C (%)	N (%)	U (%)	Statistical analyses between levels of perceived contribution p (C vs N)	p (C vs U)	p (N vs U)
Antimicrobials are required for routine desexing of companion animals						
Antimicrobials are required for routine dental procedures in companion animals	48.9	30.0	**21.1**	0.014	0.0002	ns
Antimicrobials are required for surgeries to fix a broken bone in companion animals	56.7	11.1	**32.2**	<0.0001	0.0016	0.001

C = substantial / moderate contribution; N = small / no contribution; U = unsure; ns = not significant. There was no significant difference between (1) versus (2). **Bolded signifies that over 20% of respondents are unsure.**

Table 3
Students' perceptions on importance of different stakeholders in addressing antimicrobial resistance.

Stakeholders	Level of perceived importance I (%)	S (%)	U (%)	Statistical analyses between levels of perceived contribution p (I vs S)	p (I vs U)	p (S vs U)
Doctors	100	0	0	<0.0001	<0.0001	ns
Veterinarians	100	0	0	<0.0001	<0.0001	ns
Dentists	97.8	2.2	0	<0.0001	<0.0001	ns
Professional associations (e.g., Australian Veterinary Association)	100	0	0	<0.0001	<0.0001	ns
Animal industry organisations (e.g., Meat and Livestock Australia)	100	0	0	<0.0001	<0.0001	ns
Global organisations (e.g., World Health Organisation, World Organisation for Animal Health)	100	0	0	<0.0001	<0.0001	ns
Human hospitals	100	0	0	<0.0001	<0.0001	ns
Veterinary hospitals	100	0	0	<0.0001	<0.0001	ns
Farmers and producers	98.9	1.1	0	<0.0001	<0.0001	ns
Government and policy makers	98.9	1.1	0	<0.0001	<0.0001	ns
Scientists and microbiologists	98.9	1.1	0	<0.0001	<0.0001	ns
Other veterinary students	98.9	1.1	0	<0.0001	<0.0001	ns
Pharmaceutical companies	97.8	2.2	0	<0.0001	<0.0001	ns
Pharmacists	96.7	3.3	0	<0.0001	<0.0001	ns
Myself	95.6	4.4	0	<0.0001	<0.0001	ns
Nurses	94.5	5.5	0	<0.0001	<0.0001	ns
The community and general public	91.1	8.9	0	<0.0001	<0.0001	0.0066
Pet owners	90.0	10.0	0	<0.0001	<0.0001	0.0032
The media	88.9	11.1	0	<0.0001	<0.0001	0.0015
Family and friends	80.0	20.0	0	<0.0001	<0.0001	<0.0001

I = moderately / very / extremely important; S = slightly / not important; U = unsure; ns = not significant.

and scientists/microbiologists. Two groups were perceived as having a moderately/very/extremely important role by greater than 80% of respondents: family and friends (I = 80%) and the media (I = 88.9%). Table 3 also documents that students believed human hospitals (I = 100%) and veterinary hospitals (I = 100%) have an important role in addressing the issue of AMR.

Students perceived their family, friends and pet owners as playing a less important role in addressing AMR relative to veterinarians and doctors (all with $p \leq 0.0001$). Students perceived their own responsibility in addressing AMR as very/extremely important (I = 95.6%) and 80% indicated that they have a role in the future education of patients and clients (Fig. 1). More than 90% perceived that the community/general public also had a very/extremely important role (I = 91.1%).

3.5. Strategies for addressing the challenge of AMR

Thirteen strategies regarding education, infection control, diagnostic methods, AMU and guideline development had greater than 90% agreement that they were moderately/very/extremely important (I) in addressing the challenge of AMR (Table 4), with low levels of uncertainty (<5%) or disagreement (<6%).

'Restricting veterinary use of antimicrobials of critical importance in human health' was considered moderately/very/extremely important (I) in addressing the challenge of AMR by only 58.9% of respondents, with 22.2% disagreeing and 18.9% uncertain.

4. Discussion

Students overwhelmingly agreed that AMR is a major problem and that they have a current (*myself I* = 95.6, Table 3) and future professional role (*veterinarians I* = 100%; Table 3) in helping to ameliorate the problem. Such responses aligned with students strongly agreeing that *action must be taken to control AMR* (A = 84.4%) and no student checked *no action should be taken* or *it is not my problem* (Fig. 1). It is encouraging that our students demonstrated significant engagement with the issue prior to educational strategies that seek to foster better AMS [12]. The feasibility of integrating AMS into the behaviour of these surveyed future practitioners is favourable given that 37.8% indicated that their understanding was inadequate, and 66.7% were seeking further education on the topic. Consequently, their responses provide opportunities to identify gaps in their knowledge and address such issues during the DVM program to ultimately graduate competent veterinarians that will contribute to One Health success.

4.1. Students' experience with AMR

Approximately one third of students (32.6%) reported experience with AMR themselves and/or via the medical experience of a family member, friend, or pet. Compared with European countries, where the incidence of AMR infections in people range from 677 to 1188 per million, for <100, or > 200 persons/km^2, respectively [18], the specific incidence of AMR cases in people or animals in Australia are not easily accessed. However, rates of resistance in key gram-positive pathogens are classified as moderate to high in people in Australia, *Escherichia coli* and *Klebsiella pneumoniae* AMR incidences are relatively low compared to European countries, and resistance rates to fluoroquinolones are increasing [19]. Consequently, it is problematic to make associations between students' AMR experiences with the incidence of AMR infection rates in Australia, or any locality in which they have resided.

4.2. Items with > 20% uncertainty

It was encouraging that most students had a broad, but reasonably accurate understanding of the WHO definition of AMR. Internationally, the general public has been shown to have a similar level of awareness

Table 4
Students' perceptions on the importance of potential strategies to address antimicrobial resistance.

	Level of perceived importance of potential strategies			Statistical analyses between levels of perceived importance of potential strategies		
	I (%)	S (%)	U (%)	P (I vs S)	P (I v U)	p (S vs U)
Local and national AMR surveillance data	98.9	0	1.1	<0.0001	<0.0001	ns
AMU data in humans, livestock and companion animals	96.7	2.2	1.1	<0.0001	<0.0001	ns
Research to examine strategies to combat AMR	97.8	1.1	1.1	<0.0001	<0.0001	ns
Improving existing guidelines on antimicrobial prescribing with research and evidence	97.8	1.1	1.1	<0.0001	<0.0001	ns
Education sessions on appropriate antimicrobial prescribing for practitioners	96.7	2.2	1.1	<0.0001	<0.0001	ns
Education programs to raise awareness in the community and public	96.7	2.2	1.1	<0.0001	<0.0001	ns
Changing client expectations about antimicrobials	95.5	3.4	1.1	<0.0001	<0.0001	ns
Better hand hygiene in veterinary and human hospitals	93.4	3.3	3.3	<0.0001	<0.0001	ns
More effective cleaning in human and veterinary hospitals	92.1	4.5	3.4	<0.0001	<0.0001	ns
Improving diagnostic methods	91.2	4.4	4.4	<0.0001	<0.0001	ns
Better availability of local and national guidelines and protocols	93.3	5.6	1.1	<0.0001	<0.0001	ns
Development of new antimicrobials	93.4	4.4	2.2	<0.0001	<0.0001	ns
Fewer antimicrobial prescriptions	92.3	4.4	3.3	<0.0001	<0.0001	ns
Reducing or restricting use of antimicrobials in livestock feed	87.8	3.3	8.9	<0.0001	<0.0001	ns
Using alternative treatments to antimicrobials (e.g. probiotics)	87.7	6.7	5.6	<0.0001	<0.0001	ns
Prescribing narrowest spectrum antimicrobials	82.2	5.6	12.2	<0.0001	<0.0001	ns
Restricting veterinary use of antimicrobials considered to be of critical importance in human health	58.9	22.2	18.9	<0.0001	<0.0001	ns

I = moderately / very / extremely important; S = slightly / not important; U = unsure; ns = not significant.

around the definition despite a lack of understanding of key concepts, such as the ineffectiveness of antimicrobials for treating viral infections [20]. However, five students defined AMR as a failure of the patient's own physiological response to antimicrobials. Additionally, the issues for which the students were most unsure involved *perceptions on the impact of AMR and AMU,* and *perceptions on stakeholder groups or factors contributing to AMR*. For example, there was uncertainty whether *antimicrobial use in one patient may weaken its effectiveness in the same individual in the future* (U = 23.3%), as well as strong agreement with this statement (A = 66.7%), (Table 1). However, not only were students uncertain, but there were no significant differences in responses between all three categories [A 33.3%; D 37.8%; U 28.9%] for *antimicrobial use in one patient may weaken its effectiveness in the same individual in the future*. In contrast, qualified veterinarians had a median 'agree' score for both scenarios in a previous survey [17]. It is likely that students did not understand the implications of AMR transmission given their lack of formal education around AMR or experience with these issues in a clinical setting. As future prescribers, veterinary students must be made aware of the potentially extensive impact of antimicrobial administration on other animals, humans and the environment [21]. Additionally, 72.2% were unsure *that antimicrobial resistant bacteria may last a year in a patient after a single use of an antimicrobial* (Table 1). This level of uncertainty identifies a substantial knowledge gap in predisposing factors and the mechanisms by which antimicrobial resistance occurs in pathogens, both in-vitro and in-vivo.

Over 20% were unsure about the following statements that *new antibacterials are constantly being discovered and developed to keep up with the problem of antimicrobial resistance* (U = 23.3%) (Table 1). More concerningly, agreement with this item was high at 51.2%. Furthermore, students believed that slow development of new antimicrobials has a small / no contribution to AMR (*N* = 60.0%, Table 2). Development of new antibacterial drugs has not kept pace with the speed at which some bacteria have developed resistance [22]. Therefore, implementation of AMS for maintaining current antimicrobial therapeutic efficacy and avoiding selection pressures, is vital.

There was uncertainty around the risk of AMR transfer between humans and animals (Table 1). There is clear evidence for the presence of resistant bacteria within companion animals [23,24] and sharing between humans and animal populations [24–28]. Veterinary education programs should highlight the potential for interspecies spread and highlight the need for AMS in veterinary practice to mitigate AMR consequences not just in animal patients but also in the veterinary health professionals, animal owners and in wildlife [24,26].

There was uncertainty or misconceptions regarding the need for antimicrobials in a range of routine veterinary clinical procedures. Although half of the students agreed (46.9%) that antimicrobials were required for routine desexing of companion animals, 24.4% were uncertain (Table 2). Most veterinarians do not use antimicrobials in this circumstance due to current recommendations indicating that prophylaxis is not required [8,29]. There was also uncertainty, or misconception regarding antimicrobials required for routine dental procedures (U = 32.2%; A = 48.9%) and for surgical fixation of a broken bone in companion animals (U = 32.2%; Table 2). Current recommendations are that antimicrobials are required for prophylaxis fracture repair surgeries [30] but rarely recommended for routine dental procedures [31]. Students were not expected to know the specific indications for antimicrobials given their current stage of education, although these perceptions highlight the importance of preclinical education to address such misconceptions.

A sizable proportion of students (37.8%) responded that that *too low a dose of antimicrobials used in treatment* had a small or no contribution to AMR, and 11.1% were unsure (Table 2). Low dosage of antibiotics resulting in sub-therapeutic concentrations at the site of infection, especially when antibiotic concentration is within the mutant selection window range for the antibiotic vs pathogen, is one of the greatest selection forces for AMR [32]. Students were also divided as to whether *transmission of antimicrobial resistance in animal hospitals* is a substantial / moderate contribution or had a small / no contribution to AMR (C = 48.9%; *N* = 38.9%, respectively; Table 2). It is well recognised that transmission of AMR occurs in human hospitals [33,34], but there are fewer studies on AMR in veterinary hospitals. Recent studies document that people working in veterinary hospitals are a high-risk carriage of multidrug resistant (MDR) and extended spectrum beta-lactamase (ESBL) producing bacteria [24,35,36]. It is encouraging that all students perceived that AMS in both *human* and *veterinary hospitals* were important in addressing AMR (Table 3).

4.3. Additional misconceptions

The *use of over-the-counter antimicrobials in humans* ($I = 64.5\%$) *and animals* ($I = 58.6\%$) (Table 2) were incorrectly identified as a driver of AMR since Australian prescribing legislation in human and veterinary medicine significantly limits the purchasing of antimicrobials, particularly conventional antibacterials, without a prescription [37]. This perception may be attributable to concerns about the contribution of over the counter antimicrobials to AMR in other countries [38]. It is important for veterinary students to engage with prescribing legislation within their future area of practice. Awareness of the Australian legislative framework around antimicrobial use in veterinary education is a critical element in preventing sub-optimal use and the development of AMR.

4.4. Other issues

Students perceived both *doctors prescribing antimicrobials* ($C = 73.3\%$) and *veterinarians prescribing antimicrobials* ($C = 42.2\%$) as having a similar contribution towards exacerbating AMR (Table 2). Amongst prescriber groups in Australia, a lack of agreement exists regarding the relative contributions of each profession to the problem [17]. Veterinarians generally perceive the role of animals as minimal while emphasising the importance of human medicine in perpetuating AMR, perhaps because most Australian veterinarians infrequently encounter multi-drug resistant pathogens currently [39]. AMR requires a One Health approach for effective amelioration. The importance of One Health is emphasised throughout the DVM, from the first week of the degree's first year [40]. Acceptance of the concept is evident amongst veterinary students and should be encouraged to promote communication between prescriber groups and prevent transferring responsibility for AMS to another prescribing group, other than their own prescribing group, as noted by Zhuo et al., (2018) [17].

In line with the understanding of other Australian veterinary students, veterinarians, dentists and doctors [9,12,17], our students had high agreement that *use of antimicrobials by livestock producers to prevent disease* ($C = 71.1\%$) and *to treat disease* ($C = 56.7\%$) (Table 2) contributed to AMR ($p < 0.0001$ and $p = 0.0016$, respectively). They perceived *farmers and producers* are of high importance in addressing AMR ($I = 98.9\%$, Table 3) and they perceived *reducing or restricting use of antimicrobials in livestock feed* was also important ($I = 87.8\%$, Table 4). This was the same perception as South African final year veterinary students when surveyed on this issue [13]. Other studies report that many veterinarians (especially livestock practitioners) do not share these perceptions [9,41,42]. The contribution of AMU in agriculture to AMR broadly is poorly substantiated and differs geographically [43]. This is particularly true within the Australian context, where livestock veterinarians are restricted to using a limited range of antimicrobials of generally low importance to human health [7,9] and therefore it is important to dispel exaggerated attribution of blame towards livestock producers.

Most students recognised that *the community and general public* were important ($I = 91.1\%$) in helping to minimise/address AMR (Table 3). *Pet owners* and *family and friends* were also thought to have an important involvement (90.0 and 80.0%, respectively). An effective approach to AMR recognises the role of the community and public, given a greater societal understanding around AMR leads to more appropriate attitudes towards AMU. Members of the public that exhibit a great understanding of antimicrobials also report behaviours that may help to prevent the development of AMR [44]. It is hoped that this perception will encourage respondents to engage with client education around AMR, allowing a collaborative approach to AMS.

It was also encouraging that our students generally were well informed about the following items contributing to AMR and listed in Table 2: *using an antimicrobial when the benefit to the patient is uncertain'* ($C = 84.1\%$), *unnecessary use of broad-spectrum antimicrobials* ($C = 83.2\%$) and *patients (human and animal) using antimicrobials from previously unfinished prescriptions* ($C = 77.8\%$). These results suggest that these future veterinarians will readily employ AMS principles of antibacterial prescribing. The students were fundamentally correct in that *long durations of antimicrobial treatment* contribute to AMR ($C = 57.7\%$, Table 2). However, for severe or deep tissue infections such as prostatitis, osteomyelitis, deep pyodermas in dogs, and *Rhodococcus equi* pneumonia in foals, a long duration of antibiotic treatment is warranted [32] along with patient monitoring to detect the clinical response when antibacterial administration can be terminated.

Client expectations for antimicrobials, such as requesting antimicrobials in the human and veterinary health spheres were perceived by students as an important factor contributing to AMR $C = 71.1\%$ and 67.4%, respectively (Table 2). Students also indicated that education programs to raise awareness in the community and public ($I = 96.7\%$, Table 4), would help to ameliorate this factor. Zhou et al. 2018 [17] reported veterinarians and other prescribers attributed little significance to client expectations while another study reported that client expectation and pressure can be a factor influencing prescribing within veterinary practice [39] or that misalignments between client and veterinary expectations exist. This may act as a barrier to appropriate administration if the prescriber cannot recognise these as expectations only and eliminate them from the decision-making process.

The value of interventionist strategies of r*estricting veterinary use of antimicrobials* received the lowest level of agreement as a potential strategy to address AMR ($I = 58.9$, Table 4). Qualified veterinarians, doctors and dentists have also been shown to perceive strategies to restrict their ability to prescribe as not helpful [9,17]. This represents a challenge to the acceptance of new measures around AMS given veterinary students also appear to disagree with the potential loss of autonomy created by restricted prescribing privileges. Intervention into prescribing practices has been adopted worldwide given evidence that this strategy significantly improves AMS [45]. It may be necessary to incorporate educational strategies to foster acceptance of these potential changes to prescribing policies. However, significant importance was placed on availability of *Local and national AMR surveillance data* ($I = 98.9\%$, Table 4), improving existing guidelines on antimicrobial prescribing with research and evidence, ($I = 97.8\%$), availability of local and national guidelines and protocols ($I = 93.3\%$), *Education sessions on appropriate antimicrobial prescribing for practitioners* ($I = 96.7\%$); *Education programs to raise awareness in the community and public* ($I = 96.7\%$) and *better hand hygiene in veterinary and human hospitals* ($I = 92.1\%$), as important strategies to address AMR (Table 4).

A limitation of the study was that it did not investigate the specific nature of prior AMR education reported by one third of respondents. If collected, this may have been used to account for differences in perceptions and understanding around AMR. Future studies should investigate the link between education prior to the DVM and the development of perceptions around AMR that could influence AMS and AMU.

5. Conclusions

Veterinary students demonstrated significant understanding of the importance and immediacy of AMR prior to formal veterinary education on AMR issues. The participants had adequate preliminary knowledge of AMU/AMR principles aligning with public perceptions, but a deeper understanding of the problem must be developed through education. The role of livestock in the perpetuation and amelioration of AMR was overstated amongst veterinary students. The idea of control through a multidisciplinary approach was highlighted, with veterinarians perceived as having an equal role to dentists, doctors and professional organisations. Veterinary students were resistant to the implementation of measures restricting the prescribing abilities of veterinarians. It is suggested that collecting baseline information of the AMR knowledge base of incoming students is important for delivering learning tasks that will extend student knowledge and correct their misconceptions. It is the authors' intention to quantify the impact of our educational strategies concerning AMR by surveying students before and after relevant DVM learning activities.

Author contributions

JMN, DD-H and MG conceptualized the study. JM, JMN and MG collected data. JM and MG analysed the data. JM drafted the manuscript. The manuscript was contributed to, and edited by JM, JMN, DD-H and MG.

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Author statement

Jacqueline Norris (JMN), Dale Dominey-Howes (DD-H) and Merran Govendir (MG) conceptualized the study. Josh McClelland (JM), JMN and MG collected data. JM and MG analysed the data. JM drafted the manuscript. The manuscript was contributed to, and edited by JM, JMN, DD-H and MG.

Declaration of Competing Interest

The authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.onehlt.2021.100366.

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