An updated transmission model for *Salmonella* in grower-finisher pigs


(1)Centre for Epidemiology and Risk Analysis, Veterinary Laboratories Agency, Woodham Lane, KT15 3NB, New Haw, Surrey, United Kingdom  
(2)Danish Bacon & Meat Council, Vinkelvæj 11, DK8620 Kjellerup, Denmark  
*Corresponding Author: a.hill@vla.defra.gsi.gov.uk*

Abstract

A model describing the transmission of *Salmonella* between pigs on a British continuous-production grower-finisher pig farm has previously been developed (Hill et al, 2005). We will describe improvements to the model and updates to the parameter estimation. In addition, the model has been expanded to include all-in-all-out production, a much more detailed model of serological response, and all *Salmonella* spp. rather than just *Salmonella* Typhimurium. The model now also differentiates between farms with slatted and solid flooring.

The average prevalence of infection in slaughter-age pigs (13-15%) did not change significantly given the model updates. A key feature of this model is that, almost independently of peak infection levels, equilibrium in the prevalence of infection is generally reached around the same level (~15%) and time. Therefore, while meat-juice ELISA (MJE) prevalence estimates for slatted and solid flooring show a significant difference, the model results for the prevalence of true infection at slaughter shows little difference between the flooring types.

Introduction

The UK Food Standards Agency have set a target of achieving a 50% reduction in the incidence of *Salmonella* infection in slaughter-age pigs by 2010. In order to meet this target for *Salmonella*, the British Pig Executive, BPEX, in association with Defra and the Food Standards Agency, has introduced a Zoonoses Action Plan (ZAP) programme (British Pig Executive 2003). This nationwide surveillance scheme is used to monitor all pig farms sending pigs to assured slaughterhouses and uses a meat-juice ELISA (MJE) test. Farms are categorised into 3 groups based on the level of MJE-positive pigs at slaughter. By targeting the worst-offending farms (i.e. those farms within ZAP 2 and 3 categories) with financial penalties and control programmes, the ZAP programme ultimately aims to reduce the prevalence of *Salmonella* in pigs at slaughter; in turn a reduction in the burden of human salmonellosis should be observed.

In support of this effort to reduce the incidence of *Salmonella* infection in pigs of slaughter-age, a farm-to-consumption risk assessment was developed (Hill et al, 2003). The aim of this risk assessment was to estimate the risk of *Salmonella* Typhimurium infection from the consumption of three types of pig-meat products; pork, bacon and mixed meat products. As part of this risk assessment a farm transmission model for *Salmonella* in grower-finisher pigs was developed, with the aim of estimating the prevalence of infected pigs at the age of slaughter. This farm transmission model has been further developed since the original risk assessment was finished, primarily by using meat-juice ELISA (MJE) data that has become available from the ZAP monitoring programme to improve parameter estimation (Hill et al, 2005). In this paper we report on a further update to the farm transmission model, using data from a Danish longitudinal study to improve a number of critical parameters within the model, such as the finisher pig’s individual time to a detectable serological response after initial infection with *Salmonella*.

Material and methods

A fuller description of the modeling methods used can be found in Hill et al (2005), and a full paper has been submitted for external peer-review (Hill et al, submitted). In brief, the farm transmission
model is a modified Reed-Frost SI (Susceptible-Infected) model, which includes pen-to-pen transmission of *Salmonella* (assumed to be either by the faecal-oral or airborne routes). The model output is the prevalence of infection in slaughter-age pigs, which is broken down further into the prevalence of pigs actively excreting the organism in their faeces, and the prevalence of carrier pigs. The model output also includes an estimate of the prevalence of MJE-positive slaughter-age pigs.

The model requires estimation of parameters that were/are weakly supported by data (primarily due to the size of the field studies that would be required to fill these data gaps). Examples of parameters where data are lacking include: the probabilities of an "effective" contact from one pig to another (i.e. one which results in the successful transmission of infection from one infected pig to a susceptible pig) within and between pens, denoted $p_s$ and $p_i$ respectively, and the variation in the duration of infection and the duration of time any serological response is detectable by the MJE test.

As described previously (Hill et al, 2005) data from the British ZAP monitoring programme were used to estimate the transmission parameters $p_s$ and $p_i$ by using maximum-likelihood methods (essentially the values of $p_s$ and $p_i$ were varied over a number of model simulations until the resulting distribution of MJE-positive pigs produced from the simulation model was as close as possible to the actual distribution of MJE-positive pigs recorded by the ZAP monitoring programme). However, a number of unsatisfactory assumptions were used to estimate these parameters due to a lack of knowledge about the development of the serological response in pigs; namely that once infected pigs would immediately develop a serological response detectable by the British MJE test, and that this serological response would continue to be detectable until the infected pig was slaughtered.

The two assumptions about a pig's serological response were able to be removed from the model when the raw data from a Danish longitudinal study (Kranker et al, 2003) became available. Briefly, the authors of this study took monthly faecal and blood samples from three herds, for a total of 180 finisher pigs over the course of their rearing to slaughter weight. Using standard survival analysis methods, this dataset enabled us to generate "survival curves" for the duration of *Salmonella* excretion, the time to a detectable serological response and the duration of this detectable serological response. The parameter estimation of the transmission parameters was then redone using the updated model and the same maximum-likelihood methods as before.

The model was also modified to simulate all-in-all-out (AIAO) production: briefly, the modifications taken were to populate the grower-finisher farm with weaners all of the same age at $t = 0$, remove the continuous repopulation of pens over time, and remove all pigs from the farm at slaughter age. In addition, the ZAP programme dataset was split by farms that used solid and slatted flooring: we were therefore able to estimate transmission parameters for both types of farm.

**Results**

**Epidemic curves for continuous and all-in-all-out production**

The average epidemic curves for continuous and AIAO production are presented in Figures 1a and 1b. The average prevalence of MJE-positive pigs on AIAO farms is reduced by approximately 5% compared to continuous production over the range of $t$ (the time pigs will be taken to slaughter). There are marked changes in the average prevalence of excretion and carriage for AIAO farms at slaughter age: the average prevalence of excretion within the range of slaughter age is approximately 1%, which is 2-4% lower than for continuous production, and the prevalence of carriage is reduced by around 5-6%. However, it must be noted the variation between individual farms' epidemic curves is much greater than the difference between the average epidemic curves for continuous and AIAO production.
Figure 1: Average prevalence of excretion, carriage and MJE-positive pigs for a) continuous production farms and b) all-in-all-out production farms, for 150 days post arrival (slaughter age between 84-116 days after the time of introduction to the grower-finisher farm, $t_0$, denoted by red shading).

**Epidemic curves for slatted- and solid-floored farms.**

The average epidemic curves for solid-floored and slatted-floored farms are illustrated in Figures 2a and 2b respectively (the solid-floored farm curve is very similar to the epidemic curve for all flooring-type farms). Again, as above, there is significant variation between farms, such that the prevalence of infection at slaughter age may typically vary between 0 and 30-40%. Slatted-floored farms tend to have less MJE-positive pigs sent to slaughter, which translates into lower transmission parameters for this type of farm compared to solid-floored farms. These lower transmission parameters result in less pigs become infected during the course of the growing/finishing period. However, there is no significant decrease in the prevalence of infected pigs being sent to slaughter from slatted-floored farms compared to solid-floored farms.

Figure 2: Average prevalence of excretion, carriage and MJE-positive pigs for a) solid-floored farms and b) slatted-floored farms, for 150 days post arrival (slaughter age between 84-116 days after the time of introduction to the grower-finisher farm, $t_0$, denoted by red shading).

**Discussion**

We have updated the previous farm transmission model (Hill et al., 2005) to remove key assumptions from our parameter estimation. This has increased our confidence in the results of the model, and allowed us to include a model describing the serological response within pigs and
the related MJE test within the farm transmission model. In addition, we have investigated different types of grower-finisher farms, such as those with AIAO production, and compared those farms with solid and slatted flooring.

An interesting result of the model is that while solid-floored farms have, on average, a higher peak prevalence of infection, the average prevalence of infection at slaughter is very similar to that of slatted-floored farms, even though overall less pigs are infected on slatted-floored farms. This is because the main phase of the epidemic lasts the same time in both farm types (as duration of infection is independent of how many pigs are infected), leaving a residual infection period afterwards which is driven by a much smaller population of excreting and susceptible pigs than in the main epidemic period. AIAO production follows the same trends as continuous production, but has a lower "equilibrium" prevalence of infection at the end of the finishing period, presumably due to the proportionally lower number of excreting pigs on the farm at this time compared to continuous farms.

The European Commission is expected to require that all Member States introduce National Salmonella Control programmes for pigs, in order to achieve a prescribed reduction in prevalence. Our model can be adapted to compare the predicted response to different interventions by assuming how these might impact on key parameters, such as contact rate. In addition, our model allows a comparison of MJE results with prevalence of infection at slaughter, which could enable a national control programme to consider the use of MJE tests to monitor response of the national herd to a control programme where the definitive criterion was to achieve a targeted reduction in the prevalence of infection at slaughter.

An important point to note is that the farm transmission model still contains assumptions (an important one being the initial conditions of the model) and further research is required to confirm the results of this model, and apply the results to the risk assessment model as a whole. Improvements to the risk assessment and the farm transmission model are currently underway, and the knowledge these models provide on the dynamics of Salmonella infection in pigs and its relation to human risk can only be of added value to the current monitoring programme.

Conclusions

To our knowledge we have modeled the epidemic curve of Salmonella infection in grower-finisher pigs as comprehensively as has yet been done. The main result of this updated model, that the dynamics of infection appear to reach an equilibrium towards the point where pigs reach slaughter age, has potential implications for any monitoring programme. This result therefore requires further research, which is currently underway.

References


