Assessment of the human risk associated with use of pork
with possible presence of Salmonella Typhimurium DT104
for dry-cured sausages

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Summary
We examined whether pork with suspected content of Salmonella Typhimurium
DT104 (DT104) could be used for production of dry-cured sausages without jeop-
adizing consumer safety. The results of the risk assessment showed, that if Salmo-
nella is present in raw pork, it is usually in low numbers. Additionally, during
processing, an eventual presence of Salmonella will be reduced with at least two
log units. The simulations showed that only 1-2 DT104 would be present in dry-
cured sausages made by Danish pork, and this extremely seldom. Likewise, up to 4
DT104 would be present in dry-cured sausages made by foreign pork. It is not clear
whether these low numbers of DT104 are capable of producing disease at all.
However, if higher numbers are present, disease might occur. Therefore, we set up
a monitoring and managing program, including a list with demands to processing
in order to achieve minimum two-log reduction of any DT104 bacteria. The sug-
gested scheme implies a far better and more systematic monitoring than the current
system, ensuring the consumer a higher degree of food safety.

Keywords: Risk analysis, Food safety, salami, Monte Carlo simulation

Introduction
Salmonella Typhimurium DT104 (DT104) is a specific type of Salmonella, which
is unwanted in products for human consumption due to its ability to cause disease
in humans. Furthermore, DT104 has the potential to worsen the disease course in
people undergoing antibiotic treatment due to its antibiotic resistance. DT104 has
spread into the animal populations in many countries, and there seems to be no way
of eradication as soon as it has established itself. By monitoring domestic produced
pork with subsequent tracing, infected herds might be identified. Likewise, moni-
toring imported pork will identify DT104. However, how should pork positive for
DT104 be treated? Heat treatment is an expensive way of dealing with the problem.
Furthermore, it is often difficult to delimit the pork with DT104 from the pork
without DT104, e.g. if DT104 is found on a slaughterday, is it then the entire
slaughterday which is under suspicion? We therefore wanted to examine whether
pork with low content of DT104 could be used for dry-cured sausages. This pro-
duction method was considered because it is known to reduce the amount of Salmonella spp. substantially due to the presence of starter culture (which lowers the pH), salt, smoke, and nitrite. As dry-cured sausages is a ready to eat product it should be documented that the product would pose no health risk to the consumers and thus be safe. In 2000, the Danish Veterinary and Food Administration asked the Danish Bacon and Meat Council to undertake a risk assessment on this subject. By use of the risk assessment a proposal was outlined for monitoring and use of different groups of pork. Hereby, it was the intention to improve surveillance and food safety in an economically efficient way. The paper describes in short how the quantitative risk assessment was carried out and how the monitoring scheme was derived.

Materials and methods
We started by assessing whether dry-cured sausages produced by pork with low prevalence of DT104 would jeopardize consumer safety. One assessment was made for dry-cured sausages produced of Danish pork, and one was made for dry-cured sausages made of foreign pork. Initially, a qualitative risk assessment was undertaken. Next, a quantitative risk assessment was carried out as it was judged that data of sufficient quality were available. At first, data for Salmonella spp. as such were used due to the lack of detailed data for DT104, and next, the results were transformed into how often the Salmonella finding would consist of DT104. The software program @Risk (version 4.0 Palisade Corporation, Newfield, NY, USA) was used to simulate the number of Salmonella spp. in dry-cured sausages. Monte Carlo sampling with 10,000 simulations was used. To build the model, information on each of several variables were obtained from pilot plant studies, routine surveillance, expert knowledge, and the literature (Table 1).

Number of Salmonella spp. in a serving
Low-priced sausages are usually produced by many small pieces of pork (trimmings). Random sampling was simulated for 960 meat pieces, each with a probability of harbouring Salmonella (Table 1). The total number of Salmonella occurring in one batch was calculated as the sum of Salmonella on all 960 meat pieces for Danish and foreign pork respectively. It was assumed, that the bacteria were evenly distributed due to the chopping and extended stirring. Next, the pathogen reduction was simulated (≥2 log units reduction), and finally, the number of Salmonella was calculated per g and per 10g, 25g, or 40g, representing a child serving, an adult serving, or a party serving. 100% confidence intervals were reported for the Poisson distribution. The Poisson distribution was used, since occurrence of bacteria is a discrete event.
Transformation into number of servings with DT104 per million servings
The results were subsequently transformed into the number servings specifically containing DT104 per one million servings. It was assumed, that DT104 constitutes 1.0% or 18% of the identified Salmonella isolates in Danish and foreign pork respectively (Table 1).

Results
Number of Salmonella spp. per g sausage and per serving
The simulations showed that on average 0.0010 and 0.005 Salmonella spp. would be present in one g dry-cured sausage made by Danish pork (DK) respectively foreign pork (EXT). For DK dry-cured sausages, a maximum of two Salmonella bacteria could be expected in a serving. In comparison, a serving of EXT dry-cured sausages would harbour a maximum of four Salmonella bacteria (Table 2). In conclusion, servings of sausage made of foreign pork may harbour a higher number of Salmonella than sausages made of Danish pork. The difference in numbers is, however, very small. Table 2 presents the estimated number of servings with DT104 per one million servings of 10g, 25g, or 40g respectively. It is noted, that DT104 occurs far more often in EXT sausages compared to DK sausages. Other types of sausages are produced in Denmark, however if all sausages produced by Danish pork were consumed as dry-cured sausages, there would be 43,875 average servings with one (or more seldom two) DT104 bacteria out of the 180 million servings consumed.

Discussion
The model assumed that 960 meat pieces were included in a batch of normal sausage production. However, in recipes for more expensive types of sausages, the main ingredient is entire fore-ends. These types of sausages therefore consist of fewer and larger meat pieces. Hence, the Salmonella burden may be lower in the expensive sausage products than in the low-priced ones, due to the smaller exposed surface area. Hereby, we chose the worst case with the highest Salmonella burden. The distribution of the quantitative content of Salmonella spp. on a piece of meat was derived from two other projects (Sørensen et al., 2000; Olsen et al., 2001). Discussions with experts in the field assured that the Salmonella burden was not underestimated. Contrary, the experts stated that the distribution used might have overestimated the content occurring. However, we believe that this accounts for a single day with an even higher Salmonella burden than usually. In case new and more suitable data become available, these will be incorporated into the model.

Monitoring for DT104 in pork
It is not clear whether a very low number of DT104 like estimated by our model is capable of producing disease at all. According to the literature it is not likely, however, if higher numbers are present disease might occur (Blaser and Newman,
Therefore we suggest a general monitoring scheme, where 60 samples (meat or carcasses) are taken and analysed for DT104 in 12 pools of five samples each (see Figure 1 for details). In case of carcasses, 1,400 cm² should be swabbed. If all pools are negative, we assume the prevalence is negligible – and this pork might be sold directly to the consumers. If 1 or 2 pools are positive we assume that there is a low prevalence and we suggest that this pork might be used for sausage production. In case >2 pools are positive, the prevalence is high – and the pork must be heat-treated. The entire batch or all carcasses from the same herd is evaluated based on this scheme. However, carcasses in negative pools may be sold directly to the consumers even though they formed part of a positive test round for a herd. The suggested scheme implies a far better and more systematic monitoring than the current Danish system. This means an increased sensitivity and, hence, ensures the consumer a higher degree of food safety.

The pathogen reducing effect
Regarding the pathogen reducing effect, we introduce two different concepts. A process is documented if documentation is available demonstrating a pathogen reduction of ≥2 log-units of either verotoxin producing E. coli or Salmonella in an equivalent process. Lammert and Frosstrup (2000) examined the reduction effect at different production parameters while making sausages. Table 3 is based on these results and lists recommended production parameters. A production process is considered undocumented if there is no documentation of its pathogen reduction. As soon as documentation is available, the undocumented process becomes documented.

Conclusions
The assessment showed that:

- When Salmonella spp. is present in raw pork, it is usually in low numbers
- During processing, any Salmonella spp. will be reduced with ≥2 log units
- It is not known whether a potential remaining low number (1-4 bacteria) of DT104 in the sausage is capable of causing disease in man at all

If foreign pork is used, Salmonella spp. is more frequent, and DT104 constitutes a larger part of the found isolates compared to Danish pork. Nevertheless, in Denmark DT104 has only been found once in a retail outlet, and here, cross-contamination could not be ruled out. However, DT104 will probably occur occasionally in negligible numbers due to the low background prevalence in pork. In conclusion, dry-cured sausages produced by pork with low prevalence of DT104 do not seem to constitute a risk for human health. However, if pork with suspected
presence of DT104 is used, the prevalence should be monitored, and in case a higher prevalence is found, this pork should not be used for sausages.

References
Table 1.
Description of variables included in the quantitative risk assessment

<table>
<thead>
<tr>
<th>Variable</th>
<th>Original data</th>
<th>Assumed distribution</th>
<th>Origin of information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevalence of Salmonella spp. in Danish pork on a slaughter-day</td>
<td>1.0% - all pork 1.6% - fore-end pork</td>
<td>Pert distribution min= 0%, mode=0.5%, max=8.0%</td>
<td>Routine surveillance data from the slaughterhouses</td>
</tr>
<tr>
<td>Prevalence of Salmonella spp. in foreign pork</td>
<td>7.7% - all pork 1104 samples analysed, 85 positive for Salmonella</td>
<td>Beta distribution r= 85 n= 1104</td>
<td>Import control data</td>
</tr>
<tr>
<td>Quantitative prevalence of Salmonella spp. on 250g piece of Danish pork</td>
<td>No data available</td>
<td>Discrete distribution: 0: 98.333% 5: 0.833% 50: 0.283% 500: 0.283% 5,000: 0.175% 50,000: 0.092%</td>
<td>Average taken of 2 different studies (Sorensen et al., 2000; Olsen et al., 2001)</td>
</tr>
<tr>
<td>Quantitative prevalence of Salmonella spp. on 250g piece of foreign pork</td>
<td>No data available</td>
<td>Discrete distribution: 0: 92.18% 5: 3.91% 50: 1.33% 500: 1.33% 5,000: 0.82% 50,000: 0.43%</td>
<td>Assumed that the quantitative content on a foreign piece of pork positive for Salmonella is the same as on a positive piece of Danish pork</td>
</tr>
<tr>
<td>Sausage production</td>
<td>Many small pieces of pork primarily from the fore-end are usually used</td>
<td>960 pieces of 250g</td>
<td>Expert opinion from establishments producing sausages</td>
</tr>
<tr>
<td>Pathogen reduction associated with production of dry-cured sausages</td>
<td>Minimum 2 log reduction observed, max reduction depends on production</td>
<td>Pert distribution min=1/100, mode=1/150, max=1/1000</td>
<td>Literature and data from pilot scale experiments</td>
</tr>
<tr>
<td>Relative distribution of DT104 compared to Salmonella spp.</td>
<td>0.2-1.0% - Danish 18.0% - foreign pork</td>
<td>1.0% - Danish 18.0% - Foreign</td>
<td>Routine surveillance data from the slaughterhouses and import control data</td>
</tr>
<tr>
<td>Prevalence in sausages</td>
<td>1,618 negative samples in manufacturer's own check program, 300 negative samples from production of pork with DT104. Positive samples have only been found in retail outlets once, and here, cross-contamination could not be ruled out</td>
<td>Routine surveillance data from the slaughterhouses and retail outlets</td>
<td></td>
</tr>
<tr>
<td>Serving sizes</td>
<td>Child: 10g, Adult: 25g, Party: 40g</td>
<td>Expert opinion</td>
<td></td>
</tr>
</tbody>
</table>
Table 2.
Results of quantitative risk analysis of number of bacteria and probability (per million) of finding DT104 in servings of dry-cured sausages made of Danish or foreign pork

<table>
<thead>
<tr>
<th>Origin of pork</th>
<th>Serving size</th>
<th>1 DT104 bacteria</th>
<th>2 DT104 bacteria</th>
<th>3 DT104 bacteria</th>
<th>4 DT104 bacteria</th>
<th>In total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Danish</td>
<td>10g</td>
<td>103</td>
<td></td>
<td></td>
<td></td>
<td>103</td>
</tr>
<tr>
<td>Danish</td>
<td>25g</td>
<td>235</td>
<td>10</td>
<td></td>
<td></td>
<td>245</td>
</tr>
<tr>
<td>Danish</td>
<td>40g</td>
<td>355</td>
<td>15</td>
<td></td>
<td></td>
<td>370</td>
</tr>
<tr>
<td>Foreign</td>
<td>10g</td>
<td>7,866</td>
<td>270</td>
<td>18</td>
<td></td>
<td>8,154</td>
</tr>
<tr>
<td>Foreign</td>
<td>25g</td>
<td>18,216</td>
<td>1,044</td>
<td>90</td>
<td></td>
<td>19,350</td>
</tr>
<tr>
<td>Foreign</td>
<td>40g</td>
<td>25,884</td>
<td>2,952</td>
<td>324</td>
<td>54</td>
<td>29,214</td>
</tr>
</tbody>
</table>

a: The numbers of bacteria correspond to Salmonella spp. as such, whereas the probabilities of findings are for DT104 specifically.
b: It was assumed that DT104 constitutes 1% of the Salmonella isolates identified in Danish pork, and 18% of the isolates identified in foreign pork.

Table 3.
Production parameters for dry-cured sausages in order to achieve minimum a two-log reduction in the number of E.coli

<table>
<thead>
<tr>
<th>Product type</th>
<th>Reduction due to drying</th>
<th>Salt in forcemeat</th>
<th>Dry-cured sausages</th>
<th>Pathogen reduction in log-units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Salt</td>
<td>Water</td>
</tr>
<tr>
<td>Normal</td>
<td>18%</td>
<td>3.00%</td>
<td>3.8%</td>
<td>35%</td>
</tr>
<tr>
<td>High salt</td>
<td>18%</td>
<td>3.85%</td>
<td>4.7%</td>
<td>37%</td>
</tr>
<tr>
<td>Low fat</td>
<td>18%</td>
<td>3.00%</td>
<td>4.0%</td>
<td>45%</td>
</tr>
<tr>
<td>Normal</td>
<td>30%</td>
<td>3.00%</td>
<td>4.4%</td>
<td>24%</td>
</tr>
<tr>
<td>High salt</td>
<td>30%</td>
<td>3.85%</td>
<td>5.4%</td>
<td>26%</td>
</tr>
<tr>
<td>Low fat</td>
<td>30%</td>
<td>3.00%</td>
<td>4.6%</td>
<td>37%</td>
</tr>
</tbody>
</table>

Based on Lammert and Frostrup (2000). Data in the table are averages of data from recipes with 0.6% and 1.2% dextrose respectively. Additionally, the forcemeat in these recipes was added liquid smoke in concentrations of 0.0% and 0.2%. This implies that the figures in the table are averages of four figures.
Figure 1.
Suggested monitoring and management of pork with possible presence of DT104
a: If DT104 is found on a slaughter day an evaluation of the hygiene is needed as well as whether animals have been slaughtered from herds with an increasing seroprevalence for Salmonella
b: Sanitary slaughtering focuses mainly on avoiding cross-contamination from carcasses from known infected herds. Therefore, if >60 animals are slaughtered a substantial part of the carcasses should be examined for presence of DT104 to reassure that the prevalence is low, and
c: Hot-water decontamination reduces the prevalence of any Salmonella, therefore justifiable to evaluate the status of the delivered pigs based on a sample of 60 carcasses. A DT104 herd is "high risk" first time animals from the herd are slaughtered, or if the seroprevalence in the herd is increasing, or if DT104 was found on the carcasses at previous slaughter. The herd is "low risk" if all examined carcasses were negative during examination at previous slaughter, and no increase have been observed in the seroprevalence for Salmonella.
d: The carcasses which formed part of the negative pools may be sold directly to the consumer.
e: The authorities investigate 5% of the imported batches of pork per supplier quarterly. Among the batches selected for control, five samples are analysed. We suggest that each supplier is assigned a status ("high risk"/ "low risk") based on an examination of 60 samples in a batch. If all are negative for DT104, the supplier is considered "low risk" and only 10% of his batches should be examined. If DT104 is found among the 60 samples, then the supplier is considered "high risk" and the next batches should be sampled until a negative result appear.