Antimicrobial use in the Alberta sheep industry

Brent P. Avery, Andrijana Rajić, Margaret McFall, Richard J. Reid-Smith, Anne E. Deckert, Rebecca J. Irwin, Scott A. McEwen

Abstract

Information regarding antimicrobial use in sheep is scarce. In 2001, a scrapie surveillance program was initiated in Alberta that also provided a mechanism for collecting other sheep health data including antimicrobial use information between April 2001 and April 2002. A major objective of this study was to describe antimicrobial use in the Alberta sheep industry. This was done by obtaining qualitative antimicrobial use information from all flocks (n = 212) providing cull ewes to the program using a brief, primarily flock-level, questionnaire. The respondents' flocks represented 13.6% of the total provincial flock in Alberta in 2001. By a substantial amount, the most frequent method of administering antimicrobials was through injection followed by in-feed, oral (liquids, pills, boluses), and in-water routes, respectively. Drug-specific use data were collected for injectable antimicrobials only, with the most commonly used antimicrobial classes being penicillins followed by tetracyclines. Producers rarely treated some or all of their flock with injectable antimicrobials after discovering an individual sick animal. Adult sheep were the most common age group treated with injectable antimicrobials and the most frequent reason for injectable antimicrobial use was mastitis followed by respiratory problems. This study provides some initial insight regarding antimicrobial use in Alberta sheep flocks. However, collection of more drug-specific data (drug type, dose/concentration, duration of treatment) for noninjectable routes of administration should be conducted in future studies. Assessing antimicrobial use in other sectors of the Alberta sheep industry (feedlots) and other provinces across Canada would also be beneficial.

Résumé

*Les informations concernant l'utilisation des antimicrobiens chez les moutons sont peu nombreuses. En 2001, un programme de surveillance de la tremblante du mouton a été initié en Alberta et a permis également d'amasser des données supplémentaires sur la santé des moutons, incluant des informations sur l'utilisation des antimicrobiens entre avril 2001 et avril 2002. Un objectif majeur de l'étude était de décrire l'usage des antimicrobiens au sein de l'industrie ovine en Alberta. Ceci a été accompli en obtenant des informations qualitatives sur l'utilisation d'antimicrobiens de tous les troupeaux (*n = *212) fournissant des brebis de réforme au programme à l'aide d'un questionnaire bref se limitant à des questions s'appliquant au troupeau. Le nombre de troupeaux ayant répondu représentait 13,6 % du nombre total de troupeaux en Alberta en 2001. Par une marge importante, la voie d'administration des antimicrobiens la plus fréquente était par injection, suivie par la nourriture, de manière orale (liquide, pilule, bolus) et dans l'eau de boisson. Des données spécifiques sur des antimicrobiens n'ont été obtenues que pour des produits injectables, les classes d'antimicrobiens les plus couramment utilisées étant les pénicillines, suivies des tétracyclines. Les producteurs traitent rarement quelques animaux ou tout le troupeau avec des antimicrobiens injectables suite à la mise en évidence d'un animal malade. Le groupe d'animaux le plus fréquemment traité avec des antimicrobiens injectables était les adultes et la principale raison du traitement était la mammite, suivie des problèmes respiratoires. La présente étude a fourni des informations préliminaires sur l'utilisation des antimicrobiens dans les troupeaux de moutons en Alberta. Toutefois, la collecte de données supplémentaires spécifiques sur des médicaments (type de médicament, dose/concentration, durée du traitement) administrés par voies autres que par injection devrait être effectuée dans des études ultérieures. L'évaluation de l'utilisation des antimicrobiens dans d'autres secteurs de l'industrie ovine en Alberta (parcs d'engraissement) et dans d'autres provinces canadiennes serait également bénéfique.*

(Traduit par Docteur Serge Messier)

Introduction

In some countries, antimicrobial use in the extensive production of sheep has been less frequently described than in species where production is typically more intensive (poultry, swine) (1). In North America, because sheep are a relatively minor species in comparison to cattle, swine, and poultry, few drugs are specifically labelled for ovine use. Therefore, much of the antimicrobial use that occurs in this species is classified as extra-label use with dosage, administration frequency, indication, and drug withdrawal times often being extrapolated from information based on other species (2,3,4).

Public Health Agency of Canada, Laboratory for Foodborne Zoonoses, Guelph, Ontario N1G 5B2 (Avery, Rajić, Reid-Smith, Deckert, Irwin); Population Medicine, Ontario Veterinary College, University of Guelph, Guelph, Ontario N1G 2W1 (Avery, Rajić, Reid-Smith, Deckert, McEwen); Food Safety Division, Alberta Agriculture and Food, Edmonton, Alberta T7H 4P2 (McFall).

Address all correspondence and reprint requests to Brent P. Avery; telephone: (519) 826-2354; fax: (519) 826-2255; e-mail: brent_avery@phac-aspc.gc.ca

The corresponding author's current address is 160 Research Lane — Suite 103, Guelph, Ontario N1G 5B2.

This article is part of the corresponding author's (Avery) MSc thesis, University of Guelph, Guelph, Ontario.

Accurate estimates of the volume of antimicrobials used in animal production in Canada, including sheep and lamb, do not exist. However, estimates are available for the United States that may reflect the situation in Canada. The Union of Concerned Scientists estimated that livestock producers use 24.6×10^6 lb (11.2×10^6 kg) of antimicrobials each year in the United States; however, this estimate only represents antimicrobials used for nontherapeutic purposes in 3 animal production sectors (cattle, swine, and poultry) (5). This amount would be even greater if antimicrobials utilized for therapeutic reasons as well as those used in all animals were included. The estimates published by the Union of Concerned Scientists, however, are based on numerous assumptions and expert guidance and thus, may be inaccurate. Other animal antimicrobial use estimates are available through the Animal Health Institute (AHI), the advocacy group for the American veterinary pharmaceutical industry. The AHI conducts annual surveys on antimicrobial sales by their member companies. The AHI's latest (2005) estimates suggest that the total volume of antimicrobials sold for animal use purposes by their member companies was approximately 24.4×10^6 lb (11.1×10^6 kg) with the majority (95.5%) being sold for therapeutic animal use and the remainder (4.5%) being sold for the purposes of increasing feed efficiency, promoting growth, and maintaining animal health (6). There are some methodological limitations pertaining to the AHI estimates, and it has been suggested that previous figures published by the AHI of the total amount of antimicrobials sold for animal use have been considerably underestimated (5). Needless to say, very little published information is available concerning the type and quantity of antimicrobial use in the Canadian sheep industry. The objective of this paper was to describe antimicrobial use in the Alberta sheep industry.

Materials and methods

General study aspects

In 2001, a surveillance program was initiated in Alberta to monitor sheep for scrapie, a degenerative disease of sheep and goats belonging to a family of diseases known as transmissible spongiform encephalopathies or TSEs. This program was also used to collect information on other diseases and conditions including Johne's disease, maedi-visna, caseous lymphadenitis, foot rot, mastitis, and antimicrobial resistance in bacteria of ovine origin.

Selection of sheep producers

Sheep producers from across Alberta were informed of this surveillance program through an advertisement placed in an industry newsletter and on a Web site produced by the Alberta Sheep and Wool Commission (ASWC) (http://www.absheep.com). If an interested producer had cull ewes to donate for this study, they were instructed to contact the ASWC so that the animals could be collected. The ASWC provided trained volunteers to help collect the cull ewes and administer a questionnaire to producers during the farm visit. After the ewes had been collected and ear tagged (both ears) for identification, they were transported to 1 of 3 laboratories, depending on the location of the farm within the province, for physical examination, humane euthanasia, postmortem, and sample (fecal and tissue) collection. Alberta has 7 sheep-rearing zones designated by the ASWC, with each zone containing about the same number of sheep; therefore, sheep were sampled in approximately equal proportions across the 7 zones. Cull ewes donated for the scrapie surveillance program were also used to study potential links between antimicrobial use and resistance.

Collection of antimicrobial use information

Antimicrobial use information was collected using a brief, primarily flock-level questionnaire that was administered to the producer at the farm by trained ASWC personnel. A detailed description of what antimicrobials are and some examples of antimicrobials that could potentially be administered to sheep were provided on the questionnaire to facilitate the capture of accurate data. The questionnaire was used to capture basic, flock-level antimicrobial use data, including information on routes/vehicles of administration, type and frequency of injectable antimicrobial use, most common sheep age group treated with injectable antimicrobials, most frequent reason for treating sheep with an injectable antimicrobial, and whether producers tended to treat some or all of the sheep in the flock with an injectable antimicrobial following discovery of an individual ill animal. In addition to the antimicrobial use data, some basic flock information, such as how many ewes were in the flock, was also captured using the questionnaire.

Data manipulation and statistical analyses

Data generated by the questionnaire were entered into a spreadsheet program (Microsoft Excel 2000; Microsoft, Redmond, Washington, USA). Data were verified for accuracy of entry and transferred into the statistical software package, Stata Intercooled versions 7 and 8, (Stata, College Station, Texas, USA) for descriptive statistical analyses. Frequencies and percentages of producers using various injectable antimicrobials as well as those using antimicrobials in-feed, in the drinking water, and orally (liquid, pills, boluses), were computed. Information regarding the most commonly used injectable antimicrobial in each operation at a flock level, as well as for individual study animals was gathered and frequencies and percentages pertaining to these data were determined. Frequency measures and percentages were also established at the flock level for data regarding the most common age group of sheep treated with antimicrobials and most frequent reason for administering an antimicrobial treatment. Finally, descriptive measures were computed for the practice of treating some or all of the flock with an injectable antimicrobial following the discovery of a single sick sheep.

Results

Antimicrobial use practices in Alberta sheep flocks

In total, 213 questionnaires were submitted, however, one was excluded from the study because it was largely incomplete, leaving 212 questionnaires to be used in the analysis. At the flock level, the most common method of administering antimicrobials during the 12-month period preceding collection of the cull ewes was by injection. Two hundred (94.3%) producers used an injectable

Table I. Producer estimate of the most common injectable antimicrobials used to treat sheep in study flocks (*n* = 212)

Antimicrobial drug	Number of producers using a specific injectable antimicrobial drug most commonly	Percentage of producers using a specific injectable antimicrobial drug most commonly[a] (%)
Penicillins	138	65.1
Tetracyclines	115	54.2
Trimethoprim-sulfa combination	34	16
Florfenicol	9	4.2
Tilmicosin	8	3.8
No use	8	3.8
Ceftiofur	4	1.9
No response	4	1.9

[a] The percentage of producers using a specific injectable antimicrobial drug sums to more than 100% because some producers identified more than one injectable antimicrobial drug as being most commonly used.

Table II. Most common sheep age groups treated with an injectable antimicrobial (*n* = 212)

Age group most commonly treated with an injectable antimicrobial	Number of sheep producers reporting using an injectable antimicrobial most frequently in this age group	Percentage of sheep producers reporting using an injectable antimicrobial most frequently in this age group[a] (%)
Adult sheep	121	57.1
Nursing lambs (10–65 lb or 4.5–29.5 kg)	56	26.4
Grower/feeder lambs (65–110 lb or 29.5–50 kg)	20	9.4
No response	11	5.2
All age groups equally	9	4.2
No use	5	2.4

[a] The percentage of sheep producers reporting using an injectable antimicrobial most frequently in a specific age group sums to more than 100% because some producers identified more than one age group as most commonly treated with an injectable antimicrobial drug.

antimicrobial during this time. Four (1.9%) producers did not indicate whether they had used any injectable antimicrobials in the previous year. The 2nd most common method of administering antimicrobials was in the feed, and was used by 27 (12.7%) study producers. One producer was "not sure" if antimicrobials had been used in the feed. Information on the identity of specific drugs used in the feed was not collected. Nine (4.2%) producers used oral antimicrobials, but 2 producers were unsure if an oral antimicrobial had been used in the flock. Lastly, only 4 (1.9%) producers administered antimicrobials in the drinking water of the sheep, but again, 2 producers were unsure if antimicrobials had been administered in this manner.

The 2 most common injectable antimicrobial classes used by producers in this study were penicillins (65.1%) and tetracyclines (54.2%). A trimethoprim-sulfa combination was used by 16% of the producers where as florfenicol, tilmicosin, and ceftiofur were each used by $< 5\%$ of the producers (Table I).

In total, 351 cull ewes were donated for the scrapie surveillance program, with some antimicrobial use data also being collected for these animals. Specifically regarding study sheep (not the entire flock) from the 22 operations that reported using injectable antimicrobials 30 d prior to collection of the cull ewes, 9 (40.9%) producers indicated that the cull sheep had been treated with oxytetracycline. Additionally, 7 (31.8%) producers described using a penicillin drug in the donated ewes, 2 (9.1%) producers reported previously treating with both oxytetracycline and a penicillin drug, and 1 (4.5%) producer recalled using tilmicosin. Three producers did treat sheep with an injectable antimicrobial, but failed to indicate which drug(s) were used in the donated animals.

From a short list of sheep age groups, producers were asked to select what age group they most commonly treated with injectable antimicrobials. Just over 57% of producers reported using injectable antimicrobials most frequently in adult sheep at a flock level. The use of injectable antimicrobials in nursing lambs followed by use in grower/feeder lambs were the next 2 most common age groups treated as indicated by 26.4% and 9.4% of producers, respectively. Approximately 4% of producers indicated that they used injectable antimicrobials in all age groups in their flock with equal frequency (Table II).

Using a short categorical list of specific sheep health problems, producers were asked to select the most common problem for which injectable antimicrobials were used within their flock. The most commonly reported problem was mastitis, as indicated by 41% of producers. Respiratory problems were the 2nd most frequent problem that required injectable antimicrobial treatment as reported by 37.7% of producers. About 24% of producers expressed that antimicrobial use in ewes subsequent to lambing represented the most common purpose for the use of injectable antimicrobials. Lameness represented the most frequent reason for treating sheep with injectable antimicrobials for 14.2% of producers interviewed. Scouring in lambs was the next most common reason for the use of injectable antimicrobials as indicated by 9.4% of producers. Eight percent of producers selected "other" problems as the most common reason for using injectable antimicrobials (Table III).

Finally, producers enrolled in this study were asked if they treated some or all of the sheep in their flock with an injectable antimicrobial subsequent to the discovery of an individual sick animal. The majority of the producers (93.9%) reported that they never engaged in this practice. Only 3.3% of producers stated that they "sometimes" would do so, and 1.9% said that they would treat all sheep situated in the sick pen following such a discovery (Table IV).

Table III. Most common purpose for treating sheep with an injectable antimicrobial (*n* = 212)

Most common health problem requiring use of an injectable antimicrobial	Number of sheep producers reporting using an injectable antimicrobial for this purpose	Percentage of sheep producers reporting using an injectable antimicrobial for this purpose[a] (%)
Mastitis	87	41
Respiratory problems	80	37.7
Post-lambing (ewes)	51	24.1
Lameness	30	14.2
Scours (lambs)	20	9.4
"Other"	17	8
No antimicrobial treatment	7	3.3
No response	4	1.9

[a] The percentage of producers reporting using an injectable antimicrobial for a specific purpose sums to more than 100% because some producers identified more than one illness that represented the most common purpose for the administration of an injectable antimicrobial drug.

Table IV. Practices involving injectable antimicrobial use in other sheep in the flock following the discovery of illness in an individual sheep (*n* = 212)

Injectable antimicrobial use in other sheep in the flock following the discovery of a single ill animal	Number of producers treating other sheep in the flock with an injectable antimicrobial following the discovery of a single ill sheep	Percentage of producers treating other sheep in the flock with an injectable antimicrobial following the discovery of a single ill sheep (%)
Never	199	93.9
Sometimes	7	3.3
Only sick pen	4	1.9
Not sure	2	0.9

Discussion

In Canada, sheep are primarily produced for meat rather than the production of milk or wool (7); therefore, it is likely that most producers in this study raised sheep for meat purposes, although such data were not collected by the questionnaire. Despite the fact that the sampling procedure used to select flocks for this study was a volunteer-based, convenience sample, the flocks in this study represented 13.6% of the total sheep production in Alberta and 3.3% of the national flock. Furthermore, the flocks enrolled in this study represented 31.9% of the breeding ewe population in Alberta in 2001. This suggests that the study results may provide some useful and somewhat representative information regarding the antimicrobial use behavior of Alberta sheep producers, particularly in traditional sheep rearing operations. In 2001, the average flock size in Alberta was 102 animals (8), which is lower than the average flock size (197 ewes) used in this study. This implies that the flocks sampled in this study may not be completely representative of Alberta sheep flocks in general.

In this study, "in-feed" was the 2nd most common method by which antimicrobials were administered (following injectable antimicrobial use) to sheep; however, this route was used by less than 13% of study producers and the oral and in-water routes represented even smaller percentages. Possible reasons explaining the relatively low amount of in-feed, oral, and in-water antimicrobial use in this study include the relatively low incidence of disease requiring treatment, drug cost, and the relatively low value of the animals (1).

In-feed antimicrobial use is a practice that has been suggested to be a major risk factor in the development of antimicrobial resistance (9,10). Antimicrobials are often administered in the feed in long-term, low doses, which facilitates selection of resistant microbes (1,9,10). Although detailed information on in-feed antimicrobial use was not specifically collected in this study, a prime example of this practice listed in the literature is the addition of specific tetracycline or sulfonamide drugs to the feed of the sheep. Additionally, the in-feed use of a coccidiostat such as an ionophore, has been suggested to be a common practice (2,3). Although ionophores are antimicrobials, the importance of these drugs with respect to antimicrobial resistance remains unclear and controversial. These agents are not used in humans in any manner.

Logistical constraints necessitated that the questionnaire be brief, and thus, the identity, dose, and duration of treatment regarding in-feed and in-water antimicrobials was not obtained in this study. The collection of such data would be beneficial in future studies.

Most of the information gathered from this study focused on injectable antimicrobial use in the Alberta sheep industry; such use represented the vast majority of antimicrobial administration in these flocks. Most producers in this study reportedly did not use injectable antimicrobials for prophylactic, metaphylactic, or group therapy purposes. This is a noteworthy observation, as these methods of administering antimicrobials are thought to exert greater pressure for the selection and persistence of resistant microorganisms compared with individual therapy (1,11–13).

The most commonly used classes of injectable antimicrobials, by a substantial amount relative to other drug classes, were penicillins followed by tetracyclines. Therefore, with regard to injectable antimicrobial use in Alberta sheep flocks, the use of penicillins and tetracyclines may be of considerable potential concern in relation to antimicrobial resistance, considering that these classes of drugs are also used for therapeutic purposes in human medicine (10). In Alberta, these 2 classes of injectable antimicrobials are available "over-the-counter," thus, producers do not require a prescription from a veterinarian to administer these antimicrobials to their animals.

Ceftiofur use was uncommon in Alberta sheep flocks despite the fact that it is licensed for use in sheep. Ceftiofur belongs to the cephalosporin drug class and more specifically, is a group 4, 3rd-generation parenteral cephalosporin. Like many other drug classes, cephalosporins are also used in human medicine (10,13). Group 4, 3rd-generation cephalosporins are often reserved for severe and potentially life-threatening infections in animals (ceftiofur)

and humans (ceftriaxone) (14). The Veterinary Drugs Directorate of Health Canada has proposed a categorization system for antimicrobials according to their importance in human medicine. According to this categorization system, ceftiofur, as well as all other 3rd and 4th generation cephalosporins, are designated as a category I (very high importance in human medicine) antimicrobials. This category is reserved for antimicrobials that are most important in human medicine (15). Considering the importance of antimicrobials like ceftiofur, any practice that may affect resistance to such important "last-line" drugs is of concern. Therefore, the minimal use of ceftiofur by Alberta sheep producers could be considered a favorable finding. Nonetheless, caution should be taken whenever this drug is administered to sheep due to the potential public health impact of such use.

Injectable antimicrobials not licensed for use in sheep were administered to animals in some study flocks. These included trimethoprim-sulfa and florfenicol. This finding is not unexpected considering few antimicrobials are approved for sheep. For this reason, there is often a need to use antimicrobials in an extra-label manner under the supervision of a veterinarian. However, due to the potential human health impact that could result from extra-label drug use in animals, such antimicrobial use in sheep should be monitored (13,16).

When information regarding the most common age groups of sheep treated with injectable antimicrobials was investigated, some notable findings were uncovered. Among study flocks, adult sheep were the class that most commonly received injectable medications. The high usage in adult sheep relative to the other age classes that was observed in this study and the potential associated elevation in risk for resistance in this age class may be of importance with respect to public health. For example, in the United States, a large percentage ($>$ 90%) of traditional (nonfeedlot) sheep rearing operations do not send sheep directly to feedlots (17); this may be the case in Canada as well. Instead, many operations send sheep to auction markets or salesbarns as well as directly to meat packers (17,18). In the Ontario sheep industry, most cull ewes enter the human food chain largely because these animals are not accepted for rendering. This may result from concerns regarding transmission of TSEs, as well as in some areas, there is a substantial local market for adult sheep (Menzies, personal communication; 19). It is possible that the situation is somewhat similar in Alberta, although such information is scarce. Thus, any factor that may promote antimicrobial resistance in these animals, which are often directly introduced into the food chain, could represent a potential risk to public health.

Some producers indicated that grower/feeder lambs were the age group most frequently treated with injectable antimicrobials. Antimicrobial use in this group may be of some concern because these animals could be shipped to 1 of several major feedlots in Alberta; then potentially exposed to additional antimicrobials in this more intensive production setting, possibly further selecting for resistant bacteria (1).

In summary, antimicrobial use is postulated to be a risk factor for the selection of resistant bacteria. The questionnaire used in this study captured some general, flock level, qualitative antimicrobial use information for the Alberta sheep industry. Participating producers most frequently administered antimicrobials via injection by a substantial amount, followed by in-feed antimicrobial use. Additionally, producers in this study infrequently treated some or all of their flock with injectable antimicrobials subsequent to the discovery of an individual sick sheep.

The study questionnaire was designed to determine and describe antimicrobial use in the Alberta sheep industry. This information was also used to investigate any potential epidemiological link between antimicrobial use and resistance in ovine fecal *Escherichia coli* and *Salmonella* spp. isolates. Although the antimicrobial use data obtained using the questionnaire may be correct, it is possible that recall bias may have affected the estimates since for the most part, producers were asked to recall if antimicrobials had been used in their flock at any time during the 1-y period before the questionnaire was completed. Therefore, rather than the retrospective approach taken in this study, data might be collected prospectively in future studies using a well-designed antimicrobial use recording tool (form or log) to minimize recall bias. Future studies should also identify the antimicrobials that are administered to sheep in-feed including information on concentration and the duration of exposure for such medicated feeds. Moreover, it may be beneficial to collect some data on antimicrobial use in the feedlot sector of the Alberta sheep industry where antimicrobial use may be quite different compared with traditional operations such as those sampled herein. This would provide information on sheep that are close to human consumption. Additionally, it would be worthwhile to collect data on antimicrobial use in sheep production from other provinces in Canada.

Acknowledgments

The authors thank all participating sheep producers and the Alberta Sheep and Wool Commission for their involvement in this study. We also thank all technical personnel of the Food Safety Division of Alberta Agriculture and Food and the Laboratory for Foodborne Zoonoses, Public Health Agency of Canada as well as Dr. Paula Menzies. Financial support was kindly provided by Alberta Agriculture and Food and the Public Health Agency of Canada.

References

1. Joint Expert Technical Advisory Committee on Antibiotic Resistance (JETACAR). The use of antibiotics in food-producing animals: Antibiotic-resistant bacteria in animals and humans. Commonwealth of Australia, 1999.
2. Menzies PI. Antimicrobial drug use in sheep and goats. In: Prescott JF, Baggot JD, Walker RD, eds. Antimicrobial Therapy in Veterinary Medicine 3rd ed. Ames, Iowa: Iowa State Univ Pr, 2000:591–601.
3. Navarre CB, Marley S. Antimicrobial drug use in sheep and goats. In: Giguère S, Prescott JF, Baggot JD, Walker RD, Dowling PM, eds. Antimicrobial Therapy in Veterinary Medicine 4th ed. Ames, Iowa: Blackwell Publishing, 2006:519–528.
4. Fajt VR. Label and extra label drug use in small ruminants. Vet Clin North Am Food Anim Pract 2001;17:403–420.
5. Mellon M, Benbrook C, Benbrook KL (Union of Concerned Scientists). Hogging It: Estimates of Antimicrobial Abuse in Livestock. Cambridge, Massachusetts: UCS Publications, 2001.

6. Animal Health Institute. Animal Health Companies Meet Increased Market Needs for Antibiotics. (June, 2005). [homepage on the Internet]. Available from http://www.ahi.org/mediaCenter/documents/Antibioticuse2005REVISED.pdf Last accessed 24 May 2007.
7. Statistics Canada. 2001 Census of Agriculture — Livestock — More sheep on more farms. (Date modified December 2, 2003). [homepage on the Internet]. Available from http://www.statcan.ca/english/agcensus2001/first/farmop/03livestock.htm#4 Last accessed 12 October 2007.
8. Statistics Canada. Table 21 — Sheep and lambs, by province, Census Agricultural Region (CAR) and Census Division (CD). (May 15, 2001). [homepage on the Internet]. Available from http://www.statcan.ca/english/freepub/95F0301XIE/tables/html/Table21Can.htm#4 Last accessed 24 May 2007.
9. Prescott JF. Antimicrobial resistance and its epidemiology. In: Prescott JF, Baggot JD, Walker RD, eds. Antimicrobial Therapy in Veterinary Medicine, 3rd ed. Ames, Iowa: Iowa State Univ Pr, 2000:27–49.
10. Boerlin P, White DG. Antimicrobial resistance and its epidemiology. In: Giguère S, Prescott JF, Baggot JD, Walker RD, Dowling PM, eds. Antimicrobial Therapy in Veterinary Medicine, 4th ed. Ames, Iowa: Blackwell Publishing, 2006:27–43.
11. Cohen ML, Tauxe RV. Drug-resistant *Salmonella* in the United States: An epidemiologic perspective. Science 1986; 234:964–969.
12. McEwen SA, Fedorka-Cray PJ. Antimicrobial use and resistance in Animals. Clin Infect Dis 2002;34(Supplement 3):S93–S106.
13. Advisory Committee on Animal Uses of Antimicrobials and Impact on Resistance and Human Health. Uses of Antimicrobials in Food Animals in Canada: Impact on Resistance and Human Health (Health Canada). Report of the Advisory Committee on Animal Uses of Antimicrobials and Impact on Resistance and Human Health. (June, 2002). [homepage on the Internet]. Available from http://www.hc-sc.gc.ca/dhp-mps/alt_formats/hpfb-dgpsa/pdf/pubs/amr-ram_final_report-rapport_06-27_e.pdf Last accessed 24 May 2007.
14. Prescott JF. Beta-lactam antibiotics: Cephalosporins and cephamycins. In: Prescott JF, Baggot JD, Walker RD, eds. Antimicrobial Therapy in Veterinary Medicine, 3rd ed. Ames, Iowa: Iowa State Univ Pr, 2000:134–159.
15. Veterinary Drugs Directorate (VDD), Health Canada. Categorization of antimicrobial drugs based on importance in human medicine. (Date modified 30 November 2006), [homepage on the Internet]. Available from http://www.hc-sc.gc.ca/dhp-mps/consultation/vet/consultations/amr_ram_hum-med_e.html Last accessed 11 October 2007.
16. Health Canada. Extra-Label Drug Use (ELDU) in Animals. (Date modified January 11, 2006). [homepage on the Internet]. Available from http://hc-sc.gc.ca/dhp-mps/vet/label-etiquet/index_e.html Last accessed 15 October 2007.
17. National Animal Health Monitoring System (NAHMS). Sheep 2001 Part I: Reference of Sheep Management in the United States, 2001. United States Department of Agriculture, Animal and Plant Health Inspection Service, Veterinary Services. (July, 2002). [homepage on the Internet]. Available from http://www.aphis.usda.gov/vs/ceah/ncahs/nahms/sheep/sheep01/Sheep01Pt1.pdf Last accessed 24 May 2007.
18. Alberta Agriculture, Food and Rural Development. AG-Ventures: Agriculture Business Profiles. August, 1999.
19. Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). Changes to the Rendering Industry. (August 1, 2001). [homepage on the Internet]. Available from http://www.omafra.gov.on.ca/english/livestock/deadstock/facts/info_renderingchanges.htm Last accessed 24 May 2007.