ORIGINAL ARTICLE

Maternal veterinary occupation and adverse birth outcomes in Washington State, 1992–2014: a population-based retrospective cohort study

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ABSTRACT

Objective Women in veterinary occupations are routinely exposed to potential reproductive hazards, yet research into their birth outcomes is limited. We conducted a population-based retrospective cohort study of the association between maternal veterinary occupation and adverse birth outcomes.

Methods Using Washington State birth certificate, fetal death certificate and hospital discharge data from 1992 to 2014, we compared birth outcomes of mothers in veterinary professions (n=2662) with those in mothers in dental professions (n=10 653) and other employed mothers (n=8082). Relative risks (RRs) and 95% CIs were estimated using log binomial regression. Outcomes studied were premature birth (<37 weeks), small for gestational age (SGA), malformations and fetal death (death at ≥20 weeks gestation). Subgroup analyses evaluated risk of these outcomes among veterinarians and veterinary support staff separately.

Results While no statistically significant associations were found, we noted a trend for SGA births in all veterinary mothers compared with dental mothers (RR=1.16, 95% CI 0.99 to 1.36) and in veterinarians compared with other employed mothers (RR=1.37, 95% CI 0.96 to 1.96). Positive but non-significant association was found for malformations among children of veterinary support staff.

Conclusions These results support the need for further study of the association between veterinary occupation and adverse birth outcomes.

Key messages

What is already known about this subject?

- ► While several prior efforts have been made to characterise the association between maternal veterinary occupation and reproductive risks, these studies have largely excluded veterinary support staff and have failed to reach a consensus.

What are the new findings?

- ► Our findings suggest that veterinary mothers, particularly veterinarians, may have a slightly higher risk of small for gestational age birth compared than other employed mothers, and veterinary support staff may have a slightly higher risk of malformations.
- ► However, none of these findings reached statistical significance.

How might this impact on policy or clinical practice in the foreseeable future?

- ► While these results do not rule out an association between veterinary occupation and adverse birth outcome, the small relative risk estimates and lack of statistical significance support the absence of a strong association.
- ► Given the increasing numbers of women entering the veterinary workforce, higher research priority should be given to characterising this association than has been historically, with continued precautionary measures in the interim.

INTRODUCTION

Veterinary personnel, including veterinarians, veterinary technicians and veterinary assistants, are routinely exposed to chemical, biological and physical hazards. With the proportion of women in the veterinary field increasing over the past few decades, concerns regarding the potential impact of these occupational exposures on reproductive outcomes (eg, premature birth, birth defects) are of growing public health relevance.[1] Moreover, most veterinary personnel are employed by small businesses, which often have little to no occupational health and safety programmes to manage these risks.[2]

Biological agents of concern in this regard include zoonotic pathogens such as toxoplasma and *Coxiella*; veterinary personnel may be exposed to these agents via contaminated animal excreta, aerosols, bites and scratches. Additionally, physical hazards to which veterinary personnel are exposed—ionising radiation, crushing injuries from animals and equipment, physical fatigue and workplace-associated musculoskeletal disorders—have been linked to adverse reproductive outcomes.[3 4] Finally, associations have been demonstrated between occupational exposure to chemicals commonly used in veterinary practice—including pesticides,[5] cytotoxic pharmaceuticals[6] and inhalant anesthetics[7]—and increased risk of adverse reproductive outcomes. Despite these known hazards, it is uncertain whether the veterinary workforce is at differential risk of such outcomes. Studies on this topic are few in number, low in power and generally exclude veterinary support staff (technicians and assistants), even though these individuals may have more frequent exposure to many hazards.[8]

We therefore performed a study to address two primary aims: (1) to evaluate the association between veterinary occupation and the adverse birth outcomes of preterm birth, small for gestational age (SGA), malformations and fetal death, by comparing a cohort of veterinary mothers with the general population of other employed mothers; and (2) to isolate the effects of animal-associated occupational hazards on these outcomes by comparing the same veterinary cohort with a cohort of mothers with dental occupations. Additionally, we investigated subgroup effects by job type: veterinarian versus veterinary support staff. We hypothesised that veterinary mothers—particularly veterinary staff—would be at a greater risk of adverse birth outcomes than non-veterinary mothers, with attenuation of this effect estimate on comparison with dental mothers.

METHODS

The Strengthening the Reporting of Observational Studies in Epidemiology checklist was used to guide the reporting of this article.[9]

Data sources

We conducted a population-based retrospective cohort study using linked Washington State birth certificate data and hospital discharge data from the years 1992–2014. In Washington State, birth and fetal death certificate data records use a check-box format filing form, completed by the facility using a web-based system. The mother provides demographic information, including her occupation, while the medical and prenatal records provide the medical history information and the chart—typically completed by a healthcare provider—provides the delivery information. These data were linked to mother and infant hospital discharge data from the Comprehensive Hospital Abstract Reporting System (CHARS). CHARS diagnosis codes use the International Classification of Diseases, Ninth Revision (ICD-9).

Outcome variables

We defined preterm birth as birth prior to 37 weeks gestation, per the clinical estimate of gestational age. The clinical estimate—based on estimated age at first ultrasound—was chosen over age based on last menstrual period as previous studies have shown the ultrasound-based clinical estimate to be a more valid measure.[10] Size for gestational age is based on the population distribution of birth weight for each week of gestation—determined by Washington State data from 1989 to 2002—with infants in the lowest 10% defined as SGA.[11] We defined malformations as any congenital anomaly in the birth certificate data or ICD-9 code diagnosis 740–759 (congenital anomalies), excluding 758.0 (Down's syndrome), in the CHARS data. Lastly, we defined fetal death as completion of the fetal death certificate, and infant death by CHARS or death certificate data.

Comparison groups

In our primary analysis, we compared a cohort of veterinary mothers—identified by their self-reported occupation on their child's birth certificate (code 194)—to the general population of other employed mothers. The veterinary mothers' cohort included both veterinarians and veterinary support staff. For the cohort of 'other employed mothers', we excluded the following occupations: veterinary (code 194), dentist (071), medical/dental staff (303), recreation/housemaker (165), child under 18 (996), inmate/disabled (997) and unemployed (998). We excluded these populations to optimise comparability with the veterinary cohort, achieving better control for unmeasured or unknown confounders. Students (aged ≥18) were not excluded from the 'other employed mothers' cohort.

For our secondary analysis, we compared the cohort of veterinary mothers with a cohort of dental mothers including dentists and dental support staff (code 071 or 303), an occupation expected to have similar socio-demographic attributes and with occupational exposure to ionising radiation[12] and inhalant anaesthetics,[13] but without animal-associated occupational exposures. There is no separate occupational code for oral surgeons or orthodontists, and occupational code 303 includes both dental and medical staff, without possible distinction between these groups. This article refers to this group as 'dental mothers' rather than 'medical/dental mothers' to avoid erroneously, suggesting that physicians and nurses are included in this cohort.

For the subgroup analysis, we defined veterinarians as mothers with occupational code 194 and with a doctoral degree, and veterinary staff as mothers with occupational code 194 and without a doctoral degree. Veterinarians are required to hold a Doctor of Veterinary Medicine or equivalent, which few to no veterinary support staff will hold.[14] Prior to 2003, birth certificate data collected maternal education as a self-reported continuous variable corresponding to the number of years of education completed. After 2003, self-reported maternal education was collected as a continuous variable for women who achieved an 8th grade education or less, and a categorical variable for all other women (9th–12th grade with no high school diploma/high school graduate or General Equivalency Diploma (GED)/some college, no degree/associate degree/bachelor's degree/master's degree/doctorate or professional degree); mothers can only select one category, corresponding to the highest level of education attained. As the pre-2003 birth certificate data do not define master's versus doctoral degrees, subgroup analyses were limited to data from 2003 to 2014. Each subgroup (veterinarians and veterinary staff) was compared with the general population of other employed mothers as defined above.

Data were frequency-matched by birth year for all comparisons, with each 'exposed' (veterinary) mother matched to eight 'unexposed' women in total: four dental mothers and four non-veterinary non-dental mothers.

Exclusion criteria and missingness

Data were collected only for singleton births. Following frequency matching, observations with missing data for maternal occupation (occupational code 999) were excluded from the non-veterinary non-dental mothers to generate the group 'other employed mothers'. Cases of Down's syndrome, a birth defect with a predominant causal pathway not influenced by occupational exposures, were also excluded.

For the subgroup analysis comparing veterinarians with employed women, mothers <26 years old did not appear in the exposed group and were excluded from the unexposed group to improve comparability.

Records with missing data were excluded from relevant analyses. Observations missing outcome data were excluded only from analyses of that outcome, including SGA (n=92), malformation (n=814) and fetal death (n=84).

Statistical analyses

Statistical analyses were performed with R V.3.2.2.[15] Multivariable analyses were conducted using relative risk

(RR) regression—log binomial regression—with adjustment for confounders and interaction terms for effect modifiers. Statistical significance was determined using a two-sided α=0.05. No adjustments were made for multiple comparisons to avoid compromising the sensitivity of these analyses.

Potential effect modifiers were identified a priori based on subject-matter knowledge: rural versus urban residence, infant sex and father in veterinary occupation (occupational code 194), per birth certificate data. Rural versus urban residence was selected as a proxy indicator for veterinary practice type, with urban residents expected to be nearly exclusively employed in small animal practice, and rural residents more likely to be in mixed-animal or large-animal practice; occupational exposures relevant to adverse birth outcomes vary between these practice types. Baby's sex has been shown to modify the association between in utero exposures and malformations[16] and birth weight.[17] Lastly, paternal occupational exposures may modify the outcomes of interest through male-mediated teratogenic effects or through exposure of the mother to zoonoses or other teratogens via fomitic transmission or environmental contamination of the home.[18 19]

Effect modification was determined on the basis of statistical significance testing of an effect modifier × exposure interaction term after adjustment for confounders. With the exception of urban versus rural residence, these variables were evaluated as potential confounders if they were not determined to be effect modifiers; as urban versus rural residence was considered a proxy for subtype of exposure, it would not be appropriate to adjust for this variable as a confounder. Effect modification and confounding were examined for each exposure–outcome relationship individually.

Confounders were identified via a four-step mixed a priori and data-driven approach.[20] Variables identified a priori as causally associated with the outcome of interest or its recognition were identified, and a directed acyclic graph was constructed to determine the minimal sufficient adjustment set (see Model, online supplemental digital content 1, to view .pdf of the graphical model; see Code, online supplemental digital content 2, to view dagitty.net model code).[21] Variables in this set were then evaluated qualitatively for association with maternal occupation in this dataset on the basis of bivariate descriptive statistics stratified on exposure status. Lastly, identified confounders were evaluated for collinearity; if two variables were found to be highly collinear (Pearson's product moment correlation coefficient >0.3 in absolute value), the variable more strongly associated with the exposure of interest—on a qualitative basis—was selected for the final model.

Confounders evaluated, per birth certificate data, were mother's age; mother's education (high school or less/some college or associate's degree/bachelor's degree/postgraduate studies/doctoral degree; for births prior to 2003, these categories were defined as ≤12 years of education/13–15 years/16 years/17–18 years/20 years, respectively); receipt of Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) benefits (yes/no); mother's race (white/non-white); mother's ethnicity (Hispanic/non-Hispanic); marital status (married/unmarried); other maternal morbidity (yes/no); smoking status during pregnancy (yes/no); average number of cigarettes smoked per day during pregnancy; pre-pregnancy body mass index; parity; diabetes mellitus (established/gestational/absent); previous poor pregnancy outcome (yes/no) and adequacy of prenatal care (inadequate/intermediate/adequate). Maternal education was not evaluated as a confounder for the subgroup analysis comparing veterinarians to other employed mothers due to the low number of mothers in the comparison group with a doctoral degree. Body mass index was calculated from mother's pre-pregnancy weight and height on birth certificate data. Adequacy of prenatal care was based on Kotelchuck Index, which is derived from birth certificate data on initiation of prenatal care and number of visits.[22] WIC benefits and maternal education were selected as indicators of socioeconomic status (SES), and previous poor pregnancy outcome was selected as a proxy for unknown medical factors causally associated with outcome. The other potential confounders—age,[23] race and ethnicity,[24] marital status,[25] smoking,[26] obesity,[27] high parity[28] and diabetes mellitus[29]—have been demonstrated to be risk factors for adverse birth outcomes.

Lastly, a sensitivity analysis was performed to compare the outcome of fetal death with composite fetal or infant death using data for infant death from CHARS and linked death certificates. Exposure groups were defined and effect modifiers and confounders evaluated as described above.

RESULTS

Selection of subjects for analysis

In Washington State between 1992 and 2014, 2666 veterinary mothers gave birth to singleton babies. Of the 21 328 frequency-matched 'unexposed' mothers (n=10 664 dental mothers and n=10 664 non-veterinary non-dental mothers), 2574 non-veterinary non-dental mothers with missing data on occupation were excluded from the 'other employed mothers' group. Finally, infants with Down's syndrome (n=23) were excluded, leaving 21 397 in the primary analysis: 13 315 in the comparison between veterinary and dental mothers, and 10 744 in the comparison between veterinary and other employed mothers. Of the 21 397 individuals included in the primary analysis, 6618 were included in the subgroup analysis comparing veterinary staff with other employed women and 3641 were included in the subgroup analysis comparing veterinarians with other employed women (figure 1).

CHARS data linkage was successful for at least 73% of the birth events cohort on the basis of completed infant diagnosis and maternal diagnosis codes.

Sample characteristics

Sample characteristics based on job type are provided in tables 1 and 2. Veterinary mothers (n=2662) were similar to other employed mothers (n=8082) and to dental mothers (n=10 653) with regards to distributions of their age, smoking during pregnancy, previous poor pregnancy outcomes, presence of diabetes, marital status, prenatal care, pre-pregnancy body mass index and baby's sex (table 1). However, they tended to have higher educational attainment (14.4% veterinary vs 2% employed women vs 3.4% dental holding doctoral degrees); were more likely to be white (94.9% vs 78.2% vs 79.6%), non-Hispanic (96.5% vs 88.7% vs 89.7%), of low parity (mean 0.35 vs 0.47 vs 0.74) and rural (36.1% vs 23.6% vs 25.4%); and were more likely to have a veterinary spouse (5.4% vs 0.06% vs 0.12%). While veterinary mothers had much less use of WIC benefits compared with other employed mothers (21.3% vs 31.5%), they were fairly similar to dental mothers (24.6%) in this regard.

Primary analysis

Potential confounders determined to be in the minimal sufficient adjustment set were ethnicity, race, marital status, age, parity, adequacy of prenatal care, previous poor pregnancy outcome, smoking status, mean number of cigarettes smoked during

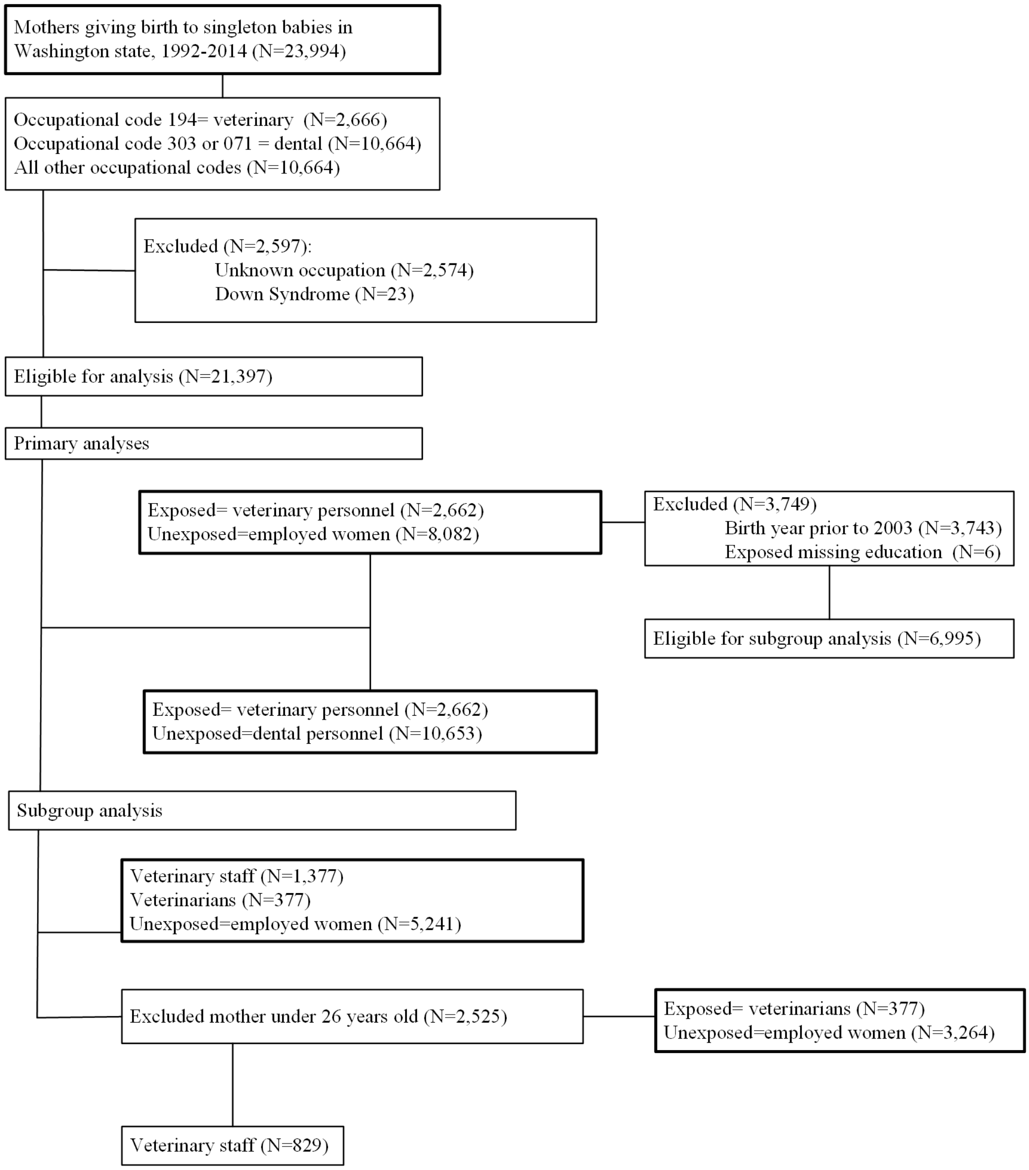

Figure 1 Flow chart showing selection of study participants.

pregnancy, BMI, other maternal morbidity and SES, approximated by maternal educational attainment and receipt of WIC benefits. Mean number of cigarettes smoked during pregnancy and maternal ethnicity were not adjusted for due to high collinearity with binary smoking status during pregnancy and maternal race, respectively. Additionally, as receipt of WIC benefits was not available for births prior to 2003, this variable was only adjusted for in the subgroup analyses. Finally, the variable 'other maternal morbidity' was not adjusted for in any analyses due to a high degree of missingness. Confounders adjusted for differed for each exposure studied, as detailed in the footnotes of table 3. Simple linear adjustment was used for all confounders, with polytomous variables categorised as detailed in tables 1 and 2. None of the potential effect modifiers evaluated was found to modify the association between occupation and outcomes studied.

No significant associations were detected in primary analyses. No evidence of association was found for preterm birth, fetal death or malformations, and compared with other employed mothers there was no evidence of association for SGA. However, compared with dental mothers, veterinary mothers had a non-significant 16% higher risk of having an SGA baby (RR=1.16, 95% CI 0.99 to 1.36) (table 3).

Subgroup analysis

No significant associations were found on subgroup analyses. Veterinarians were found to be 37% (RR=1.37, 95% CI 0.96 to 1.96) more likely to experience an SGA birth than other employed mothers, and veterinary staff were found to be 14% (RR=1.14, 95% CI 0.85 to 1.52) more likely to experience malformations than other employed mothers; however, neither association was statistically significant. No evidence was found that veterinarians or veterinary staff are more likely than other employed women to experience preterm birth or fetal death (table 3).

Sensitivity analysis

No significant associations were found for veterinary occupation and composite fetal or infant death, and due to the low frequency of this outcome statistical precision was generally low. A non-significant 24% higher risk of fetal or infant death was found among veterinary mothers compared with dental mothers;

Table 1 Maternal and infant characteristics by mother's occupation, Washington State, 1992–2014*†

Variable	Veterinary mothers (n=2662) n	%	Other employed mothers (n=8082) n	%	Dental mothers (n=10 653) n	%
Mother's age (years)‡	28.5	5.2	27.8	5.7	28.4	5.0
Missing	0		2		1	
Mother receives WIC§						
Yes	336	21.3	1488	31.5	1570	24.6
No	1243	78.7	3239	68.5	4802	75.4
Missing	1083		3355		4281	
Mother's education§						
High school diploma or less	547	20.9	2655	33.5	2874	27.4
Some college	1086	41.5	2616	33.0	5640	53.8
Bachelor's degree	304	11.6	1627	20.5	1298	12.4
Postgraduate studies	300	11.5	879	11.1	317	3.0
Doctoral degree	377	14.4	156	2.0	360	3.4
Missing	48		149		164	
Mother's race						
White	2510	94.9	6240	78.2	8390	79.6
Non-white	134	5.1	1737	21.8	2152	20.4
Missing	18		105		111	
Mother's ethnicity						
Hispanic	92	3.5	904	11.3	1130	10.7
Non-Hispanic	2550	96.5	7061	88.7	9380	89.3
Missing	20		117		143	
Mother smoked during pregnancy						
Yes	228	8.6	777	9.8	752	7.1
No	2406	91.3	7169	90.2	9780	92.9
Missing	28		136		121	
Cigarettes/day during pregnancy‡	0.70	2.8	0.86	3.3	0.61	2.7
Missing	37		170		134	
Parity‡	0.35	0.71	0.47	0.91	0.74	0.99
Missing	29		105		134	
Previous poor pregnancy outcome§						
Yes	15	0.86	55	1.1	94	1.4
No	1725	99.1	5098	98.9	6851	98.6
Missing	922		2929		3708	
Maternal diabetes						
Established	13	0.50	54	0.69	88	0.85
Gestational	96	3.7	356	4.6	586	5.7
No	2489	95.8	7404	94.6	9645	93.5
Missing	64		268		334	
Other maternal morbidity§						
Yes	46	2.9	156	3.0	143	2.1
No	1682	97.3	4961	97.0	6772	97.9
Missing	934		2965		3738	
Mother marital status						
Single	578	21.7	2444	30.3	2448	23.0
Married	2081	78.3	5622	69.7	8191	77.0
Missing	3		16		14	
Prenatal care¶						
Inadequate	196	8.2	687	9.6	706	7.5
Intermediate	389	16.2	1191	16.7	1453	15.4
Adequate or greater	1811	75.6	5274	73.7	7307	77.2
Missing	266		930		1187	
Pre-pregnancy BMI§ **	26.0	5.5	26.2	6.0	27.4	6.7
Missing	1023		3271		4126	
Rural or urban residence††						
Rural	908	36.1	1824	23.6	2608	25.4
Urban	1604	63.9	5900	76.4	7641	74.6
Missing	150		358		404	
Father occupation						
Veterinary	128	5.4	4	0.06	11	0.12
Other	2222	94.6	6750	99.9	9242	99.9
Missing	312		1328		1400	

*Percentages may not total 100% due to rounding.
†Numbers may not add up to totals because of missingness.
‡Mean (SD).
§Variable included only on post-2003 birth certificate.
¶Inadequate, intermediate and adequate levels of prenatal care defined by the Kotelchuck Index; this variable is available only for births in 1997 or later.
**Units are kg/m^2.
††Rural or urban residence is defined as whether the mother reported living inside or outside city limits when she gave birth.
BMI, body mass index; WIC, Special Supplemental Nutrition Program for Women, Infants, and Children.

however, the CI around this point estimate was wide (RR=1.24, 95% CI 0.77 to 2.00) (table 4).

DISCUSSION

Most prior research efforts on the reproductive risks of veterinary occupational exposures have included only veterinary personnel, without a non-veterinary comparison group. In exception to this are four large studies in the 1990s–2000s that compared veterinarians with non-veterinary mothers, but excluded veterinary support staff. These include an Australian study (n=1197),[30–32] a Finnish study (n=549)[33] and two US studies: one in California (n=547)[34] and one national (n=2997).[35] A 2002 Canadian study included veterinary support staff, but was limited in size (n=95) and is not further discussed.[36] With the exception of the Finnish study—which used hospital records—these studies used self-reported outcome data.

These studies have not reached consensus; the Australia and California studies both found a positive association for birth defects, but no evidence of association for spontaneous abortion. The US and Finnish studies found a lower risk of adverse birth outcomes among veterinarians—for preterm birth and SGA in the US study, and for spontaneous abortion in the Finnish study.

When compared with dental mothers, we found veterinary mothers were at a slight but non-significant elevated risk of SGA. On comparison with other employed mothers, this association was detected only among veterinarians. While veterinary personnel are exposed to zoonotic diseases that can cause fetal growth restriction, including Q fever[37] and toxoplasmosis,[38 39] association due to such exposures should not be limited to comparison with dental mothers. This finding may be attributable to occupational exposures that are more common among both veterinary mothers and other employed mothers than dental mothers—including physically demanding work,[40] prolonged periods of standing[41 42] and increased gestational age at work cessation[41]—or may represent superior comparability in the comparison with dental mothers, and thus improved control for unmeasured confounders. Apparent restriction of this finding to veterinarians may reflect an artefact of the data or comparatively greater exposure to such hazards among veterinarians versus veterinary support staff; this may arise if these

Table 2 Maternal and infant characteristics by mother's occupation and job type, Washington State, 2003–2014 (subgroup analysis)* †

	Veterinarian (n=377)‡		Other employed mothers older than 25 (n=3264)‡		Veterinary staff (n=1377)‡		Other employed mothers (n=5241)‡	
	n	%	n	%	n	%	n	%
Mother's age (years)§	32.8	3.5	31.3	4.0	27.1	4.7	27.8	5.7
Missing	0		1		0		1	
Mother receives WIC¶								
Yes	5	1.5	530	18.1	330	26.8	1488	31.5
No	338	98.5	2402	81.9	902	73.2	3239	68.5
Missing	34		332		145		514	
Mother's education¶								
High school diploma or less	0	0	582	17.9	330	24.0	1548	29.7
Some college	0	0	941	29.0	812	59.0	1782	34.2
Bachelor's degree	0	0	1042	32.1	213	15.5	1189	22.8
Postgraduate studies	0	0	522	16.1	22	1.6	534	10.3
Doctoral degree	377	100	156	4.8	0	0	156	3.0
Missing	0		21		0		32	
Mother's race								
White	352	93.8	2498	77.3	1300	94.8	4006	77.4
Non-white	23	6.1	732	22.7	72	5.2	1168	22.6
Missing	2		34		5		67	
Mother's ethnicity								
Hispanic	5	1.3	318	9.9	63	4.6	678	13.1
Non-Hispanic	369	98.7	2881	90.1	1307	95.4	4485	86.9
Missing	3		65		7		78	
Mother smoked during pregnancy								
Yes	2	0.54	158	4.9	142	10.4	399	7.7
No	371	99.5	3054	95.1	1225	89.6	4771	92.3
Missing	4		52		10		71	
Cigarettes/day during pregnancy§	0.02	0.30	0.44	2.4	0.82	2.9	0.67	2.9
Missing	4		52		10		72	
Parity§	0.23	0.52	0.47	0.95	0.32	0.71	0.39	0.83
Missing	2		57		22		79	
Previous poor pregnancy outcome¶								
Yes	5	1.3	36	1.1	10	0.7	55	1.1
No	367	98.7	3167	98.9	1355	99.3	5098	98.9
Missing	5		61		12		88	
Maternal diabetes								
Established	2	0.54	31	0.97	8	0.59	42	0.82
Gestational	12	3.2	215	6.7	63	4.6	278	5.4
No	358	96.2	2957	92.3	1294	94.8	4833	93.8
Missing	5		61		12		88	
Other maternal morbidity¶								
Yes	19	5.2	105	3.3	27	2.0	156	3.0
No	348	94.8	3071	96.7	1331	98.0	4961	97.0
Missing	10		88		19		124	
Mother marital status								
Single	15	4.0	624	19.1	424	30.8	1701	32.6
Married	360	96.0	2635	80.9	953	69.2	3521	67.4
Missing	2		5		0		13	
Kotelchuck Index of prenantal care**								
Inadequate	26	7.8	239	8.5	114	9.2	480	10.5
Intermediate	50	14.9	484	17.2	204	16.5	815	17.8
Adequate or greater	259	77.3	2086	74.3	918	74.3	3291	71.8
Missing	42		455		141		655	
Mother pre-pregnancy BMI§¶ ††	24.2	4.1	26.1	6.0	26.5	5.7	26.2	6.0
Missing	26		301		91		430	
Rural or urban residence‡‡								

continued

Table 2 continued

	Veterinarian (n=377)‡		Other employed mothers older than 25 (n=3264)‡		Veterinary staff (n=1377)‡		Other employed mothers (n=5241)‡	
	n	%	n	%	n	%	n	%
Rural	132	36.6	681	21.4	466	35.2	1226	24.1
Urban	229	63.4	2494	78.6	859	64.8	3851	75.9
Missing	16		89		52		164	
Father occupation								
Veterinary	44	12.3	1	0.14	18	1.5	2	0.05
Other	313	87.7	2910	99.9	1179	98.5	4403	100.0
Missing	20		353		180		836	

*Percentages may not total 100% due to rounding.
†Numbers may not add up to totals because of missingness.
‡Observations with birth year prior to 2003 were excluded from this analysis, as were individuals with missing 2003 maternal education variable. Veterinarians versus veterinary staff were defined by presence versus absence of a doctoral degree, respectively. All veterinarians were at least 26 years of age, thus women 25 years of age or younger were excluded from the comparison group. Veterinary staff included women under 26 years of age.
§Mean, SD.
¶Variable included only on post-2003 birth certificate.
**Inadequate, intermediate and adequate levels of prenatal care defined by the Kotelchuck Index; this variable is available only for births in 1997 or later.
††Units are kg/m^2.
‡‡Rural or urban residence is defined as whether the mother reported living inside or outside city limits when she gave birth.
BMI, body mass index; WIC, Special Supplemental Nutrition Program for Women, Infants, and Children.

hazards are more common among large animal practitioners as these individuals typically work without support staff.

On primary analyses, no evidence of association was found for preterm birth or malformations, discordant with the lower risk of preterm birth[35] and higher risk of malformations found in veterinarians in prior literature.[32 34] On subgroup analyses, veterinary staff were found to be at a slightly higher but non-significant risk of malformations.

Lastly, we found the risk of fetal death to be non-significantly lower among veterinary mothers than other employed mothers on primary and subgroup analyses. Conversely, in sensitivity analyses the risk of composite fetal/infant death was non-significantly higher among veterinary mothers than dental or other employed mothers, with this association being restricted to veterinary staff on subgroup analyses. While prior literature suggests veterinarians are not at a higher risk of spontaneous abortions than other mothers,[30 33 34] the absence of a clear trend in our results limits conclusions on concordance versus discordance between these findings.

While there are important strengths of our study—the use of a primary study base, the large cohort size, the validity of outcome measurement—there are several limitations that may result in bias or compromise sensitivity. As with all observational studies, our adjusted risk estimates may remain biased by residual confounding. Several confounders could not be adjusted for due to a high degree of missingness, including maternal alcohol consumption and other maternal morbidities. SES, a latent variable not easily measured and thus not easily adjusted for, is likely a strong confounder of the association between maternal occupation and adverse birth outcomes. While receipt of WIC benefits and maternal educational attainment were used to approximate SES status in this dataset, WIC benefits were not recorded on birth certificates prior to 2003, and thus were not adjusted for in primary analyses.

There were several potential sources of information bias in this analysis. We expect minimal misclassification of occupation generally—sensitivity of birth certificate data for parental occupation is close to 100% for mothers who are healthcare practitioners, and specificity exceeds 95% across occupational groups[43]—however, exposure to specific occupational hazards was not measured, and pregnant women may work for varying portions of their pregnancy or not at all. If veterinary mothers work later into their pregnancy than other employed mothers,[44] risks inherent to any work would be over-represented among veterinary mothers, falsely exaggerating effect estimates.

Second, the occupational code for medical/dental staff was included to ensure dental hygienists were captured and because the group coded as dentists was too small for adequate precision. The presence of other occupational groups in the medical/dental staff code may result in bias, with magnitude and direction dependent on the proportion that are not dental staff and their own occupational exposures. In our analysis, 3.4% of dental mothers were doctoral degree holders; however, in 2016 the ratio of dental hygienists and assistants to dentists was approximately 3.5:1.[45] This suggests that the contribution of other dental support staff to the dental mothers group is large or, more likely, that some non-dental personnel were included in this group.

Third, subgroup misclassification cannot be ruled out; there do not appear to be studies on the validity of birth certificate data for maternal education, and veterinarians educated abroad may not hold Doctor of Veterinary Medicine degrees. In the subgroup analysis restricted to veterinarians, no women under 26 years of age appeared in the exposed group. This suggests the presence of misclassification of international degree-holding veterinarians as veterinary staff as veterinary schools outside of North America typically do not require a prior undergraduate degree. However, several years likely elapse between graduation abroad and childbirth in Washington State, and as all veterinarians licensed in the USA may use the title *Doctor*[46] we expect most licensed veterinarians will identify as doctoral degree holders.

Lastly, birth defects resulting in elective abortion were not captured, resulting in information bias due to underascertainment of this outcome; if adequate prenatal care is associated with detection of these defects and thus elective abortion, this underascertainment will be more common in veterinary mothers than other employed mothers, biassing the risk estimate towards the null. This is unlikely to be an important source of bias for the outcome of malformations, given the exclusion of Down's syndrome and moderate frequency of this outcome. However,

Table 3 Associations between maternal occupation and adverse birth outcomes in 21 397 maternal–infant pairs, Washington State*

	Veterinary mothers (exposed)†		Non-veterinary mothers (unexposed)‡			
	n	%	n	%	Adjusted RR	Adjusted 95% CI
Small for gestational age§						
Veterinary vs employed mothers	227	8.6	813	10.1	0.95¶	0.81 to 1.12
Veterinary vs dental mothers			850	8.0	1.16**	0.99 to 1.36
Veterinarian vs employed mothers >25 years	37	9.8	304	9.4	1.37††	0.96 to 1.96
Staff vs employed mothers	117	8.5	512	9.8	0.93‡‡	0.74 to 1.16
Preterm birth§§						
Veterinary vs employed mothers	191	7.2	577	7.1	1.03¶	0.87 to 1.24
Veterinary vs dental mothers			811	7.6	1.00**	0.84 to 1.19
Veterinarian vs employed mothers >25 years	26	6.9	230	7.1	0.94††	0.58 to 1.50
Staff vs employed mothers	100	7.3	378	7.2	1.04‡‡	0.81 to 1.32
Fetal death¶¶						
Veterinary vs employed mothers	17	0.64	53	0.66	0.95¶	0.50 to 1.83
Veterinary vs dental mothers			63	0.59	1.02**	0.55 to 1.91
Veterinarian vs employed mothers >25 years	1	0.27	22	0.68	0.90***	0.10 to 8.00
Staff vs employed mothers	10	0.73	36	0.69	0.93‡‡	0.38 to 2.26
Malformations†††						
Veterinary vs employed mothers	144	5.6	505	6.5	0.98¶	0.80 to 1.20
Veterinary vs dental mothers			641	6.3	1.03**	0.84 to 1.26
Veterinarian vs employed mothers >25 years	18	4.9	227	7.1	1.00††	0.61 to 1.63
Staff vs employed mothers	72	5.3	327	6.4	1.14‡‡	0.85 to 1.52

*Comparisons including all veterinary mothers are for the years 1992–2014. Comparisons restricted to veterinarians or veterinary support staff are for the years 2003–2014.
†The exposed group is either all veterinary mothers (n=2662), veterinarians (n=366) or veterinary staff (n=1110), as specified by row.
‡In comparisons with all veterinary mothers, the unexposed group is either other employed mothers (n=8082) or mothers in a dental occupation (n=10 653), as indicated by the row. In comparisons with veterinarians, the unexposed group is other employed mothers over 25 years of age (n=3091). In comparisons with veterinary staff, the unexposed group is other employed mothers not restricted by age (n=4478).
§Small for gestational age is defined as the lowest 10% of the distribution for birth weight for each week of gestation, determined from Washington State data 1989–2002.
¶Adjusted for mother's race, marital status, father in veterinary occupation and mother's educational attainment as a linear term. Mother's ethnicity was not adjusted for due to collinearity with race.
**Adjusted for mother's race, parity, mother's educational attainment as a linear term and father in veterinary occupation. Mother's ethnicity was not adjusted for due to collinearity with race.
††Adjusted for mother's race, marital status, parity, smoking status during pregnancy (binary), father in veterinary occupation and receipt of Special Supplemental Nutrition Program for Women, Infants, and Children benefits. Mother's ethnicity was not adjusted for due to collinearity with race; number of cigarettes smoked on average during pregnancy not adjusted for due to high collinearity with binary smoking status during pregnancy.
‡‡Adjusted for mother's race, mother's education as a linear term, father in veterinary occupation and receipt of Special Supplemental Nutrition Program for Women, Infants, and Children benefits. Mother's ethnicity was not adjusted for due to collinearity with race.
§§Preterm birth is defined as birth prior to 37 weeks of gestation.
¶¶Fetal death is defined by completion of a fetal death certificate.
***Adjusted for mother's race, marital status, parity, smoking status during pregnancy (binary) and receipt of Special Supplemental Nutrition Program for Women, Infants, and Children benefits. Father in veterinary occupation could not be adjusted for due to zero cells.
†††Malformations include both congenital anomalies on the birth or fetal death certificate, or ICD-9 code diagnosis 740–759, excluding ICD-9 758.0 (Down's syndrome).
ICD-9, International Classification of Diseases, Ninth Revision.

given the rarity of the outcome of fetal deaths, even a small number of elective abortions due to non-viable pregnancies may result in bias.

Selection bias may arise from the use of self-reported exposure—occupation—if women who stopped working during pregnancy are misclassified as unemployed and thus excluded. If such misclassification is associated both with occupation and pregnancy risk status, bias will result. Furthermore, survivor bias results from the fact that fetuses must survive until 20 weeks of gestation to be captured, a limitation inherent to the study of congenital outcomes.

Finally, missingness was handled with complete case analysis, potentially biassing estimates if missingness is not completely at random. While missingness was very low for most variables, multivariate missingness may be markedly higher.

Sensitivity of this study may be limited by inclusion of other causal pathways for the outcomes studied. We did not attempt to exclude cases of fetal death due to iatrogenic causes, or mothers with comorbidities unassociated with occupation. Failure to complete fetal death certificates is common, resulting in under-ascertainment of fetal death and compromising precision.[47 48] In the subgroup analysis, sensitivity is further compromised by the use of only post-2003 data. Most importantly, the lack of data on exposure to specific occupational hazards limits both the sensitivity of this study and the conclusions that can be drawn.

While these small RR estimates and the lack of statistically significant findings should reassure pregnant veterinary personnel that they do not have a markedly increased risk of adverse birth outcomes as a result of their occupation, the presence of small associations cannot be ruled out. Larger studies that define exposure on the basis of specific hazards—rather than occupational group—and achieve superior control for confounding are required to explore the hypotheses suggested by these analyses and provide guidance for policy makers and women in the veterinary workforce. In the interim, precautionary measures should not be abandoned.

Table 4 Associations between maternal occupation and fetal and infant death in 17 176 maternal–infant pairs, Washington State, 1992–2014: sensitivity analysis*

	Veterinary (exposed)		Unexposed		Adjusted RR: fetal or infant death	95% CI: fetal or infant death
	n	%	n	%		
Veterinary vs employed mothers†	29	1.09	90	1.11	1.11‡	0.68 to 1.82
Veterinary vs dental mothers†			98	0.92	1.24§	0.77 to 2.00
Veterinarian vs employed mothers>25 years¶	1	0.27	36	1.10	0.48**	0.06 to 3.60
Veterinary staff vs employed mothers¶	16	1.16	57	1.09	1.10††	0.56 to 2.14

*Fetal or infant death includes both deaths after 20 weeks gestation and infant death as defined by death certificates and Comprehensive Hospital Abstract Reporting System data.
†Sample size: veterinary mothers (n=2189), employed mothers (n=6732) and dental mothers (n=8722).
‡Adjusted for mother's race, marital status, mother's education as a linear term and father in veterinary occupation. Mother's ethnicity was not adjusted for due to collinearity with race.
§Adjusted for mother's race, parity, mother's education as a linear term and father in veterinary occupation. Mother's ethnicity was not adjusted for due to collinearity with race.
¶Sample size: veterinarian (n=366), employed mothers>25 years (n=3091), veterinary staff (n=1110) and employed mothers (n=4478).
**Adjusted for mother's race, marital status, parity, smoking status during pregnancy (binary), and receipt of Special Supplemental Nutrition Program for Women, Infants, and Children benefits. Father in veterinary occupation could not be adjusted for due to zero cells. Mother's ethnicity was not adjusted for due to collinearity with race; number of cigarettes smoked on average during pregnancy not adjusted for due to high collinearity with binary smoking status during pregnancy.
††Adjusted for mother's race, urban versus rural residence, father in veterinary occupation, mother's education as a linear term and receipt of Special Supplemental Nutrition Program for Women, Infants, and Children benefits.

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Ethics approval Because all data were anonymous and deidentified, the Washington State Institutional Review Board considered this research to be exempt from review.

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Maternal veterinary occupation and adverse birth outcomes in Washington State, 1992–2014: a population-based retrospective cohort study

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