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

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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, Opiressnig and others 2007, Segalés 2012), often functioning as an important causal agent in subclinical infections (Opiressnig 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 2015).

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 carcass 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 farmers. 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.
Materials and methods
Data recording and collection
The data set used contained automatically recorded postmortem findings of 247,508 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±3.7 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 Circovac®; 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. If a piglet producer recorded group or pen treatment against PCV-2, it was assumed that all piglets from this farm 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 (2015) 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.

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 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).

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 β1, ..., β8 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 1 Number of pigs from 72 farms that had a negative or a positive pneumonia finding (postmortem) in the investigation period](attachment:table1.png)

![Table 2 Number of slaughtered pigs and proportion (per cent) of vaccinated pigs according to year and farm type](attachment:table2.png)

![Table 3 Estimated coefficients β1, ..., β8 with 95 per cent confidence intervals (CIs) for the fixed effects and the interactions between them](attachment:table3.png)
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: −0.14; OR 0.83) 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=1) 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.

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

| Threshold | Estimated coefficients and 95% CI | OR (related to reference category) |
|-----------|----------------------------------|-----------------------------------|
| 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) |                                   |

| 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.

**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.
among the country information available about the current PCV-2 prevalence.

Among the countries, vaccines against PCV-2 were eventually introduced in the years used as a reference value. Due to the detrimental effects on the economy and the urgent need for prevention strategies, a pig on the fattening farm had odds of 0.53 for positive pneumonia detected at the postmortem meat inspection in a 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 point 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. Chaie (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 (Rekaran and others 2010, Beach and Meng 2012, Chaie 2012), meta-analysis (Kristensen and others 2011) and field studies (Opiepnssig and others 2010, Kim and others 2011, Kürmann and others 2011, Martelli and others 2011, Fraile and others 2012a, b, Heissenberger and others 2013, Opiepnssig 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 Weissenberg 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 2011) and allow an estimation about animal health and associated management and farming factors in each population (Blaaha and others 1994).

**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 | 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** Odds ratio (OR) for a positive pneumonia 1 (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** Reference       | Farrow-to-finish | Vaccinated                | 0.95|
| Reference             | Farrow-to-finish | Non-vaccinated            | 0.78|
| **B** Reference       | Fattening        | Vaccinated                | 0.81|
| Reference             | Fattening        | Non-vaccinated            | 0.51|
| **C** Reference       | Farrow-to-finish | Vaccinated                | 0.53|
| Reference             | Farrow-to-finish | Non-vaccinated            | 0.65|

**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, Greise Breilage 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 environmental 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 Mycoplasma in November and the 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. 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 2015). 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, Opreissnig and others 2007). In contrast to other reports (Harms and others 2002, Kim and others 2003, Opreissnig 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.

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