Antimicrobial use through feed, water, and injection in 20 swine farms in Alberta and Saskatchewan

Leigh B. Rosengren, Cheryl L. Waldner, Richard J. Reid-Smith, John C.S. Harding, Sheryl P. Gow, Wendy L. Wilkins

Abstract

Antimicrobial resistance (AMR) is an emerging animal welfare and public health issue linked to antimicrobial use (AMU) in livestock. This study was conducted in 2004 on 20 swine farms in Alberta and Saskatchewan. On-farm records and questionnaires were used to retrospectively describe the antimicrobial exposures of pigs through feed, water, and injection. Antimicrobial use in all production categories was described over 12 months. On-farm records and questionnaires provided sufficient data to describe antimicrobial exposure rates through feed and water. In contrast, on-farm records did not supply sufficient data to describe parenteral antimicrobial exposure rates. Records lacked data on the number of exposures per treatment, therefore parenteral AMU was described as an exposure incidence. Parenteral exposure records were often unavailable for pigs less than 22 kg, in which case questionnaires were used. The incidence of parenteral AMU was significantly higher in herds reporting exposure by questionnaire compared with existing records, suggesting that on-farm records did not reliably describe parenteral AMU. However, because antimicrobial exposures in feed and water were markedly more common than through injection, it was concluded that existing on-farm data would be a valuable resource for investigating AMU and AMR in pigs.

Résumé

La résistance aux antimicrobiens (AMR) est une préoccupation émergente en bien-être animal et en santé publique liée à l'utilisation des antimicrobiens (AMU) chez le bétail. Cette étude a été réalisée en 2004 sur 20 fermes porcines en Alberta et en Saskatchewan. Des registres à la ferme et des questionnaires ont été utilisés afin de décrire rétrospectivement l'exposition des porcs aux antimicrobiens via la nourriture, l'eau de boisson et par injection. L'utilisation d'antimicrobiens dans toutes les catégories de production a été décrite sur une période de 12 mois. Les registres à la ferme et les questionnaires ont fourni suffisamment de données pour décrire les taux d'exposition aux antimicrobiens via la nourriture et l'eau de boisson. Par contre, les registres à la ferme n'ont pas fourni suffisamment de données pour décrire les taux d'exposition parentérale aux antimicrobiens. Les registres étaient déficients quant aux données sur le nombre d'exposition par traitement et ainsi l'AMU parentérale a été décrite en tant qu'incidence d'exposition. Les registres d'exposition parentérale étaient souvent manquants pour les porcs de moins de 22 kg et dans ces circonstances des questionnaires ont été utilisés. L'incidence d'AMU parentérale était significativement plus élevée dans les troupeaux rapportant l'exposition par questionnaire comparativement aux registres, suggérant ainsi que les registres à la ferme ne décrivaient pas adéquatement l'AMU parentérale. Toutefois, étant donné que les expositions aux antimicrobiens via la nourriture et l'eau de boisson étaient beaucoup plus fréquentes que celles via injection, il a été conclu que les registres à la ferme seraient une source d'informations de valeur pour étudier l'AMU et l'AMR chez les porcs.

(Traduit par Docteur Serge Messier)

Introduction

Antimicrobial resistance (AMR) is an animal welfare and public health problem; resistant bacterial infections are associated with greater morbidity, mortality, and expense than their susceptible counterparts (1–4). Agricultural antimicrobial use (AMU) provides many benefits to livestock and producers including disease treatment, prevention, and growth promotion (5). However, AMU also increases the prevalence of resistant bacteria, some of which are zoonotic (6–9). Despite this, descriptions of the quantities and reasons for AMU in Canadian livestock are scarce: this knowledge gap limits the understanding of the link between AMU and AMR in food animals.

Numerous metrics can describe AMU in livestock including the weight consumed, therapeutic costs, and treatment doses (10). Some Scandinavian countries publish the amount of antimicrobials consumed by livestock, which allows comparisons to be made over time and between countries when combined with the number of animals at risk (11–14). These data, however, provide little insight into the selective pressures for AMR because drug potencies and exposure rates are not considered (10,15).

Canada has not reported national antimicrobial consumption from sales data because of limited data availability, an inability to stratify data by species, production class, or indication, and concerns in the pharmaceutical industry about confidentiality (16,17). Instead, regional surveys and research projects have described

Western College of Veterinary Medicine, University of Saskatchewan, 52 Campus Drive, Saskatoon, Saskatchewan S7N 5B4 (Rosengren, Waldner, Harding, Gow, Wilkins); Antimicrobial Resistance Surveillance Unit, Laboratory for Foodborne Zoonoses, Public Health Agency of Canada, 160 Research Lane — Unit 103, Guelph, Ontario N1G 5B2 (Reid-Smith, Gow); Ontario Veterinary College, University of Guelph, Guelph, Ontario N1G 2W1 (Reid-Smith).

Address all correspondence and reprint requests to Dr. Leigh B. Rosengren; telephone: (306) 458-2967; fax: (306) 458-2267; e-mail: leigh.rosengren@vetepi.com

Dr. Rosengren's current address is Box 451, Midale, Saskatchewan S0C 1S0.

AMU on swine farms (18–20). In Ontario, AMU data were collected for 2 mo from 34 swine herds (20). The AMU through feed and water was described qualitatively while injectable drug use was described as an exposure incidence. The parenteral exposures calculated from records were 35% lower than those calculated from drug disappearance. Underreporting was a primary reason for this discrepancy despite efforts to simplify the collected data (20). This illustrates some of the challenges in describing AMU in individual animals and the problems with prospective data collection. The primary objective of this study, therefore, was to investigate the use of existing data, supplemented with data from questionnaires, for describing AMU through feed, water, and injection on swine farms in western Canada.

An Alberta study found all of the 76 farrow-to-finish producers surveyed included antimicrobials in nursery diets more than 95% of the time, and that 83% of these producers used antimicrobials in grower diets more than 95% of the time (19). These data, however, provide little insight into how the selective pressures for AMR change within barns over time because the consistency of the drug used, dose, and duration of exposure was not described. The secondary objective of the present study, therefore, was to describe AMU for 12 mo; these data enabled subsequent investigation into risk factors for AMR in these 20 farms (22,30).

Materials and methods

Herd selection and data collection

Eight veterinarians, 7 of whom practiced swine medicine exclusively, enrolled swine farms in Saskatchewan (n = 13) and Alberta (n = 7). Each veterinarian enrolled 2 to 4 farms that had a minimum of 100 sows, maintained pigs until market weight, and were enrolled in the Canadian Quality Assurance (CQA) Program (21). Study herds were visited once between May and September of 2004 by a study veterinarian who administered questionnaires to the herd owners or managers. The questionnaires pertained to AMU, herd inventory, and the pig flow through production (22). The study veterinarian photocopied all available CQA records describing AMU including the 'Medication and Vaccine Usage Plan On Farm,' the 'Rations Used On Farm,' and the 'Pen or Individual Treatment Records for all Pigs beyond the Weaning Phase' (21). Collected data were organized using a relational database (Microsoft Access; Microsoft Corporation, Redmond, Washington, USA) and descriptive statistics were calculated using Microsoft Excel (Microsoft Corporation).

Feed and water (group) exposure

Data were collected on antimicrobial exposures through feed by photocopying CQA forms and administering a questionnaire (21,22). The CQA program only required producers to record water-soluble AMU in grow-finish pigs and sows, so questionnaires were administered to describe AMU through drinking water.

A "group antimicrobial exposure" is the use of an antimicrobial in a production phase at 1 intended dose. Use of the same product at a different dose or in a different age category of pigs was considered as a separate exposure. For each exposure in the previous 12 mo data were collected on the production phase exposed, antimicrobial used, number of pigs exposed, duration of exposure, intended concentration of drug administered, and the primary reason for drug use. The group antimicrobial exposure rate (AER_G) per 1000 "pig-days" was determined for each exposure (Equation 1). Each day that antimicrobials were offered was an event in the numerator.

$$AER_G = [(Pigs_E \times Days_E)/(Pigs_R \times Days_R)] \times 1000 \quad \textit{(Equation 1)}$$

Where: E = exposed
R = at risk

All herds had open populations; animals had entered and left the herd during previous 12 mo. Inventory data did not identify individual animals or batches of pigs. The "pigs-at-risk" was the average number of pigs moved into and out of each phase over this time. This assumed that mortality and culls occurred, on average, halfway through each phase. The "time-at-risk" was the average number of days spent in each phase. Time-weighted averages accounted for groups of pigs within a phase with different durations at risk. This occurred in herds where animals were sold as breeding stock or where batches of nursery pigs were sold at a younger age than the typical transfer age to grow-finish. Combination drug products were considered as a single exposure regardless of the number of antimicrobials they contained except when describing exposure to individual antimicrobials.

Parenteral (individual) exposure

Data on parenteral AMU in the previous 12 mo were obtained through 1 of 2 methods. When parenteral AMU records were unavailable in a production phase, the study veterinarian administered a questionnaire to collect data on the typical frequency of antimicrobial exposures, the most commonly used antimicrobials, typical dose, duration and reason for use (22). When parenteral exposure records were available they were photocopied, and all available data describing the antimicrobial used, number of pigs exposed, dose and duration of exposure, were subsequently entered into the database. These data were used to calculate the parenteral antimicrobial exposure incidence (AEI_P) (Equation 2). All pig exposures to a drug within 5 d were considered a single exposure because the CQA form for recording individual animal treatments only indicates that a pig was exposed, not the number of times. Hence, parenteral AMU was described as an exposure incidence while feed and water AMU were described as an exposure rate. The parenteral antimicrobial exposure incidence (AEI_P) was adjusted for herds that had missing data, because of lost or incomplete records for the previous twelve mo. This was accomplished by multiplying the denominator by the percent of records available. Data were assumed to be missing at random.

$$AEI_P = Pigs_E/[Pigs_R \times Days_R \times \text{percent of records available}] \quad \textit{(Equation 2)}$$

Where: E = exposed
R = at risk

Statistical analysis and data comparisons

Statistical models were adjusted for clustering in herds using generalized estimating equations (PROC GENMOD, SAS version 9.1;

Table I. Probability and 95% confidence intervals of antimicrobial exposure by a given route per pig-day and distribution of the antimicrobial exposure rates/incidences per 1000 pig-days of each production phase in herds with any use (N = 20 herds)

Phase	Administration route	Probability of exposure	95% Confidence interval	Exposure rate/incidence in herds reporting use		
				Herds	Median	IQR
Suckling	Feed[b,d]	0.17	0.05–0.44	10	333	276–492
	Water	—	—	0	—	—
	Parenteral[b,c,d]	0.04	0.02–0.07	20	29	11–57
Nursery	Feed[a,c,d]	0.78	0.55–0.92	19	667	394–1000
	Water[c,d]	0.06	0.02–0.19	8	200	125–514
	Parenteral[a]	0.001	0.0004–0.002	18	1	0–1
Grow-finish	Feed[b,d]	0.31	0.16–0.51	15	714	160–977
	Water[b]	0	0–0.001	3	5	3–8
	Parenteral[a,d]	0.0003	0.0001–0.0009	15	0	0–0
Sow	Feed[a,b,c]	0.03	0.01–0.09	8	49	15–197
	Water[b]	0	0–0.004	1	7	—
	Parenteral[a,c]	0.001	0.0004–0.002	20	1	0–1

Feed, $n = 80$, parenteral, $n = 79$, and water, $n = 60$.

IQR — Interquartile range.

[a] Different from suckling piglets ($P < 0.05$).

[b] Different from nursery pigs ($P < 0.05$).

[c] Different from grow-finish pigs ($P < 0.05$).

[d] Different from sows ($P < 0.05$).

SAS Institute, Cary, North Carolina, USA). All models had a logit-link function, binomial distribution, and exchangeable correlation structure, and were adjusted for the production phase exposed. Binomial response models estimated the probability of exposure to an antimicrobial by feed, water, or injection for pigs in each production phase. The outcome was the number of exposure events in the numerator and the "pig-days-at-risk" in the denominator. Model convergence was a problem when estimating exposure by water; therefore, this model was restricted to exposures of nursery pigs, grow-finish pigs and sows because no water exposure occurred in suckling piglets. The probability of exposure was estimated by the effect estimate (β) and 95% confidence intervals (CI) in the formula $1/[1 + \exp(-\beta)]$ (23). Significant differences were noted in pair-wise comparisons between phases within routes. The difference between the 2 methods used to collect parenteral AMU data was investigated by considering the data source, 'questionnaire' versus 'existing records,' as a predictor of AEI_P. The association was reported as an odds ratio (OR = $\exp\beta$) with 95% CI (23). Associations were reported as statistically significant if $P < 0.05$.

Results

Herd description

The 20 study herds had a median of 456 sow [interquartile range (IQR), 274 to 1042]. Seven herds sold animals for breeding stock while the remaining 13 sold animals only for slaughter. Fifteen herds had all animals located on 1 site, 2 herds had the finishing unit separated from the breeding and nursery barns, and 3 herds had the breeding, nursery, and grow-finish phases housed in separate locations.

Every producer provided records that described the pig inventories at the time of data collection and 12 mo previous, allowing the pigs-at-risk to be calculated for each phase. Likewise, every producer described the duration pigs were kept in each production phase enabling calculation of the time-at-risk. Grow-finish pigs in 2 herds were not exposed to any antimicrobials. In every other herd, pigs in all production phases had some antimicrobial exposure.

Antimicrobial use through feed

Every producer provided the CQA records describing in-feed AMU. Questionnaire data on the number of pigs exposed and duration of each exposure were provided from computerized records, calendars, other farm records, or recall. Of the 95 exposures reported through feed, 75% had been administered to every pig in the previous 12 mo. Thus, only 25% relied on records to calculate the number of pigs exposed.

One producer reported no AMU through feed in any production phase. Of the other 19, all added antimicrobials to nursery diets, 15 to grow-finish diets, 10 to suckling piglet diets (commonly referred to as creep diets), and 8 to sow diets (Table I). The probability of nursery pig exposure was twice any other production phase. Chlortetracycline, lincomycin, tiamulin, and tylosin were the predominant drugs administered through feed (Table II). Producers reported more than 90% of the antimicrobials added to sow diets were to treat disease compared to less than 20% in the other pig phases (Table III). The opposite occurred with AMU for disease prevention. Producers reported that roughly 80% of creep and nursery diet exposures were to prevent disease compared to less than 10% of the use in sows. The only production phase with substantial growth promotion AMU reported was grow-finish (Table III).

Table II. Antimicrobial exposure rate per 1000 pig days through feed, by product, in herds with an exposure rate greater than zero (N = 20)

		Feed antimicrobial exposure rate		
Phase	Antimicrobial	Herds	Median	Interquartile range
Suckling	Chlortetracycline	5	333	232–455
	Tiamulin	4	184	29–465
	Lincomycin	3	700	333–778
	Spectinomycin	3	700	333–778
	Penicillin G	3	286	190–333
	Sulfonamides[a]	3	286	190–333
	Tylosin	1	286	—
Nursery	Chlortetracycline	13	226	198–614
	Lincomycin	10	433	248–826
	Tiamulin	9	264	190–475
	Spectinomycin	6	319	137–525
	Tylosin	5	316	257–750
	Penicillin G	4	175	126–221
	Sulfonamides[a]	4	175	126–221
	Tilmicosin	1	200	—
	Oxytetracycline	1	173	—
	Neomycin	1	173	—
Grow-finish	Tylosin	11	500	111–953
	Lincomycin	5	697	217–1000
	Chlortetracycline	1	720	—
	Tilmicosin	1	52	—
	Penicillin G	1	24	—
	Sulfonamides[a]	1	24	—
Sow	Oxytetracycline	3	37	16–233
	Chlortetracycline	2	99	—
	Lincomycin	2	18	—
	Tylosin	1	300	—
	Penicillin G	1	64	—

[a] The specific sulfonamide used was not available for all herds.

Antimicrobial use through water

A list of the water-soluble antimicrobials used on each farm was obtained from CQA records and each exposure was described from records similar to the in-feed AMU. Of the 13 exposures reported from the study herds, 7 exposures were reportedly given to every pig in the production phase over the previous year, while 6 exposures relied on records to calculate the number of pigs that had been exposed.

Antimicrobials were administered by water in 10 herds; 6 producers reported use in nursery pigs only, 2 in nursery and grow-finish pigs, 1 in grow-finish pigs only, and 1 in sows. In herds with water AMU, the median nursery exposure rate was 40 times higher than in the grow-finish phase (Table I). In nursery pigs, the predominant reason for water exposure was to prevent disease. The reported reason for all use in grow-finish pigs and sows was to treat disease (Table III). In nursery and grow-finish pigs, the most commonly used antimicrobial was penicillin G (Table IV).

Table III. Percent of group antimicrobial exposure rate (AER_G) according to producer-declared reason for antimicrobial use

		Percent group antimicrobial exposure rate		
Route	Phase	Disease treatment	Disease prevention	Growth promotion
Feed	Suckling	18.5	81.5	0.0
	Nursery	12.9	79.9	7.2
	Grow-finish	10.8	47.1	42.1
	Sow	93.0	7.0	0.0
Water	Nursery	13.6	86.4	—
	Grow-finish	100.0	0.0	—
	Sow	100.0	0.0	—

Table IV. Antimicrobial exposure rate per 1000 pig-days through water, by product, in herds with a treatment rate greater than zero (N = 20)

		Water antimicrobial exposure rate		
Phase	Antimicrobial	Herds	Median	Interquartile range
Nursery	Penicillin G	4	252	194–823
	Neomycin	3	71	12–600
	Sulfonamide[a]	2	108	—
	Tetracycline	1	600	—
	Amoxicillin	1	194	—
Grow-finish	Penicillin G	2	6	—
	Tetracycline	1	5	—
Sow	Tetracycline	1	7	—

[a] The sulfonamide derivative was not available for all herds.

Parenteral antimicrobial use

The availability of parenteral exposure records differed markedly between herds. One herd had no existing records and 1 herd provided records for all production phases. The data collected from existing records always included the antimicrobial used, production phase exposed, and number of pigs exposed, and for most exposures the dose administered had been recorded (Table V). The duration of exposure was often unavailable, which was expected because the CQA program did not require these data (21). With one exception, producers unable to supply existing records completed a questionnaire describing parenteral AMU: data from 1 herd were insufficient to calculate the AEI_P in the nursery. Producers relied exclusively on recall to complete the parenteral exposure questionnaires. The AEI_P was higher in herds providing data by questionnaire compared to data from existing records (OR, 2.9; 95% CI, 1.5 to 5.6; $P = 0.002$).

Every producer administered parenteral antimicrobials to suckling piglets and sows, 1 reported no use in nursery pigs, and 5 reported no use in grow-finish pigs. Suckling piglets were routinely injected in 9 herds; all piglets were injected once in 6 herds, and twice in 3 herds. All sows were routinely injected with an antimicrobial after farrowing in 1 herd. For all phases, the parenteral exposure incidence was very low relative to exposure rates through feed or water (Table I).

Table V. Availability and completeness of on-farm parenteral antimicrobial use data (N = 20 herds)

	Phase			
	Suckling	Nursery	Grow-finish	Sow
Herds providing any records	1	4	19	12
12 months	1	2	16	10
10 to 11 months	—	—	—	1
8 to 9 months	—	2	3	1
Total exposures	1336	3466	9968	1577
Exposures with dose recorded (%)	1190 (89)	3424 (98)	9805 (98)	1276 (81)
Exposures with duration recorded (%)	1336 (100)	2475 (71)	2386 (24)	658 (42)

Table VI. Parenteral antimicrobial exposure incidence per 1000 pig days, by product, in herds with an exposure incidence greater than zero and providing data by existing records (Nursery N = 4, Grow-finish N = 19, Sow N = 12)

		Parenteral antimicrobial exposure incidence		
Phase	Antimicrobial	Herds	Median	Interquartile range
Nursery	Penicillin G[a]	4	0.14	0.02–0.56
	Trimethoprim-sulfadoxine	4	0.04	0.01–0.45
	Oxytetracycline	4	0.04	0.01–0.18
	Ceftiofur	2	0.16	—
	Lincomycin	2	0.04	—
Grow-finish	Penicillin G[a]	14	0.08	0.01–0.41
	Trimethoprim-sulfadoxine	8	0.03	0.01–0.18
	Ceftiofur	7	0.01	0.002–0.03
	Oxytetracycline	5	0.05	0.00–0.10
	Lincomycin	4	0.14	0.01–0.45
	Tylosin	3	0.001	0.000–0.004
	Tiamulin	1	0.22	—
	Ampicillin	1	0.1	—
Sow	Penicillin G[a]	12	0.16	0.06–0.46
	Trimethoprim-sulfadoxine	9	0.11	0.02–0.23
	Oxytetracycline	8	0.2	0.01–0.61
	Tylosin	4	0.05	0.01–0.11
	Ceftiofur	3	0.004	0.002–0.01
	Lincomycin	2	0.23	0.01–0.45
	Ampicillin	1	0.03	—

[a] Procaine and benzathine penicillin G use could not be distinguished.

Although suckling piglets received the most parenteral antimicrobials, records were the least available for this phase. Therefore, data on the most common products used in suckling piglets came from the questionnaires. Fourteen producers listed penicillin G as 1 of the 2 most common drugs used in their suckling piglets, 9 listed trimethoprim-sulfadoxine, and 6 listed ceftiofur. Other antimicrobials mentioned less frequently were oxytetracycline, spectinomycin, and gentamicin. In the other phases, the parenteral products used were described from existing records and ranked by the exposure incidence (Table VI). Penicillin G was used in every herd and trimethoprim-sulfadoxine was used in most.

Discussion

Farm level data allow the relationship been AMU and AMR to be studied while accounting for confounding factors such as herd management. Published North American studies have quantified exposures to injectable drug, but have only qualitatively described exposures to antimicrobials through feed and water (18,20,24–27). Quantifying AMU is desirable, but challenging. Maintaining records is labor-intensive so prospective studies may be subject to participation bias and may underestimate use because of underreporting (20). Retrospective data may be subject to recall bias (23). In this

study, CQA records, supplemented with questionnaires, were used to estimate phase-specific antimicrobial exposure rates. Bias was not formally investigated; however, using records that producers maintained regardless of participation in the study should have minimized participation bias and using existing records should have minimized recall bias. The use of existing records also allowed AMU to be described over 12 mo, thus avoiding concerns of seasonal variations in disease and AMU.

The primary objective of the CQA drug use records is to prevent antimicrobial residues at slaughter (21). This program was not designed to address AMR and the forms do not collect sufficient data to allow antimicrobial consumption to be quantified. Instead of an estimate of antimicrobial consumption, AMU was described as the AER_G. This metric describes the intention to expose pigs to antimicrobials and assumes every animal consumed the offered feed or water. Hence, creep feed estimates overstated exposure because consumption in suckling piglets is low and variable, and feed wastage is not accounted for (28). In the other production phases, the AER_G data might approximate consumption. A prospective study could investigate this by comparing reported exposures to feed tags, invoices, or feed disappearance.

In humans a standardized system of defined daily doses (DDD) is used to describe drug use. The DDD reflects the average maintenance dose per day in a human adult for a drug's major indication and is useful for considering the selective pressure for resistance (10,15). This methodology has been extended to livestock. Denmark has described AMU data as animal daily doses (ADD), and a Belgian research project describes the prescribed and used daily doses on swine farms (15,29). To date, internationally accepted ADDs are not available and the commonly prescribed/used doses in Canadian pigs have not been established. Standardized metrics are most valuable when definitions are stable (10,15). Therefore, AMU was described as exposure rates, rather than ADDs, because standard dose definitions are required to compare ADDs across studies and these definitions must be consistent for data to remain useful over time.

Parenteral AMU was more challenging to describe than feed or water exposure. Parenteral AMU records for nursery and suckling piglets were not available in most herds because, at the time of data collection, the CQA program required producers to maintain records only for animals over 22 kg (21). Sow exposure data were not available in some herds because records were maintained on sow cards that traveled with the sow and were often not retained between parities.

In addition to a lack of records, 2 concerns arose with estimating the antimicrobial exposure rates from existing records. First, the exposures per treatment regimen were often not available, thereby limiting exposure description to the parenteral exposure incidence rather than the rate. Second, the AEI_P was significantly higher for pigs in herds where data was reported by questionnaire rather than taken from existing records. Although the data from questionnaires could have overestimated the injectable use, others have found that treatment records underestimated this use by 35% compared to inventory disappearance (20). In this study, existing records likely underestimated parenteral AMU because records were often kept in the rooms with the pigs thus subjecting them to loss and/or damage. Additionally, treatments may go unreported during staff shortages or disease outbreaks. On-farm records were, therefore, useful for describing what injectable antimicrobials were used on study farms, but were insufficient to describe parenteral antimicrobial exposure rates.

The producers that completed questionnaires on parenteral AMU described the typical exposure rates, reasons for AMU, and doses by recall. Antimicrobial use may be inconsistent across seasons or groups of pigs, however, and a producer's estimate of drug use could be biased by the current rate of use in the barn; this might result in an over- or underestimation of the true exposure. As the study was retrospective, we were unable to assess the extent of this potential bias. The parenteral exposure questionnaire was also limited because the exposure incidence could not be stratified by antimicrobial. Producers listed the 2 most commonly used antimicrobials in the production phase, as well as the 1st and 2nd choice treatments for common disease problems, but this was insufficient to calculate the exposure incidence to individual antimicrobials. This limitation restricted the number of herds in the description of AEI_P by product and precluded considering AEI_P as a risk factor for AMR in *Escherichia coli* and *Campylobacter* (22,30).

The herd selection and the study inclusion criteria could have affected AMU estimates and the availability of AMU data. This study was limited to herds with more than 100 sows to better represent market hog production in western Canada. Although 70% of Saskatchewan pig farms marketed less than 1000 pigs in 2004 (which roughly corresponds to herds of 50 sows or less), these farms marketed less than 3% of Saskatchewan's pigs (31). The herds enrolled in this study were a convenience sample based on the presence of a veterinary — client — patient (VCP) relationship. This could be important considering United States producers with a VCP relationship were more likely to use feed grade antimicrobials than those without (26). It is also plausible that herds with a VCP relationship might maintain better records than those without. All study herds were enrolled in the CQA program (21). While this may have affected AMU, and almost certainly affected the availability of AMU data, the herds were reflective of western Canada at the time of the study; 98% of market hogs produced in Alberta and 99.8% in Saskatchewan came from herds enrolled in the CQA program (Harvey Wagner, Sask Pork; Sarah Turner, Alberta Pork; personal communication).

Describing AMU as rates and incidences made it difficult to compare these data to previous reports; however, the proportion of producers using antimicrobials by each route, and the most commonly used products, were similar to a description of 90 Alberta swine farms (19). Combining the detailed, semi-quantitative data from this study with the robust, but qualitative, data from the previous larger study provides a detailed account of AMU in this important swine-producing region of Canada (19). Future research should investigate if exposure rates, common dosage regimens, and feed budgets can be combined to accurately estimate antimicrobial consumption. If so, this data collection methodology could be extended to describe antimicrobial consumption, which would facilitate comparison over time and between studies (32,33). Finally, the differences in the administration routes between age categories suggest AMU data collection could be tailored to each production phase. Retrospective on-farm data did not adequately

describe AMU in suckling piglets because of the high rates of parenteral exposure and the overestimation of exposure through creep feed. In contrast, on-farm records were a practical way to describe AMU in the other production phases. On-farm records revealed that most exposures were through feed and water, and were given to all pigs at the same dose and for the same duration. In conclusion, on-farm records were useful for describing group medication in pigs beyond weaning in these herds, but were inadequate for describing parenteral AMU in any phase or antimicrobial exposures of suckling piglets.

Acknowledgments

The authors thank all of the swine producers and veterinarians that participated in this study. Financial support from the Sask Pork Development fund and the Public Health Agency of Canada is also gratefully acknowledged.

References

1. Martin LJ, Fyfe M, Doré K, et al. The Multi-Provincial *Salmonella* Typhimurium Case-Control Study Steering Committee. Increased Burden of Illness Associated with Antimicrobial-Resistant *Salmonella enterica* Serotype Typhimurium Infections. J Infect Dis 2004;189:377–384.
2. Barza M. Potential mechanisms of increased disease in humans from antimicrobial resistance in food animals. Clin Infect Dis 2002;34 S3:S123–125.
3. Harvey RB, Anderson RC, Genovese KJ, Callaway TR, Nisbet DJ. Use of competitive exclusion to control enterotoxigenic strains of *Escherichia coli* in weaned pigs. J Anim Sci 2005;83:44–47.
4. Fairbrother JM, Nadeau É, Gyles CL. *Escherichia coli* in postweaning diarrhea in pigs: An update on bacterial types, pathogenesis, and prevention strategies. Animal Health Research Reviews 2005; 6:17–39.
5. McEwen SA, Fedorka-Cray PJ. Antimicrobial use and resistance in animals. Clin Infect Dis 2002;34 S3:S93–106.
6. Delsol AA, Anjum M, Woodward MJ, Sunderland J, Roe JM. The effect of chlortetracycline treatment and its subsequent withdrawal on multi-resistant *Salmonella enterica* serovar Typhimurium DT104 and commensal *Escherichia coli* in the pig. J Appl Microbiol 2003;95:1226–1234.
7. Delsol AA, Sunderland J, Woodward MJ, Pumbwe L, Piddock LJV, Roe JM. Emergence of fluoroquinolone resistance in the native *Campylobacter coli* population of pigs exposed to enrofloxacin. J Antimicrob Chemother 2004;53:872–874.
8. Dunlop RH, McEwen SA, Meek AH, Clarke RC, Black WD, Friendship RM. Associations among antimicrobial drug treatments and antimicrobial resistance of fecal *Escherichia coli* of swine on 34 farrow-to-finish farms in Ontario, Canada. Prev Vet Med 1998;34:283–305.
9. Blake DP, Humphry RW, Scott KP, Hillman K, Fenlon DR, Low JC. Influence of tetracycline exposure on tetracycline resistance and the carriage of tetracycline resistance genes within commensal *Escherichia coli* populations. J Appl Microbiol 2003;94:1087–1097.
10. Chauvin C, Madec F, Guillemont D, Sanders P. The crucial question of standardization when measuring drug consumption. Vet Res 2001;32:533–543.
11. DANMAP. Uses of antimicrobial agents and occurrence of antimicrobial resistance in bacteria from food animals, foods and humans in Denmark. DANMAP, National Veterinary Institute, National Food Institute, 2005. [database on the Internet] Available from http://www.danmap.org/ Last accessed May 14, 2007.
12. SVARM. Swedish Veterinary Antimicrobial Resistance Monitoring. Uppsala, Sweden: The National Veterinary Institute (SVA), 2004. [database on the Internet]. Available from www.sva.se Last accessed May 14, 2007.
13. NORM/NORM-VET 2003. Usage of Antimicrobial Agents and Occurrence of Antimicrobial Resistance in Norway. Tromso, Oslo: National Veterinary Institute, 2004. [database on the Internet]. Available from www.zoonose.no Last accessed May 14, 2007.
14. Veterinary Medicines Directorate. Sales of Antimicrobial Products used as Veterinary Medicines, Growth Promoters and Coccidiostats in the UK. Antibiotic Related Publications. [homepage on the Internet]. Available from http://www.vmd.gov.uk/Publications/Antibiotic/AntiPubs.htm Last accessed May 14, 2007.
15. Jensen VF, Jacobsen E, Bager F. Veterinary antimicrobial-usage statistics based on standardized measures of dosage. Prev Vet Med 2004;64:201–215.
16. Singer RS, Reid-Smith R, Sischo WM. Stakeholder position paper: Epidemiological perspectives on antibiotic use in animals. Prev Vet Med 2006;73:153–161.
17. Carnevale RA, Shryock TR. Animal health pharmaceutical industry. Prev Vet Med 2006;73:217–220.
18. Dunlop RH, McEwen SA, Meek AH, Friendship RA, Clarke RC, Black WD. Antimicrobial drug use and related management practices among Ontario swine producers. Can Vet J 1998;39: 87–96.
19. Rajić A, Reid-Smith R, Deckert AE, Dewey CE, McEwen SA. Reported antibiotic use in 90 swine farms in Alberta. Can Vet J 2006;47:446–452.
20. Dunlop RH, McEwen SA, Meek AH, Black WD, Clarke RC, Friendship RM. Individual and group antimicrobial usage rates on 34 farrow-to-finish swine farms in Ontario, Canada. Prev Vet Med 1998;34:247–264.
21. Canadian Pork Council. Canadian Quality Assurance Producer Materials. CQA For Canadian Hog Producers. Last Updated 2007. [homepage on the Internet]. Available from http://www.cqa-aqc.ca/home_e.cfm Last accessed March 17, 2007.
22. Rosengren L. Antimicrobial resistance of *Salmonella, Escherichia coli* and *Campylobacter* from pigs on-farm in Alberta and Saskatchewan Canada [PhD dissertation]. Saskatoon, Saskatchewan: University of Saskatchewan, 2007.
23. Dohoo I, Martin W, Stryhn H. Veterinary Epidemiologic Research. Charlottetown, PEI: AVC Inc., 2003.
24. Rajić A. Prevalence, Antimicrobial Resistance and Risk Factors for *Salmonella* in 90 Alberta Swine Finishing Farms [PhD dissertation]. Guelph, Ontario: University of Guelph, 2005.

25. Dewey CE, Cox BD, Straw BE, Bush EJ, Hurd HS. Use of antimicrobials in swine feeds in the United States. J Swine Health Prod 1999;7:19–25.
26. Dewey CE, Cox BD, Straw BE, Bush EJ, Hurd HS. Associations between off-label feed additives and farm size, veterinary consultant use, and animal age. Prev Vet Med 1997;31:133–146.
27. Bush EJ, Biehl LG. Use of antibiotics and feed additives in weaned market pigs by U.S. pork producers. Proceedings of American Association of Swine Veterinarians 2002:329–331.
28. Pluske JR, Le Dividich J, Hampson DJ. Nursery Pig Management. In: Straw BE, Zimmermann JJ, D'Allaire S, Taylor DJ, eds. Diseases of Swine. 9th ed. Ames, Iowa: Blackwell Publishing, 2006:1039–1053.
29. Timmerman T, Dewulf J, Catry B, et al. Quantification and evaluation of antimicrobial drug use in group treatments for fattening pigs in Belgium. Prev Vet Med 2006;74:251–263.
30. Rosengren L, Waldner C, Reid-Smith R, Dowling P, Harding J. Associations between feed and water antimicrobial use in farrow-to-finish swine herds and antimicrobial resistance of fecal *Escherichia coli* from grow-finish pigs. Microb Drug Resist 2007;13 *(In press)*.
31. Sask Pork. Annual Report 2004–2005. Sask Pork 2005. [homepage on the Internet]. Available from http://www.agr.gov.sk.ca/agrifood/boards/SKPorkAnnualRpt2005.pdf Last accessed March 19, 2007.
32. World Health Organization. Joint First FAO/OIE/WHO Expert workshop on Non-human Antimicrobial Usage and Antimicrobial Resistance: Scientific Assessment. Geneva, Switzerland: 2003. [homepage on the Internet]. Available from http://www.who.int/foodsafety/publications/micro/en/amr.pdf Last Accessed March 22, 2007.
33. Nicholls T, Acar J, Anthony F, et al. Antimicrobial resistance: Monitoring the quantities of antimicrobials used in animal husbandry. Rev Sci Tech 2001;20:841–847.