OPEN ACCESS

Paper

Influence of porcine circovirus type 2 vaccination on the probability and severity of pneumonia detected postmortem

J. Raith, S. Kuchling, C. Schleicher, H. Schobesberger, J. Köfer

To evaluate the influence of porcine circovirus type 2 vaccination (PCV-2) on the probability and severity of pneumonia, postmortem findings of 247,505 pigs slaughtered between 2008 and 2011 were analysed by applying a cumulative link mixed model. Three major effects could be observed: (1) PCV-2 vaccination significantly ($P<0.01$) reduced the odds (coefficient: −0.05) of postmortem findings of mild, moderate and severe pneumonia for vaccinated pigs. (2) Pigs from fattening farms were less likely (coefficient: −0.44; $P<0.05$) to exhibit signs of pneumonia at slaughter than pigs from farrow-to-finish farms. (3) When vaccinated, the odds of detecting postmortem signs showed an even more pronounced reduction (coefficient: −0.19; $P<0.001$) for pigs from fattening farms. Combining PCV-2 vaccination, farm type and interaction effects between these two factors, a pig vaccinated against PCV-2 from a fattening farm had only half the chance (OR 0.51) of pneumonia being detected at postmortem than a non-vaccinated pig from a farrow-to-finish farm. The study demonstrates the benefit of a vaccination programme against PCV-2 as an important tool to reduce the risk of postmortem pneumonia findings and the severity of pneumonia in pigs at slaughter.

Introduction

It is well known that respiratory diseases are a major health problem in growing pigs (Harms and others 2002) and the prevalence of porcine respiratory disease complex (PRDC) is likely to increase if no active counter-measures are taken in the near future (Chae 2012). Porcine circovirus type 2 (PCV-2) is known to play a major role in PRDC and in proliferative necrotising pneumonia (Chae 2005, Segalés and others 2005, Opriessnig and others 2007, Segalés 2012), often functioning as an important causal agent in subclinical infections (Opriessnig and others 2007). PCV-2 was first described in the late 1990s within the context of the postweaning multisystemic wasting syndrome (PMWS) (Allan and others 1998, Ellis and others 1998). Since then, it has been associated with a number of disease syndromes in pigs (Allan and Ellis 2000, Chae 2005, Segalés 2012) collected under the term of porcine circovirus diseases (PCVDs) (Allan and others 2002, Segalés 2012). Today, PCV-2 is recognised as one of the major pathogens of domestic swine, causing a severe negative economic impact on the pig industry worldwide (Segalés and others 2013, Ticó and others 2013).

PCV transmission occurs mainly via the oronasal route (Segalés and others 2005, Grau-Roma and others 2011) and therefore poor biosecurity and inadequate hygiene, husbandry or herd management procedures are significant risk factors (Madec and others 2008). Schmoll and others (2008) reported a widespread distribution of PCV-2 in the semen of Austrian and German boars and suggested this contributed to the high prevalence of PCV-2 in the swine population in this region. Apart from focusing primarily on improving management strategies, current prevention strategies against the majority of porcine circovirus diseases most prominently utilise PCV-2 vaccination (Heissenberger and others 2013).

The wide distribution of PCV-2, the associated economic damage and the need for efficient prevention strategies, led to the introduction of vaccines against PCV-2 in Austria in 2008 and they have been an integral part of the recommendations of the Austrian Animal Health Service since then (Anonymous 2012). The economic losses in cases of PCV-2-associated PRDC are predominantly due to the effect of increased mortality rate, decreased liveweight gain, longer time to market and reduced carcase weight (Fachinger and others 2008). PCV-2 evidently plays an important role as a causative agent of porcine pneumonia, especially in finishing pigs (Fachinger and others 2008, Wellenberg and others 2010). The question remains, however, whether the use of vaccines against PCV-2 enhances lung health in pigs, thereby providing an additional economical benefit for the farmer? To answer this question, the study presented here analysed porcine postmortem findings and attempted to identify impact factors potentially influencing the probability and severity of pneumonia.

Veterinary Record (2014) doi: 10.1136/vr.102755

J. Raith, MVM,
H. Schobesberger, DVM,
J. Köfer, DVM, Professor,
Institute for Veterinary Public Health, University of Veterinary Medicine Vienna, Veterinaerplatz 1, Vienna A-1210, Austria
S. Kuchling, MSc,
C. Schleicher, MSc,
Division for Data, Statistics & Risk Assessment, Austrian Agency for Health and Food Safety, Zinzendorfgasse 27/1, Graz A-8010, Austria
E-mail for correspondence: johannes.raith@vetmeduni.ac.at

Provenance: not commissioned; externally peer reviewed
Accepted September 29, 2014

Materials and methods

Data recording and collection

The data set used contained automatically recorded postmortem findings of 247,505 fattening pigs slaughtered between January 1, 2008 and June 30, 2011 at an Austrian abattoir. The mean carcase weight was 96.6±8.0 kg for pigs originating from fattening farms and 95.4±8.7 kg for pigs originating from farrow-to-finish farms. All pigs were examined by a pool of 12 official meat inspectors (qualified veterinarians) during the mandatory slaughter and meat inspection process (SMI). The SMI encompasses 55 standardised postmortem parameters, modified according to the scheme devised by Blaha (1993). Three of these postmortem parameters refer to pneumonia and classify the signs as +mild, ++moderate and +++severe. The prevalence of these postmortem findings of pneumonia in the data set is shown in Table 1.

Corresponding medication records from 2007 to 2011 were used to identify pigs that were vaccinated against PCV-2 during the breeding period. If a piglet producer recorded group or pen treatment against PCV-2, it was assumed that all piglets from this producer in the corresponding time period were vaccinated. Three different vaccines (Circovac®; Ingelvac CircoFLEX®; Porcilis® PCV) were used in the programme.

The data set also contained the farm of origin and the corresponding piglet producer for each individual pig. All pigs originated from a group of 72 conventional farms (21 fattening farms and 51 farrow-to-finish farms). Table 2 shows the number of vaccinated pigs slaughtered per year and farm type. The programme for PCV-2 vaccination commenced in 2008 and the first vaccinated pigs were due for slaughter in 2009. The rate of vaccinated pigs increased continuously reaching a maximum of 97.1 per cent for fattening and 59.7 per cent for farrow-to-finish farms in 2011. With respect to vaccination against pneumonia, the use of vaccines against mycoplasma was part of normal farming practice. Of pigs originating from fattening farms, 97.7 per cent were vaccinated against *Mycoplasma hyopneumoniae* in the investigated period, compared with 94.3 per cent of pigs from farrow-to-finish farms.

Statistics

In order to investigate the impact of PCV-2 vaccination on the probability and severity of a postmortem finding of pneumonia a cumulative link mixed model (CLMM) was used. Apart from PCV-2 vaccination or non-vaccination, farm type, piglet producer and the seasonal quarter of the year in which the pigs had been slaughtered were assumed as additional potential risk factors for postmortem findings of pneumonia. Regarding the explanatory variable 'piglet producer', the eight largest piglet producers were differentiated. Farrow-to-finish farms and breeding farms that provided pigs to only one of the 72 farms were collated in the category 'other'. As all available explanatory variables were categorical, the following categories were defined as reference categories: *not vaccinated against PCV-2* (PCV-2 vaccination); *farrow-to-finish farm* (farm type); the *first quarter of 2008* (quarter of slaughter).

To account for interactions between PCV-2 vaccination and farm type, the model also included an interaction term between these two parameters. Since other factors, which however lie outside the focus of this study (e.g. hygiene, barn air quality, etc.), might also contribute to the probability of pneumonia, the farm of origin was incorporated as a random effect in the CLMM. Consequently, the statistical dependency between pigs originating from the same farm was taken into account by this random farm effect. Since the meat inspection was carried out by 12 official meat inspectors, it can be safely assumed that a corresponding statistical variability existed with respect to the inspection results. Thus, a variable 'meat inspector' was also included as a random effect. Schleicher and others (2013) reported on the specific amount of variation in the probabilities of a specific postmortem finding attributable to the variance introduced by the particular meat inspectors.

According to the natural order of pneumonia findings, the results of the three postmortem findings were analysed by means of a CLMM with flexible thresholds, a special subtype of generalised linear mixed models. The major objective of estimating the CLMM was to determine whether PCV-2 vaccination reduces the odds for mild, moderate or severe pneumonia. The response was therefore classified into categories (j) 0 (pneumonia negative), 1 (mild pneumonia), 2 (moderate pneumonia) and 3 (severe pneumonia).

The CLMM is given by

$$\text{logit}\,(P(Y_i \leq j)) = \alpha_j - \beta_1 x_{i,1} - \beta_2 x_{i,2} - \cdots - \beta_n x_{i,n} - \mathbf{u_i b}_{m,f} \qquad j = 0, 1, 2$$

where $x_i=(x_{i,1}, \ldots x_{i,n})$ specify the fixed effects: PCV-2 vaccination; farm type; quarter of slaughter; piglet producer; interaction term of PCV-2 vaccination and farm type.

The random effects meat inspector $\mathbf{b}_m$ and farm $\mathbf{b}_f$ follow a normal distribution, namely

$$b_{m,I} \sim N(0, T_m^2), \quad I = 1, \ldots, 12$$
$$b_{f,k} \sim N(0, T_f^2), \quad k = 1, \ldots, 72.$$

Significance of the results regarding fixed effects was determined through forward selection and Bayesian information criterion. All calculations were carried out using R 3.0.2 (R Core Team 2013) and the R-package 'ordinal' (Christensen 2013).

TABLE 1 Number of pigs from 72 farms that had a negative or a positive pneumonia finding (postmortem) in the investigation period

Postmortem finding	Material	Pigs (total)	Pigs (%)
Negative pneumonia	Pluck	173,077	69.9
Mild pneumonia	Pluck	33,707	13.6
Moderate pneumonia	Pluck	29,162	11.8
Severe pneumonia	Pluck	11,559	4.7

TABLE 2 Number of slaughtered pigs and proportion (per cent) of vaccinated pigs according to year and farm type

Year	Farm type	Number of pigs (total)	Pigs vaccinated against PCV-2 (%)
2008	Farrow-to-finish	38,412	0.0
	Fattening	18,348	0.0
2009	Farrow-to-finish	46,300	15.5
	Fattening	21,713	36.7
2010	Farrow-to-finish	48,217	55.1
	Fattening	26,673	96.3
2011	Farrow-to-finish	31,797	59.7
	Fattening	16,045	97.1

PCV-2, porcine circovirus type 2.

Results

Among the model parameters, annual quarter of slaughter, farm type, PCV-2 vaccination and interaction between farm type and PCV-2 vaccination were shown to be significant factors influencing the probability of finding postmortem signs of pneumonia.

Table 3 lists the estimated coefficients $\beta_1, \ldots, \beta_n$ with 95 per cent confidence intervals (CIs). Additionally, the odds ratios (ORs) for the fixed effects and the interactions between them are shown in relation to the respective reference category. The odds of a positive finding were highest in the first quarter of 2008, which was used as the temporal reference date. All coefficients for the remaining annual quarters were negative and their

TABLE 3 Estimated model parameters from the cumulative link mixed model and odds ratios (ORs) in relation to the respective reference category

Fixed effects	Estimated coefficients and 95% CI	OR (related to reference category)
Threshold		
Negative	0.43 (0.13 to 0.73)	
Mild pneumonia	1.31 (1.02 to 1.61)	
Moderate pneumonia	2.80 (2.50 to 3.09)	
2008 I (reference)		
2008 II	−0.25 (−0.30 to −0.21)***	0.78
2008 III	−0.43 (−0.49 to −0.38)***	0.65
2008 IV	−0.26 (−0.31 to −0.21)***	0.77
2009 I	−0.01 (−0.05 to 0.04)	0.99
2009 II	−0.31 (−0.36 to −0.26)***	0.73
2009 III	−0.65 (−0.70 to −0.60)***	0.52
2009 IV	−0.33 (−0.38 to −0.27)***	0.72
2010 I	−0.28 (−0.34 to −0.22)***	0.76
2010 II	−0.45 (−0.51 to −0.40)***	0.64
2010 III	−0.51 (−0.56 to −0.46)***	0.60
2010 IV	−0.32 (−0.38 to −0.27)***	0.72
2011 I	−0.19 (−0.24 to −0.14)***	0.83
2011 II	−0.49 (−0.54 to −0.44)***	0.61
Farrow-to-finish farm (reference)		
Fattening farm	−0.44 (−0.87 to 0.00)*	0.65
Not vaccinated against PCV-2 (reference)		
Vaccinated against PCV-2	−0.05 (−0.09 to −0.01)**	0.95
Farrow-to-finish farm/Not vaccinated against PCV-2 (reference)		
Fattening farm/Vaccinated against PCV-2 (interaction)	−0.19 (−0.23 to −0.15)***	0.83
Random effects	Variance component	
Farm	0.712	
Meat inspector	0.103	

Significance level: *P<0.05; **P<0.01; ***P<0.001
PCV-2, porcine circovirus type 2.

ORs smaller than one. The decreasing odds of a positive finding exhibited an observable seasonal trend highlighting an increased risk of postmortem pneumonia signs during cold months (first and fourth quarters) and a lower risk during warm months (second and third quarters). The estimated coefficient for PCV-2 vaccination (−0.05) indicates a significantly (P<0.01) reduced risk (OR 0.95) of pneumonia, as well as a decreased severity of pneumonia in vaccinated pigs compared with those, which had not been vaccinated. With regards to farm type, pigs from fattening farms were less likely to show postmortem pneumonia signs (coefficient: −0.44; OR 0.65) (P<0.05) than pigs from farrow-to-finish farms. When affected, these animals also tended to suffer from pneumonia with a milder severity than pigs from farrow-to-finish farms. The probability and severity of pneumonia was additionally reduced for pigs vaccinated against PCV-2 originating from fattening farms (coefficient: −0.19; OR 0.83) (P<0.001). The estimated variance component of the random effect *farm of origin* accounted for 0.712, and the estimated variance component for the random effect *meat inspector* was 0.103 (Table 3).

Fig 1 compares the expected probabilities of pneumonia for pigs from fattening farms in different situations. The first and the second bars display the probabilities of a negative finding or of a positive pneumonia finding at different severity grades for vaccinated and non-vaccinated pigs slaughtered during the first quarter of 2009. The same parameters are provided in the third and fourth bars for the third quarter of 2009. The probability of a positive pneumonia finding in the first quarter of 2009 ranged from 29.5 per cent among non-vaccinated pigs to 24.7 per cent for pigs vaccinated against PCV-2 and from 18.1 per cent to 14.7 per cent, respectively, in the third quarter of 2009. The probability of pneumonia of all severities being reported was much lower in the third quarter compared with the first quarter of 2009 (e.g. the probability of moderate pneumonia for vaccinated pigs was reduced from 9.0 per cent to 5.1 per cent) (Fig 1).

The estimated probabilities P (Y=j) for pigs from the reference category (i.e. pigs slaughtered in the first quarter of 2008, originating from a farrow-to-finish farm and not vaccinated against PCV-2) are listed in Table 4. For a pig within the reference category, the estimated probability of demonstrating no signs of postmortem pneumonia was 60.6 per cent. The estimated probabilities for mild, moderate and severe pneumonia were 18.2 per cent, 15.5 per cent and 5.8 per cent, respectively.

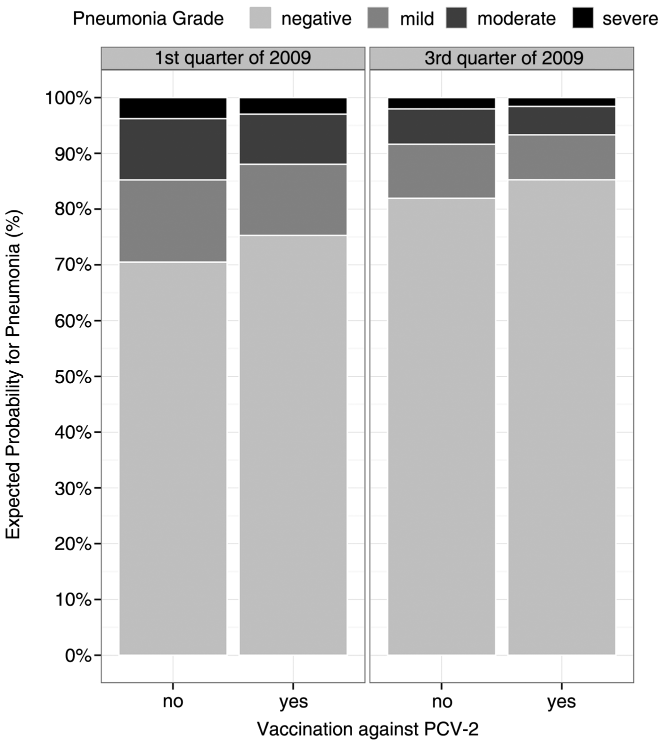

FIG 1 Expected probabilities of pneumonia for a pig from a fattening farm based on the results of the cumulative link mixed model under the assumption that the random intercepts are zero. PCV-2, porcine circovirus type 2.

TABLE 4 Estimated probabilities for pigs from the reference category (pigs that were slaughtered in the first quarter 2008, originated from a farrow-to-finish farm and were not porcine circovirus type 2 vaccinated) assuming that the random intercepts are zero

Pneumonia finding	P (Y=j|reference category) %
Negative (0)	60.6
Mild (1)	18.2
Moderate (2)	15.5
Severe (3)	5.8

These results were obtained under the assumption that the random intercepts are zero.

Table 5 lists the estimated OR for pneumonia ≥j (j=0, 1, 2, 3) for a defined pig in a defined quarter and year comparing different settings regarding farm type and vaccination status against PCV-2 . The odds of postmortem pneumonia signs, or, when affected by lung pathology, for increased severity of pneumonia, were reduced by a factor of 0.95 for a pig vaccinated against PCV-2 when compared with a non-vaccinated pig, both originating from the same farm type (farrow-to-finish farm). The odds of a vaccinated pig from a fattening farm were reduced by a factor of 0.78 when compared with a non-vaccinated pig from a fattening farm, and by 0.51 when compared with a non-vaccinated pig originating from a farrow-to-finish farm. When comparing two vaccinated pigs originating from different farm types, a pig on the fattening farm had odds of 0.53 for positive postmortem pneumonia signs, or, when affected by pneumonia, for an increasingly severe pathology, compared with its counterpart from the farrow-to-finish farm.

Discussion

A variety of authors consider PCV-2 as the most important and prevalent pathogen in relation to PRDC (Kim and others 2003, Hansen and others 2010, Ticó and others 2013). Although previous studies have indicated a wide distribution of PCV-2 in Austria (Anonymous 2012), there is unfortunately no accurate information available about the current PCV-2 prevalence among the country's herds. Furthermore, the impact of PCV-2 vaccination on the porcine lung health is still unknown. Therefore the aim of the present study was to evaluate the influence of PCV-2 vaccination on the probability and severity of pneumonia detected at the postmortem meat inspection in slaughter pigs.

Vaccines against PCV-2 had yet to be established on the national market in early 2008, therefore the first quarter of this year was used as a reference value. Due to the detrimental effects on the economy and the urgent need for prevention strategies, vaccines against PCV-2 were eventually introduced in the latter course of 2008. As the rate of PCV-2 vaccination increased in the population included in this study (Table 2), it significantly reduced the odds of postmortem findings of mild, moderate and severe pneumonia among vaccinated pigs (Tables 3 and 5; Fig 1). These results confirm those reported by Fachinger and others (2008), who carried out a field study evaluating the effects of PCV-2 vaccination in pigs suffering from PRDC. They pointed out that vaccination led to a reduction in the average PCV-2 viral load (between 55 per cent and 83 per cent), in the mean duration of viraemia (50 per cent) and to a general improvement in overall growth performance of pigs. Chae (2012) also considers PCV-2 vaccination an important tool in controlling PRDC. The current commercially available vaccines against PCV-2 (Circovac®, Ingelvac CircoFLEX®, Circumvent®, Porcilis® PCV and Fostera™ PCV) are recognised to be effective in minimising herd exposure to PCV-2, in reducing clinical disease and in improving production parameters in farms with PCV-2 infection (Beach and Meng 2012). Various reviews (Kekarainen and others 2010, Beach and Meng 2012, Chae 2012), meta-analysis (Kristensen and others 2011) and field studies (Opriessnig and others 2010, Kim and others 2011, Kurmann and others 2011, Martelli and others 2011, Fraile and others 2012a, b, Heissenberger and others 2013, Opriessnig and others 2013) have investigated the effects of different vaccines against PCV-2 and a variety of vaccination strategies on clinical and immunological parameters (e.g. level and duration of viraemia) and on production parameters (e.g. average daily liveweight gain, mortality rate). The current study is an approach to evaluate the efficacy of PCV-2 vaccination by analysing postmortem findings from a slaughterhouse. According to Wellenberg and others (2010), PCV-2 plays a role in pneumonia in 10–24-week-old fattening pigs and IgM antibodies against PCV-2 at the age of 20–22 weeks may decrease the probability of developing pneumonia by slaughter. Fachinger and others (2008) further detected the greatest vaccination effects within the 8-week period from the onset of viraemia to the end of finishing. These conclusions support the investigation and are a possible explanation for the identified effect of PCV-2 vaccination on pulmonary postmortem findings.

The study presented here used postmortem findings, detected during the mandatory SMI process, as an indicator for general animal health. Antemortem and postmortem meat inspection represents an important checkpoint in food production and processing. Collected data can be used for internal processes and official controls and they are also very useful in the context of a feedback system to the farmer (Köfer and others 2001). Blaha and others (1994) consider changes in the lungs, serous membranes and liver as most important indicators for animal performance and subsequent economic benefit. The pathological and anatomical changes of organs are objective measures for the diseases acquired throughout the animal's life and allow an estimation about animal health and associated management and farming factors in each population (Blaha and others 1994).

Considering the overall estimated effect of PCV-2 vaccination (Table 3) and the expected probability for pneumonia in 2009 (Fig 1), it appears that the vaccination effect was more prominent at the beginning of the intervention programme (2009). Vaccination rates on fattening farms, in particular, have risen rapidly up to 97.1 per cent in 2011 (Table 2). Therefore it was increasingly difficult over time to detect a difference between those animals who were vaccinated and the declining number of non-vaccinated pigs. It can also be assumed that with an increasing proportion of vaccinated pigs, the herd immunity effect of vaccination became more and more important. As is well-known, herd immunity leads to a reduced risk of infection among susceptible individuals (e.g. unvaccinated animals, vaccine failures) in a population by the presence of immune individuals in that population (Fine and others 2011). Furthermore, it could be shown that the vaccination effect is closely related to the respective farm type. Pigs from fattening farms were less likely to have postmortem findings of pneumonia than pigs from

TABLE 5 Odds ratio (OR) for a positive pneumonia ≥j (j=0, 1, 2, 3) for a specific pig in a specific quarter and year in different settings (farm type and vaccination status), based on the significant estimated coefficients of the cumulative link mixed model

Setting	Farm type	Vaccination status (PCV-2)	OR
A	Farrow-to-finish	Vaccinated	0.95
Reference	Farrow-to finish	Non-vaccinated	
B	Fattening	Vaccinated	0.78
Reference	Fattening	Non-vaccinated	
B	Fattening	Vaccinated	0.51
Reference	Farrow-to-finish	Non-vaccinated	
B	Fattening	Vaccinated	0.53
Reference	Farrow-to-finish	Vaccinated	
C	Fattening	Non-vaccinated	0.65
Reference	Farrow-to-finish	Non-vaccinated	

PCV-2, porcine circovirus type 2.

farrow-to-finish farms, and they also suffered from less severe pneumonia than pigs from farrow-to-finish farms, even when they were not vaccinated against PCV-2 (Tables 3 and 5). At first glance, this is a somewhat counterintuitive result considering the higher risk of introducing of pathogens into open operation systems compared with closed systems (i.e. farrow-to-finish) (Waldmann and others 2004, Grosse Beilage and others 2013). Presumably rehousing of animals on the fattening farms led to more stringent biosecurity measures (e.g. all-in, all-out system) and, as such, fattening farms might have an additional advantage in preventing pneumonia compared with one-site farrow-to-finish farms. When vaccinated, probability and severity of postmortem pneumonia signs showed an even more pronounced reduction for pigs originating from fattening farms (Tables 3 and 5; Fig 1). Combining the effect of PCV-2 vaccination, the influence of farm type and interaction effects between these two factors, a pig from a fattening farm vaccinated against PCV-2 has only half the chance of a positive postmortem finding or an increased severity of pneumonia, than a non-vaccinated pig from a farrow-to-finish farm (Table 5). Vaccine efficacy depends on various cofactors (Ellis 2014) and these results demonstrate that a particular type of system on farm, as well as management and environment factors in force on each farm, exert a crucial influence on animal health. On fattening farms in particular, the herd immunity effect of vaccination may have played an important role as the PCV-2 vaccination became more prevalent.

The use of mycoplasma vaccines as a part of normal farming practice against pneumonia could be a further influencing factor. The proportion of pigs vaccinated against *M hyopneumoniae* in the study population was extremely high in fattening (97.7 per cent) and farrow-to-finish farms (94.3 per cent). Therefore the conditions were almost identical for both farm types and the outcome of the study could not be explained by the minor differences in the proportion of pigs vaccinated against this bacterium.

In the current study, a seasonal trend characterised by higher odds of postmortem pneumonia signs in cold months compared with warm months became apparent (Table 3; Fig 1). This outcome is in line with personal experience and empirical knowledge about possible seasonal influences on pneumonia and was therefore not surprising. The result also agrees with that of other researchers in the northern hemisphere, such as Elbers and others (1992) who reported the highest prevalence of pneumonia in January-February and the lowest in July-August. Sanchez-Vazquez and others (2012) also found a seasonal peak of respiratory conditions in November-December and lowest level in July. However, when interpreting this observed seasonal trend, it is important to take into account that postmortem findings of pneumonia at slaughter may also represent a previous disease event or the chronic course of pneumonia. An observed seasonal influence on postmortem signs of pneumonia does not necessarily mean a seasonal influence on pneumonia. Nonetheless, in order to uncover the influence of PCV-2 vaccination, it is important to integrate a possible effect of season on pneumonia into the model, to prevent a potential masking of the vaccination effect.

Two putative influencing parameters were incorporated in the CLMM as random effects: meat inspectors and farm of origin. The correlation between a pool of meat inspectors and the consistency of their inspection findings of slaughtered pigs has already been analysed in detail by Schleicher and others (2013). The results of the study presented here (Table 3) show that the farm of origin accounts for a higher proportion of the remaining unexplained variance than the variance component introduced by the meat inspectors. It would appear that there are hitherto unspecified effects at work at farm level, which nonetheless have an impact on animal health and the likelihood of pneumonia being detected at postmortem (Neumann and others 2014). Poor biosecurity in relation to inadequate hygiene and herd management are known risk factors for the spread of pathogens on farm level (Madec and others 2008), which may explain the large farm effect determined. The effect of farm management on PCV-2 diseases incidence has long been known and Madec and others (1999) proposed a 20-point plan of prevention strategies and methods to minimise the impact of PCV-2-related disease in severely affected farms as far back as 1999.

Many hypotheses have been raised with the aim to explain, at least in theory, the exact influence of PCV-2 on lung health, but firm evidence has remained rather inconclusive so far. The outcome of this study emphasises the negative role of PCV-2 in the context of porcine lung health. A key question regarding PCV-2 is the individual expression of its related diseases, as only few pigs develop clinical signs (Segalés and others 2013). The subclinical form is the most common (Segalés 2012) and is responsible for the greatest proportion of negative economic impacts (Alarcon and others 2013). A further complication is the fact that it seems to be difficult to distinguish between PCV-2-associated systemic infection (PMWS) and PCV-2-associated pneumonia (as a part of PRDC) due to the diagnostic overlap between the two conditions (Kim and others 2003, Opriessnig and others 2007). In contrast to other reports (Harms and others 2002, Kim and others 2003, Opriessnig and others 2007, Segalés 2012) Ticó and others (2013) did not support the theory of an isolated PCV-2-associated lung infection and they further concluded that PCV-2 mainly contributes to PRDC in relation to PCV-2-systemic disease (PMWS) or PCV-2-subclinical infections. Fachinger and others (2008) suggested that the vaccination-induced reduction of PCV-2 viraemia may help reduce the incidence of co-infections by secondary pathogens and thus may lessen the clinical effects of PRDC. Similarly, Alban and others (2013) reported a lower prevalence of pneumonia following vaccination whereas the use of antimicrobials against respiratory infections declined over the same period.

It is important for the farm owner or farm manager and the attending veterinarian to have hard evidence that preventive measures are efficacious. Therefore a retrospective evaluation of postmortem findings can be a valuable tool for ensuring preventive measures (e.g. vaccination) are integrated into the management systems of the respective farm. The investigation identifies the importance of a vaccination programme against PCV-2 as a vital tool to reduce the risk of postmortem pneumonia findings and the severity of pneumonia in pigs at slaughter. The strong relationship between the vaccination effect and the respective farm type further underlines the important role of the system in operation on farm, as well as of management and environmental factors and their power to exert a critical influence on animal health and economic prosperity.

Acknowledgements

This study was conducted within the COMET K-Project ('Preventive Veterinary Medicine'; project number: 825339) which was handled by the Austrian Research Promotion Agency (FFG). Further support was provided by VET-Austria, a research cooperation between the Austrian Federal Ministry of Health (BMG), the Austrian Agency for Health and Food Safety (AGES) and the University of Veterinary Medicine Vienna (Vetmeduni Vienna). Additional thanks go to the meat production company providing the data and to Clair Firth, MVM, for editing assistance.

References

ALARCON, P., RUSHTON, J., & WIELAND, B. (2013) Cost of post-weaning multi-systemic wasting syndrome and porcine circovirus type-2 subclinical infection in England - an economic disease model. *Preventive Veterinary Medicine* **110**, 88–102

ALBAN, L., DAHL, J., ANDREASEN, M., PETERSEN, J. V. & SANDBERG, M. (2013) Possible impact of the "yellow card" antimicrobial scheme on meat inspection lesions in Danish finisher pigs. *Preventive Veterinary Medicine* **108**, 334–341

ALLAN, G. M. & ELLIS, J. A. (2000) Porcine circoviruses: a review. *Journal of Veterinary Diagnostic Investigation* **12**, 3–14

ALLAN, G., KRAKOWKA, S., & ELLIS, J. (2002) PCV2: ticking time bomb? *Pig Progress* **18**, 14–15

ALLAN, G. M., MCNEILLY, F., KENNEDY, S., DAFT, B., ELLIS, J. A., HAINES, D. M., MEEHAN, B. M. & ADAIR, B. M. (1998) Isolation of porcine circovirus-like viruses from pigs with a wasting disease in the USA and Europe. *Journal of Veterinary Diagnostic Investigation* **10**, 3–10

ANONYMOUS (2012) Kundmachung des Österreichischen Bundesministeriums für Gesundheit betreffend "ÖTGD-Programm Circovirus Impfung beim Ferkel", Stand: November 2012, gemäß der Tiergesundheitsdienst-Verordnung 2009, BGBL. II Nr. 434/2009 GZ: 74200/0044-II/B/10/2012. [Animal Health Service Regulation 2009, BGBL. II Nr. 434/2009 GZ: 74200/0044-II/B/10/2012]. www.ris.bka.gv.at

BEACH, N. M. & MENG, X.-J. (2012) Efficacy and future prospects of commercially available and experimental vaccines against porcine circovirus type 2 (PCV2). *Virus Research* **164**, 33–42

BLAHA, T. (1993) Erfassung pathologisch-anatomischer Organbefunde am Schlachthof. 1. Mitteilung: Ansatz zu neuen Wegen bei der Wahrnehmung der Verantwortung für Verbraucherschutz und Tiergesundheit. *Fleischwirtschaft* **73**, 877–881

BLAHA, T., GROSSE BEILAGE, E. & HARMS, J. (1994) Erfassung pathologisch-anatomischer Organbefunde am Schlachthof. 4. Quantifizierung der Organbefunde als Indikator für die Tiergesundheit von Schweinebeständen und erste Ergebnisse. *Fleischwirtschaft* **74**, 427–429

CHAE, C. (2005) A review of porcine circovirus 2-associated syndromes and diseases. *The Veterinary Journal* **169**, 326–336

CHAE, C. (2012) Commercial porcine circovirus type 2 vaccines: efficacy and clinical application. *The Veterinary Journal* **194**, 151–157

CHRISTENSEN, R. H. B. (2013) Ordinal Regression Models for Ordinal Data R package version 2013.9 30. www.cran.r-project.org/package=ordinal/

ELBERS, A. R. W., TIELEN, M. J. M., SNIJDERS, J. M. A., CROMWIJK, W. A. J. & HUNNEMAN, W. A. (1992) Epidemiological studies on lesions in finishing pigs in the Netherlands. I. Prevalence, seasonality and interrelationship. *Preventive Veterinary Medicine* **14**, 217–231

ELLIS, J. (2014) Porcine circovirus: a historical perspective. *Veterinary Pathology* **51**, 315–327

ELLIS, J., HASSARD, L., CLARK, E., HARDING, J., ALLAN, G., WILLSON, P., STROKAPPE, J., MARTIN, K., MCNEILLY, F., MEEHAN, B., TODD, D. & HAINES, D. (1998) Isolation of circovirus from lesions of pigs with postweaning multisystemic wasting syndrome. *The Canadian Veterinary Journal* **39**, 44–51

FACHINGER, V., BISCHOFF, R., BEN JEDIDIA, S., SAALMÜLLER, A. & ELBERS, K. (2008) The effect of vaccination against porcine circovirus type 2 in pigs suffering from porcine respiratory disease complex. *Vaccine* **26**, 1488–1499

FINE, P., EAMES, K., HEYMANN, D.L. (2011) "Herd Immunity": a rough guide. *Clinical Infectious Diseases* **52**, 911–916

FRAILE, L., GRAU-ROMA, L., SARASOLA, P., SINOVAS, N., NOFRARÍAS, M., LÓPEZ-JIMENEZ, R., LÓPEZ-SORIA, S., SIBILA, M. & SEGALÉS, J. (2012a) Inactivated PCV2 one shot vaccine applied in 3-week-old piglets: improvement of production parameters and interaction with maternally derived immunity. *Vaccine* **30**, 1986–1992

FRAILE, L., SIBILA, M., NOFRARÍAS, M., LÓPEZ-JIMENEZ, R., HUERTA, E., LLORENS, A., LÓPEZ-SORIA, S., PÉREZ, D. & SEGALÉS, J. (2012b) Effect of sow and piglet porcine circovirus type 2 (PCV2) vaccination on piglet mortality, viraemia, antibody titre and production parameters. *Veterinary Microbiology* **161**, 229–234

GRAU-ROMA, L., FRAILE, L. & SEGALÉS, J. (2011) Recent advances in the epidemiology, diagnosis and control of diseases caused by porcine circovirus type 2. *The Veterinary Journal* **187**, 23–32

GROSSE BEILAGE, E., NATHUES, H., GRUMMER, B., HARTUNG, J., KAMPHUES, J., KIETZMANN, M., ROHDE, J., SPINDLER, B. & WEISSENBÖCK, H. (2013) Diagnostik, Prohylaxe und Therapie von Atemwegserkrankungen in Schweinebeständen. In: *Diagnostik und Gesundheitsmanagement im Schweinebestand*. Hrsg.: E. GROSSE BEILAGE & M. WENDT. Stuttgart: Ulmer KG. pp. 232–233

HANSEN, M. S., PORS, S. E., JENSEN, H. E., BILLE-HANSEN, V., BISGAARD, M., FLACHS, E. M. & NIELSEN, O. L. (2010) An investigation of the pathology and pathogens associated with porcine respiratory disease complex in Denmark. *Journal of Comparative Pathology* **143**, 120–131

HARMS, P. A., HALBUR, P. G. & SORDEN, S. D. (2002) Three cases of porcine respiratory disease complex associated with porcine circovirus type 2 infection. *Journal of Swine Health and Production* **10**, 27–30

HEISSENBERGER, B., WEISSENBACHER-LANG, C., HENNIG-PAUKA, I., RITZMANN, M. & LADINIG, A. (2013) Efficacy of vaccination of 3-week-old piglets with Circovac® against porcine circovirus diseases (PCVD). *Trials in Vaccinology* **2**, 1–9

KEKARAINEN, T., MCCULLOUGH, K., FORT, M., FOSSUM, C., SEGALÉS, J. & ALLAN, G. M. (2010) Immune responses and vaccine-induced immunity against Porcine circovirus type 2. *Veterinary Immunology and Immunopathology* **136**, 185–193

KIM, J., CHUNG, H.-K. & CHAE, C. (2003) Association of porcine circovirus 2 with porcine respiratory disease complex. *The Veterinary Journal* **166**, 251–256

KIM, D., KIM, C. H., HAN, K., SEO, H. W., OH, Y., PARK, C., KANG, I. & CHAE, C. (2011) Comparative efficacy of commercial Mycoplasma hyopneumoniae and porcine circovirus 2 (PCV2) vaccines in pigs experimentally infected with M. hyopneumoniae and PCV2. *Vaccine* **29**, 3206–3212

KÖFER, J., KUTSCHERA, G. & FUCHS, K. (2001) Tiergesundheitsmonitoring durch Organbefundung am Schlachthof. *Fleischwirtschaft* **10**, 107–111

KRISTENSEN, C. S., BAADSGAARD, N. P. & TOFT, N. (2011) A meta-analysis comparing the effect of PCV2 vaccines on average daily weight gain and mortality rate in pigs from weaning to slaughter. *Preventive Veterinary Medicine* **98**, 250–258

KURMANN, J., SYDLER, T., BRUGNERA, E., BUERGI, E., HAESSIG, M., SUTER, M. & SIDLER, X. (2011) Vaccination of dams increases antibody titer and improves growth parameters in finisher pigs subclinically infected with porcine circovirus type 2. *Clinical and Vaccine Immunology* **18**, 1644–1649

MADEC, F., EVENO, É., MORVAN, P., HAMON, L., MORVAN, H., ALBINA, E., TRUONG, C., HUTET, É., CARIOLET, R., ARNAULD, C. & JESTIN, A. (1999) La Maladie de l'Amaigrissement du Porcelet (MAP) en France 1 – Aspects descriptifs, impact en élevage. *Journées Recherche Porcine en France* **31**, 347–354

MADEC, F., ROSE, N., GRASLAND, B., CARIOLET, R. & JESTIN, A. (2008) Post-weaning multisystemic wasting syndrome and other PCV2-related problems in pigs: a 12-year experience. *Transboundary and Emerging Diseases* **55**, 273–283

MARTELLI, P., FERRARI, L., MORGANTI, M., DE ANGELIS, E., BONILAURI, P., GUAZZETTI, S., CALEFFI, A. & BORGHETTI, P. (2011) One dose of a porcine circovirus 2 subunit vaccine induces humoral and cell-mediated immunity and protects against porcine circovirus-associated disease under field conditions. *Veterinary Microbiology* **149**, 339–351

NEUMANN, E. J., HALL, W. F., STEVENSON, M. A., MORRIS, R. S. & LING MIN THAN, J. (2014) Descriptive and temporal analysis of post-mortem lesions recorded in slaughtered pigs in New Zealand from 2000 to 2010. *New Zealand Veterinary Journal* **62**, 110–116

OPRIESSNIG, T., MENG, X.-J. & HALBUR, P. G. (2007) Porcine circovirus type 2-associated disease: update on Current terminology, clinical manifestations, pathogenesis, diagnosis, and intervention strategies. *Journal of Veterinary Diagnostic Investigation* **19**, 591–615

OPRIESSNIG, T., O'NEILL, K., GERBER, P. F., DE CASTRO, A. M. M. G., GIMENÉZ-LIROLA, L. G., BEACH, N. M., ZHOU, L., MENG, X.-J., WANG, C. & HALBUR, P. G. (2013) A PCV2 vaccine based on genotype 2b is more effective than a 2a-based vaccine to protect against PCV2b or combined PCV2a/2b viremia in pigs with concurrent PCV2, PRRSV and PPV infection. *Vaccine* **31**, 487–494

OPRIESSNIG, T., PATTERSON, A. R., MADSON, D. M., PAL, N., RAMAMOORTHY, S., MENG, X.-J. & HALBUR, P. G. (2010) Comparison of the effectiveness of passive (dam) versus active (piglet) immunization against porcine circovirus type 2 (PCV2) and impact of passively derived PCV2 vaccine-induced immunity on vaccination. *Veterinary Microbiology* **142**, 177–183

R CORE TEAM (2013) *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. www.R-project.org/

SANCHEZ-VAZQUEZ, M. J., NIELEN, M., GUNN, G. J. & LEWIS, F. I. (2012) Using seasonal-trend decomposition based on loess (STL) to explore temporal patterns of pneumonic lesions in finishing pigs slaughtered in England, 2005–2011. *Preventive Veterinary Medicine* **104**, 65–73

SCHLEICHER, C., SCHERIAU, S., KOPACKA, I., WANDA, S., HOFRICHTER, J. & KÖFER, J. (2013) Analysis of the variation in meat inspection of pigs using variance partitioning. *Preventive Veterinary Medicine* **111**, 278–285

SCHMOLL, F., LANG, C., STEINRIGL, A S., SCHULZE, K. & KAUFFOLD, J. (2008) Prevalence of PCV2 in Austrian and German boars and semen used for artificial insemination. *Theriogenology* **69**, 814–821

SEGALÉS, J. (2012) Porcine circovirus type 2 (PCV2) infections: clinical signs, pathology and laboratory diagnosis. *Virus Research* **164**, 10–19

SEGALÉS, J., ALLAN, G. M. & DOMINGO, M. (2005) Porcine circovirus diseases. *Animal Health Research Reviews* **6**, 119–142

SEGALÉS, J., KEKARAINEN, T. & CORTEY, M. (2013) The natural history of porcine circovirus type 2: From an inoffensive virus to a devastating swine disease? *Veterinary Microbiology* **165**, 13–20

TICÓ, G., SEGALÉS, J. & MARTÍNEZ, J. (2013) The blurred border between porcine circovirus type 2-systemic disease and porcine respiratory disease complex. *Veterinary Microbiology* **163**, 242–247

WALDMANN, K.-H., WENDT, M., BICKHARDT, K., HEINRITZI, K., LAHRMANN, K. H., PLONAIT, H, ZIMMERMANN, W. (2004) Lehrbuch der Schweinekrankheiten. 4. Auflage. Hrsg.: K.-H. WALDMANN & M. WENDT. Stuttgart: Parey. pp 549–550

WELLENBERG, G. J., BOUWKAMP, F. T., WOLF, P. J. V. D., SWART, W. A. J. M., MOMBARG, M. J. & DE GEE, A. L. W. (2010) A study on the severity and relevance of porcine circovirus type 2 infections in Dutch fattening pigs with respiratory diseases. *Veterinary Microbiology* **142**, 217–224

CrossMark