A risk assessment for *Salmonella* in pigs in Great Britain.

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Abstract

Along with poultry, pig meat has been identified as a potential source of human foodborne *Salmonella* infection. In order to minimise the risk of human illness, a number of EU countries have initiated *Salmonella* monitoring programmes for pigs (e.g. Denmark, Germany, UK) and EU requirements for control of *Salmonella* in pigs will be based on the results of recent surveys together with risk assessment and economic studies that are under way. However, control programmes cannot be successful unless practical interventions are available for pig farmers and producers to implement. Therefore, as part of a large risk-based study investigating control of *Salmonella* in pigs, a full British farm-to-consumption risk assessment has been developed in order to predict the impact of interventions upon the risk of human disease. The interventions investigated within the risk assessment were: vaccination, feeding of organic acids, rodent control, anal bunging and washing and drying of the carcass at dehauling.

Using current values for pig meat consumption, the model predicts an average of 502, 96 and 2 human salmonellosis cases per year can be attributed to domestic sausage, pork chop and bacon consumption respectively. This accounts for around 2-3% of the estimated total annual burden of *Salmonella* illness in the British population. In the best case scenario, the number of cases attributable to pig meat consumption fell by 81%, 70%, 60% and 36% when bunging, rodent control, organic acid and vaccination interventions were assumed to be universally applied across the GB pig industry. These results are subject to a number of important assumptions and uncertainties (e.g. the likelihood that the effectiveness of these interventions would remain at experimental/trial levels when rolled out across a large number of farms), but could be vital for informing future National Control Plans and GB/EU policy.

Introduction

*Salmonella* is the second most commonly reported form of bacterial gastro-enteritis in Great Britain (GB), with 11,779 reported cases in 2007 (Health Protection Agency, 2008). It is estimated that only one in three cases are reported to national surveillance (FSA, 2000) and so community cases are likely to exceed 30,000 per year. A recent survey reported 21.2% of pigs were infected with *Salmonella* spp. on entry to the slaughterhouse (EFSA, 2008), indicating a potentially significant burden of *Salmonella* contaminated carcasses entering the food-chain. Source attribution models suggest that pig meat products may contribute towards 10% of foodborne cases of *Salmonella* (Hald et al., 2004). Given this likely burden, both the GB and EU governments are keen to reduce levels of *Salmonella* in pigs, and indeed targets for reductions in the prevalence of infection in slaughter pigs will be set by the EU within the next 2-3 years. However, there is no direct causal link between the prevalence of *Salmonella* in pigs and human illness, as there are many processes that occur between the farm and human consumption that could affect the risk of *Salmonella* in pigmeat. It is therefore of interest to develop a greater understanding of these processes in order to investigate where best to focus interventions in order to reduce *Salmonella*, whether at the source (pig farm) or abattoir.

Quantitative Microbiological Risk Assessments (QMRAs) are a useful modelling tool to assess the risk of illness from pathogen/ source pairs and have been used in the field of food safety for the last ten years. Indeed, a number of QMRAs have focused on *Salmonella* over the whole pork farm to consumption chain (VLA, 2003, Van der Gaag, et al., 2004, Hurd et al. 2008).
The model discussed here is an extension of a previous farm-to-consumption risk assessment for *Salmonella* in British pig meat products (VLA, 2003). The main aim was to improve and expand the methodology and data parameterisation adopted in the original risk assessment, in order to investigate proposed interventions at the farm and abattoir stages. In addition, the results of these intervention analyses will form part of a cost-effectiveness analysis (see accompanying paper, Simons et al., 2009).

**Material and Methods**

The overall farm-to-consumption risk assessment framework consists of five modules, relating to Farm & Transport, Slaughter & Processing, Distribution & Storage, Preparation & Consumption and finally Hazard & Risk Characterisation (i.e. dose-response to estimate the exposure levels from the first four modules). The first module is used to estimate the prevalence of infection in pigs as they enter the slaughterhouse. We assume infection is seeded into a breeding herd by one piglet and then use a modified SIR (Susceptible-Infected-Recovered) transmission model to estimate the spread of infection between pigs over the rearing cycle. At any given time, a pig can be either Susceptible (S), Excreting (I), Carrier (C), or Recovered (R). We assume weekly batching of pigs in an All-in-all-out system. Pigs may be raised on either a 1, 2 or 3 site system (various combinations of breeder, weaner, and finisher buildings). After 20 weeks the batch of pigs born on the breeding farm leave finishing and are transported to lairage at the abattoir, during which time prevalence may increase via a linear relationship estimated from data (Berends et al., 1996). Using the abattoir module we model the change in prevalence and concentration of *Salmonella* on pig carcasses through the production line from exsanguination to chilling (specifically considering scalding, dehairing, singeing, polishing, evisceration and chilling). After chilling, the carcasses undergo further processing where we model the process of manufacturing the carcasses into chops (cutting), bacon (curing) and sausages (mincing and mixing of meat from different carcasses). From here, the distribution model is used to estimate the change in *Salmonella* concentration in the meat products during transport and storage between further processing and the home, considering the likely temperature and timeframes involved as inputs to the growth model (Oscar, 2009). The consumption module is used to estimate the change in *Salmonella* concentration in a serving of pork, bacon or sausage as impacted by preparation methods such as defrosting, cooking and preparing the meat along with other raw foods such as salads. At this point we are able to estimate the likelihood of exposure (and associated dose) given consumption of British pig meat and/or the consumption of other foods cross-contaminated with *Salmonella* from raw pig meat. Lastly, the risk of human *Salmonella* infection is estimated by estimating the probability of infection given exposure (using the WHO/FAO *Salmonella* dose response model (FAO/WHO, 2002)), and multiplying this by the probability of exposure.

Interventions were modelled using available data (VLA, 2006, Creus et al. 2007, Roesler et al.2006, FSA, 2008) to change the prevalence and/or concentration of *Salmonella* in live pigs or carcasses during processing.

**Results**

The results of the baseline risk assessment model are shown in Table 1, and the intervention analyses in Table 2.

**Table 1: Main results from baseline risk assessment model for each product type considered.**

<table>
<thead>
<tr>
<th>Product</th>
<th>Average risk</th>
<th>95% C.I. (*10^7)</th>
<th>% of cont. portions</th>
<th>% of cont. portions resulting in illness</th>
<th># of cont. servings consumed per person year</th>
<th>Avg. # illnesses per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chops</td>
<td>1.6*10^7</td>
<td>(1.4, 1.6)</td>
<td>1.3*10^5</td>
<td>11.4</td>
<td>13</td>
<td>96.5</td>
</tr>
<tr>
<td>Bacon</td>
<td>1.4*10^7</td>
<td>(0.01, 0.02)</td>
<td>1.1*10^5</td>
<td>1.3</td>
<td>26</td>
<td>1.7</td>
</tr>
<tr>
<td>Sausage</td>
<td>4.1*10^7</td>
<td>(4.0, 4.1)</td>
<td>1.8*10^3</td>
<td>2.3</td>
<td>26</td>
<td>502.4</td>
</tr>
</tbody>
</table>
Table 2: Results of intervention analysis, percentage change from baseline model result for total number of human cases per year (i.e. chops + bacon + sausages)

<table>
<thead>
<tr>
<th>Intervention</th>
<th># illnesses per year</th>
<th>Percentage change from baseline model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm: Organic acids</td>
<td>241.3</td>
<td>59.8%</td>
</tr>
<tr>
<td>Farm: Rodent control</td>
<td>182.2</td>
<td>69.6%</td>
</tr>
<tr>
<td>Farm: Vaccination</td>
<td>381.2</td>
<td>36.5%</td>
</tr>
<tr>
<td>Abattoir: Bunging</td>
<td>113.7</td>
<td>81.0%</td>
</tr>
<tr>
<td>Abattoir: Washing and drying</td>
<td>527.1</td>
<td>12.2%</td>
</tr>
<tr>
<td>Multi: Vaccination and bunging</td>
<td>26.2</td>
<td>95.6%</td>
</tr>
<tr>
<td>Multi: Vaccination, rodent control and bunging</td>
<td>21.9</td>
<td>96.3%</td>
</tr>
</tbody>
</table>

Figure 1 shows that the estimated probability of illness given consumption of a contaminated pork product is generally low, but there are some high risk products that are more likely to cause illness (~1% of contaminated chops have a probability of greater than 0.6).

Figure 1: Distribution of probability of illness given consumption of contaminated product.

Discussion

We estimated that the average number of cases attributable to British pig meat consumption within GB was 600.6 per year (2-3% of total Salmonella cases in GB per year), although this estimate is likely to be uncertain given the lack of a validated dose-response model. The vast majority of cases were due to the consumption of sausages, rather than chops or bacon. Within the model, this is primarily due to the mixing of meat from different pigs during the processing of sausages, which distributes Salmonella over a large proportion of portions.

The effects of interventions shown in Table 2 represent what we think are the best case scenarios. There is great variation in the literature in the effect of interventions such as organic acids for Salmonella in live pigs. We also assume that uptake of these interventions is 100% across all GB pig farms and abattoirs, and that the effectiveness of these interventions can be maintained in commercial conditions. However, assuming all this, interventions across the whole chain, including the bunging of the anus during carcass processing, appear to be the most effective in terms of reducing human illness.

As with most models, the results are heavily reliant on the assumptions made and the quality of the data used to parameterise the model. Sensitivity analysis suggests that the results are highly sensitive to the values assigned to dose-response and the probability of transferring Salmonella from meat to hands during preparation, which both are highly uncertain due to a lack of data. Therefore, while there is great value in using the current risk assessment to investigate the effect of potential interventions on human health (given there is no practical way to observe this), the current results must be treated with caution and
backed up with further field investigation. The value of the model may lie more in a comparison of the relative efficacy of different interventions rather than as a prediction of the absolute benefit of any particular option upon public health.

**Conclusion**

We have expanded and improved an original risk assessment developed in 2003 in order to be able to assess the effectiveness of farm and abattoir interventions in reducing human Salmonellosis attributable to pig meat consumption. We estimate that around 600 *Salmonella* cases per year are attributable to pig meat consumption, approximately 2-3% of the total GB burden. According to model results, rodent control and bunding the anus are the most effective farm and abattoir interventions respectively. These results are important in a policy context for both GB and the EU, and may help to derive effective National Control Plans.

**References**


Food Standards Agency (2008). Project MO1040: How can current slaughter, dressing and cleaning procedures in UK pig slaughterhouses be improved to reduce the risk of Salmonella contamination of pig meat?


