Washing and chilling as critical control points in pork slaughter hazard analysis and critical control point (HACCP) systems

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D.J. BOLTON, R.A. PEARCE, J.J. SHERIDAN, I.S. BLAIR, D.A. MCDOWELL AND D. HARRINGTON. 2002.

Aims: The aim of this research was to examine the effects of preslaughter washing, pre-evisceration washing, final carcass washing and chilling on final carcass quality and to evaluate these operations as possible critical control points (CCPs) within a pork slaughter hazard analysis and critical control point (HACCP) system.

Methods and Results: This study estimated bacterial numbers (total viable counts) and the incidence of *Salmonella* at three surface locations (ham, belly and neck) on 60 animals/carcasses processed through a small commercial pork abattoir (80 pigs d^{-1}). Significant reductions ($P < 0.05$) in bacterial numbers were noted at some stages of the slaughter/dressing process, i.e. the process of hair removal (scalding–dehairing and singeing) resulted in an approx. 4·5 $\log_{10}$ cfu cm^{-2} decrease in bacterial numbers. A significant increase ($P < 0.05$) in bacterial numbers was observed after pre-evisceration washing. Final washing increased the bacterial counts to between 3·6 and 3·8 $\log_{10}$ cfu cm^{-2} while chilling effected a small but statistically significant ($P < 0.05$) increase to between 4·5 and 4·7 $\log_{10}$ cfu cm^{-2}. The incidence of *Salmonella* on pigs at the farm was 27%, decreasing to 10% after preslaughter washing. However, stunning and bleeding effected a considerable increase in *Salmonella* contamination and the incidence after these operations was 50%, which was reduced to 0% during the scalding–dehairing process.

Conclusions: Washing the live animals and subsequent carcasses with cold water is not an effective control measure but chilling may be used as a CCP.

Significance and Impact of the Study: Recent changes in European Union legislation legally mandate HACCP in pork slaughter plants. This research will provide a sound scientific basis on which to develop and implement effective HACCP in pork abattoirs.

INTRODUCTION

Pork products may be contaminated with a range of human pathogens, including *Salmonella* (Berends *et al*. 1998; Cloak 1999), *Campylobacter* (Bolton *et al*. 1982; Epling *et al*. 1993), *Escherichia coli* (Doyle and Schoeni 1987; Korsak *et al*. 1997), *Yersinia* (Feng and Weagant 1994; Duffy *et al*. 1999)

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and *Listeria* (Sheridan *et al*. 1994; Borch *et al*. 1996). With the exception of *Listeria*, which is more usually an environmental contaminant, many such pathogens enter the slaughter environment on or in live animals. Thus, *Salmonella*, *Campylobacter*, *E. coli* and *Yersinia* are carried into the plant in the porcine intestinal tract or in faeces adhering to the skin, while *Yersinia* can also be carried on porcine tongue and tonsils. Thus, most abattoir environments quickly become contaminated (Mafu *et al*. 1989; Hald *et al*. 1999). Consequent cross-contamination of the product

becomes inevitable; for example, studies of Irish retail pork products report the incidence of *Salmonella* as 9·9% (Cloak 1999), of *Yersinia* as 100% (Duffy *et al.* 1999) and of *Listeria* as 45% (Sheridan *et al.* 1994). The consumption of such at risk products obviously contributes to the overall burden of foodborne disease in the wider community, although a range of epidemiological and societal influences makes it difficult to derive precise correlations between pathogen incidence in foods such as pork and rates of clinical report. However, some data are available. For example, the estimated average incidence of salmonellosis in the Netherlands is about 450 per 100 000 of the population, with an estimated 15% of these being associated with pork consumption (Berends *et al.* 1998). The corresponding figures in Denmark are approx. 95 cases per 100 000, with 10–15% being attributed to pork consumption (Hald and Wegener 1999). In addition to human illness and suffering, there are major economic costs of pork-associated food poisoning. Thus, the Economic Research Service of the United States Department of Agriculture estimate the cost of pork-associated foodborne *Salmonella* infection in the USA to be between $0·1 and 0·2 billion per year (Frenzen *et al.* 1999).

Against such a background, and recognizing an increase in consumer concerns and pressure in terms of reducing such human, societal and economic costs, there is considerable interest in the development and wider application of more robust and secure methods within pork production and processing systems. One such system is hazard analysis and critical control point (HACCP), a systematic, science-based approach to process control designed to prevent, reduce or eliminate identified hazards in food products (Kukay *et al.* 1996). It is generally accepted that the HACCP approach is the most effective way of reducing or eliminating contamination during food processing (National Advisory Committee on Microbiological Criteria for Foods 1998) and it will soon become a legal requirement under European Union (EU) food safety law. However, HACCP is not easily applied to small-scale pork slaughter processes, as there are no immediately obvious critical control points (CCPs) and major changes in production processes to introduce new interventions that would provide effective CCPs, e.g. steam pasteurization, are currently not a realistic option due to the high capital costs involved. Alternative strategies, which focus on the identification of minor, commercially viable changes or enhancements to current elements of the pig slaughter and processing process are more likely to be adopted by the industry. Thus, this paper examines the impact and ability of the current practices of washing the live animals, washing of carcasses and carcass chilling as affordable interventions in enhancing food safety control and contributing to more effective HACCP systems for pork slaughter operations.

MATERIALS AND METHODS

Plant and processing

The study was based on a small pig-slaughtering plant, processing locally sourced pigs at a rate of approx. 80 pigs per day.

Upon arrival in lairage, pigs were immediately power-hosed with potable water at approx. 19°C, applied at a pressure of approx. 1030 kPa. Animals were then transferred into the abattoir, stunned using low voltage electrical stunning tongs and secured to an overhead conveyor rail by a chain looped around one of the hind legs. The stunned animals were immediately bled by cutting the main blood vessels using a knife. Each animal was scalded and dehaired in a combined process involving individual immersion for 2–3 min in a scald tank (held at temperatures between 62 and 70°C) and direct transfer into a linked dehairing machine. After dehairing, pigs were secured to an overhead conveyor belt by hooking the hind legs and manually singed using a hand-held gas singer.

Singed animals were given a pre-evisceration wash by power-hosing with potable warm water (40°C) applied at a pressure of approx. 1030 kpa. Evisceration involved three separate tasks (debunging, slitting the belly open and gut removal), all of which were performed by the same operative. Debunging or detachment of the rectum was initially completed before the belly was slit open and the connective tissues joining the bung and viscera to the carcasses were cut. The diaphragm, heart, lungs, trachea and tongue (with tonsils) were manually removed together as part of the pluck set, along with the digestive tract. The kidneys were not removed at this stage. The carcasses were subsequently manually cut along the midline from the hind to the fore using a splitting saw. The heads were not removed, but the spinal cord was cut away. Carcasses did not receive a final trim and were spray-washed with cold (15°C) potable water to remove bone dust and blood clots before chilling and cold storage.

Determination of bacterial numbers

This research was performed during three separate visits to the abattoir. At each visit 20 pigs were examined, giving a total sample of 60 animals. Bacterial numbers on live animals before transport to the abattoir and on carcasses at various stages (after power-hosing, bleeding, scalding–dehairing, singeing, pre-evisceration power-hosing, evisceration, final washing and chilling) were determined by swabbing a 50-cm^2 area on each of the ham, belly and neck using a sterile cellulose sponge moistened in buffered peptone water (BPW). These sponges were prepared in a sterile plastic bag and used by inverting the bag to expose the moistened sponge. After swabbing, the sponge was withdrawn into the

stomacher bag and stomached with 100 ml BPW in a Colworth Stomacher (BA 6024; A.J. Steward, London, UK). Serial dilutions of the resultant bacterial suspension were prepared and plated onto Plate Count Agar (PCA; Oxoid) and incubated at 25°C for 48 h.

Air sampling

The bacterial content of the air in the abattoir was sampled using a dual head impaction air sampler (AES; Laboratoire Sampl′ air®, Combourg, France) operating at a flow rate of 100 l min^{-1} and an impaction speed of 3 m s^{-1}. These were placed at a height of 1 m from the abattoir floor during slaughter and operated for periods of 2 min to sample 200 l air onto two 9-cm plates of PCA. These plates were subsequently recovered, incubated at 25°C for 48 h and used to calculate bacterial numbers as cfu m^{-3} air.

Detection of *Salmonella* on carcasses and in scald tank water

Carcasses were examined for the presence of *Salmonella* using the methods recommended by the International Standards Organization (ISO 1981). Swabs were taken at the sites and stages mentioned above. These were stomached with 100 ml BPW (Oxoid) for 1 min and incubated at 37°C for 24 h.

Samples of scald tank water (100 ml), drawn from throughout the tank, were added to 100-ml volumes of double-strength BPW and incubated at 37°C for 24 h.

Enriched BPW cultures were subcultured (0·1 ml) into 10 ml Rappaport Vassiliadis medium (Oxoid), incubated at 42°C for a further 24 h, streaked onto Brilliant Green Agar (BGA; Oxoid) and Mannitol Lysine Crystal Violet Brilliant Green Agar (MLCB; Oxoid) and incubated at 37°C for 24 h. Presumptive *Salmonella* colonies (red on BGA plates; large purple-black colonies on MLCB) were purified, cultured on Tryptic Soya Agar (TSA; Oxoid) for 24 h at 37°C and stored at 2°C.

Speciation of *Salmonella*

Presumptive *Salmonella* colonies were identified to genus level using a range of biochemical and serological tests. The former included the Gram reaction, Kohns two-tube test (Mast Group Ltd, Merseyside, UK; to test for the fermentation of dextrose, mannitol and sucrose/salicin, urease, motility, hydrogen sulphide and indole production), lysine decarboxylase test (Oxoid) and a test for β-galact-osidase activity (*o*-nitrophenyl-β-D-galacto-pyronoside (ONPG) discs; Oxoid). Colonies exhibiting the biochemical profile of *Salmonella* spp. (motile, positive for dextrose, mannitol and lysine decarboxylase, negative for urease,

sucrose/salicin, ONPG, indole and the production of hydrogen sulphide) were maintained on TSA slopes at 2°C and serologically tested. The serological tests included latex agglutination (Murex Biotech Ltd, Kent, UK) specific for cell-associated *Salmonella* O antigens and polyvalent O and H slide agglutinations (Murex).

Confirmed colonies were maintained on TSA slopes prior to speciation. Further serological identification of the isolates was carried out by the Central Veterinary Research Laboratory (Abbotstown, Castleknock, Dublin) using a series of slide agglutinations specific for *Salmonella* O and H antigens (Kaufmann 1966).

Scald tank temperature measurement

The temperature of the scald tank water was continuously monitored and recorded using three temperature probes and data loggers (Testo, Lenzkirch, Germany).

Analysis of data

Analysis of variance of log$_{10}$ bacterial counts was performed using Genstat 5 (Statistics Department, Rothamsted Experimental Station, Hertfordshire, UK). A log value of -0.5/cm^2 was assumed for samples in which the bacterial counts were not detected at the level of 1 cfu per 50 cm^2. Significant differences were determined at the 5% level ($P < 0.05$).

RESULTS

The total viable counts (TVCs) on pork ham, belly and neck at various stages of the pork production chain are presented in Fig. 1. There were considerable differences in the numbers of bacteria recovered at the different stages within the pork slaughter chain and significant differences ($P < 0.05$) between the counts at the three sites after singeing, pre-evisceration washing, evisceration and final washing.

The level of airborne bacterial contamination was consistent throughout the plant at approx. 3 log$_{10}$ cfu m^{-3} (Table 1).

The average TVCs on live animals, prior to transport to the abattoir (4 miles), were approx. 5 log$_{10}$ cfu cm^{-2} (Fig. 1). Salmonellas were isolated from 27% of these animals (Table 2). All of the *Salmonella* isolates recovered at this stage were subsequently identified as *Salmonella agona*.

Washing (power-hosing) after arrival at the abattoir produced visibly clean pigs, although this process did not lead to any significant change in TVCs, which remained at approx. 5 log$_{10}$ cfu cm^{-2}. After this power-hosing, the incidence of *Salmonella* was considerably lower (10%) than the incidence on 'on-farm' animals. The *Salmonella* isolates
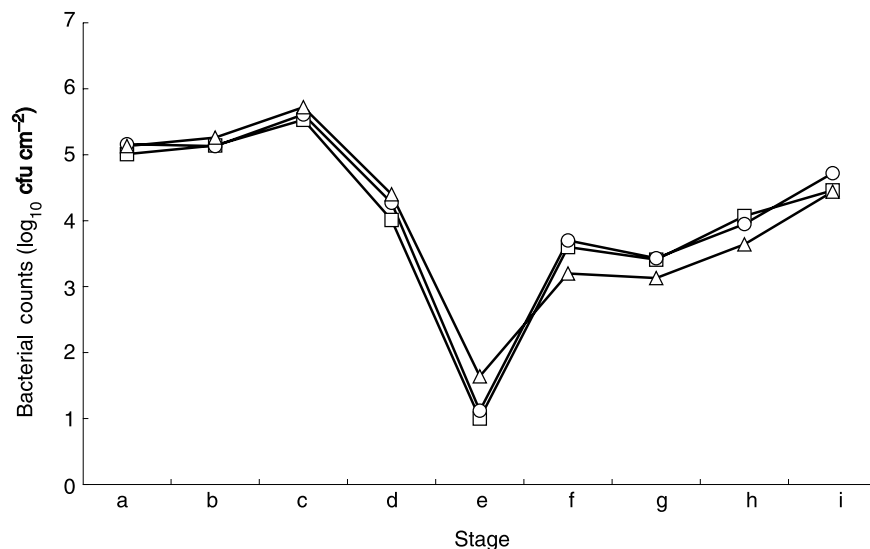
Fig. 1 Total counts ($\log_{10}$ cfu cm^{-2}) on pork carcasses at the ham ($\square$), belly ($\bigcirc$) and neck ($\triangle$) (a) on the farm and after (b) washing; (c) bleeding; (d) scalding–dehairing; (e) singeing; (f) power-hosing; (g) evisceration; (h) washing and (i) chilling

recovered at this stage were subsequently identified as *Salm. agona* or *Salm. typhimurium*.

The TVCs after bleeding were significantly ($P < 0.05$) higher than after (live animal) power-hosing. The incidence of *Salmonella* after (stunning and) bleeding was 50% of the carcasses, the highest incidence noted in this study. All of the isolates recovered at this stage were subsequently identified as *Salm. typhimurium*.

The TVCs after scalding–dehairing were approx. 4 $\log_{10}$ cfu cm^{-2}. These values were significantly lower ($P < 0.05$) than the TVCs after bleeding. *Salmonella* were not detected on any carcasses at this stage.

Table 1 The levels of bacteria in the air at various locations throughout the abattoir

Location	Average bacterial numbers ($\log_{10}$ cfu m^{-3})
Lairage	2·9
Bleeding	2·9
Scald tank	3·4
Singeing/power-hosing	3·0
Evisceration	3·4

The average TVCs after singeing were between 1·0 and 1·6 $\log_{10}$ cfu cm^{-2}. These values were approx. 3 $\log_{10}$ cfu cm^{-2} lower than the TVCs after scalding–dehairing, which represented a significant ($P < 0.05$) decrease in contamination levels. *Salmonella* were not detected on any carcasses at this stage.

Pre-evisceration power-washing removed burnt/singed material, producing visibly clean carcasses. However, total bacterial counts were significantly higher ($P < 0.05$) than after singeing, i.e. between 3·2 and 3·7 $\log_{10}$ cfu cm^{-2}. *Salmonella* was detected on 7% of the carcasses at this stage and all tested isolates were subsequently identified as *Salm. agona*. The TVCs after evisceration were not significantly different from TVCs after pre-evisceration power-hosing. *Salmonella* was not detected on any carcasses at this stage.

The TVCs after final washing were between 3·6 and 4·0 $\log_{10}$ cfu cm^{-2}. These values were not significantly different from the TVCs after evisceration, except at the belly. *Salmonella* was not detected on any carcasses at this stage.

The increase in TVCs during chilling was significant ($P < 0.05$) and the final carcass loadings were between 4·5

Process stage	% *Salmonella* positive	Serotypes
1. Before transport	27	*Salm. agona*
2. After power-hosing	10	*Salm. agona*, *Salm. typhimurium*
3. After bleeding	50	*Salm. typhimurium*
4. After scalding–dehairing	0	
5. After singeing	0	
6. After power-hosing	7	*Salm. agona*
7. After evisceration	0	
8. After washing	0	
9. After chilling	0	

Table 2 Incidence of *Salmonella* on pigs and pig carcasses at different stages of the pig production and slaughter process

and 4.7 $\log_{10}$ cfu cm^{-2}. *Salmonella* was not detected on any carcasses at this stage.

DISCUSSION

Overall, this study showed that preparation, slaughter and dressing processes can have substantial effects on bacteria on animals and derived carcasses. Such effects can be quantitative, involving overall changes in bacterial numbers, as reflected by 4–5 log changes in TVCs during processing. They can also be qualitative, involving major changes in the incidence of pathogens, such as *Salmonella* (from 0 to 50%), and serotype/species at consecutive stages of processing. The scale and nature of such changes and their implications for product stability and safety confirm the value of re-examining and modifying individual and combined processes within improved HACCP and similar quality control systems.

This study confirmed that animals moving from the farm into the slaughter environment represent major sources of general bacterial and specific pathogen contamination and that the levels of general bacterial contamination were high (between 5 and 6 log), posing considerable risks to product quality. The study also demonstrated an undesirably high incidence of *Salmonella* on pigs at the farm immediately before transport to the abattoir. The observed incidence (27%) is similar to that reported in a similar previous study of Irish pigs, which reported a 31% incidence of *Salmonella* on pigs in lairage at another Irish pork-processing plant (Pearce *et al.*, unpublished observations). These reports are in line with other EU studies including a study in Holland reporting a 21% incidence (Oosterom *et al.* 1985) and a study in The Netherlands reporting an incidence of up to 30% (Berends *et al.* 1998). They are also similar to US reports, e.g. Epling *et al.* (1993) reported an incidence of 29%.

Some of these differences may be related to the presence and rigor of application of national programmes for *Salmonella* control at farm level. These programmes appear to be effective, producing much lower incidences of *Salmonella* in 'finished' pigs being dispatched for slaughter. (Christensen *et al.* 1999; Letellier *et al.* 1999).

One specific response to the problems posed by faeces, soil, feed, etc. as major vehicles in the transfer of 'on-farm' bacteria into the abattoir environment has been the washing of animals arriving at the abattoir, and/or whole animal washing as the first stage of the slaughter process. This study confirmed that preslaughter washing of the live pigs with cold water does produce visibly clean animals. However, it also found that such cold water washing did not significantly alter the numbers of bacteria on the neck, belly and ham areas of the live animal. Thus, in terms of the control of general bacterial contamination, this process produces merely cosmetic effects. In more specific terms, however, cold water washing of live animals did have some effects on the incidence of *Salmonella* on live animals, in that such washing did reduce the incidence of *Salmonella* from 27 to 10% at this stage.

Just as live animal washing has been suggested as a partial solution to contact with an identified source of contamination, i.e. faeces, soil, etc., washing has been suggested as a means of reducing the impact of contact with another well-recognized source of contamination, i.e. gut contents which may contact the carcass during the evisceration process. The significance of the gut contents as a major source of carcass contamination is well established. However, this study found that (as in the case of live animal washing) the washing of carcasses with cold potable water before and after evisceration (final wash) did not have any perceivable decontamination effects. Rather than achieving net reductions in bacterial numbers on treated carcasses, pre-evisceration washing was associated with an increase of 2.5 $\log_{10}$ cfu cm^{-2}, while postevisceration washing was associated with an increase of 1 $\log_{10}$ cfu ml^{-1} in bacterial numbers. Such increases may be the result of deposition from the air (since the bacterial counts in the air of the processing environment were 2.9–3.4 $\log_{10}$ cfu m^{-3} during slaughter operations). Alternatively, they may reflect the mobilization of bacteria from the animal exterior surface, leading to improved recoveries during sampling. Irrespective of the relative contribution of these and other factors to recovered bacterial numbers, it is clear that such cold water washing does not provide any desirable net reductions in bacterial numbers on postevisceration-washed pig carcasses.

Recognizing the limited contribution of cold water washing, a number of studies have reported that wash water temperatures of 85°C or higher are necessary if a decontamination effect is to be obtained (Gill *et al.* 1995). Experiments washing carcasses for 20 s with water at 85°C have been reported to yield a 2 $\log_{10}$ cfu cm^{-2} reduction in *E. coli* (Gill *et al.* 1995) and *Salm. typhimurium* numbers (Van Netten *et al.* 1995). Commercial trials of a system to treat polished, uneviscerated pig carcasses with sheets of water at 85°C for 15 s have achieved similar reductions in bacterial numbers, suggesting the clear value of such interventions as part of more effective HACCP-based control systems (Gill *et al.* 1997).

In more general terms, the decontamination effects of such washing could be enhanced by the inclusion of additional wash components. For example, recent studies have established that the addition of chlorine (up to 25 μg l^{-1}) or trisodium phosphate to the wash water can significantly decrease bacterial and Enterobacteriaceae counts on other meat products, i.e. poultry carcasses (Whyte *et al.* 2001). Similarly, lactic acid treatment of beef carcasses,

prior to chilling, has been shown to reduce bacterial levels by up to 3 log cycles on these products (Castillo *et al.* 2001).

Although washing with hot water and/or decontaminating agents can produce some useful reductions in general and specific pathogen numbers, they are, in themselves, unlikely to provide adequate levels of consumer protection. In strategic terms, greater levels of protection from pathogens such as *Salmonella* should be attained by reducing the incidence of pathogens in pigs and other animals entering the slaughter process, rather than by trying to remove them from carcasses and derived meat products. Considerable efforts are currently being applied in the development of more effective carcass decontamination methods. However, until they become robust, cost effective and widely available, it is imperative that effective control measures are taken at farm level. These should include the establishment of *Salmonella*-free areas, in which the animals are reared, protection against contamination from the environment, feed and water, the establishment of *Salmonella*-free breeding stock and the transport of animals under conditions which do not allow contamination (Huis In't Veld *et al.* 1992). The observance of strict hygiene in pig-fattening units would bring immediate benefits in the reduction and elimination of *Salmonella* and other pathogens (Oosterom and Notremans 1983). Immediate preslaughter treatments should include feed withdrawal (Miller *et al.* 1997), which ensures that the porcine gut is not turgid at the time of slaughter and reduces the chance of gut rupture during evisceration. Interventions to suppress pathogen numbers in the gut, such as the inclusion of sodium chlorate in preslaughter feed which has been reported to reduce the levels of *Salm. typhimurium* (Anderson *et al.* 2001), may also be useful.

This study detected *Salm. agona* on live animals. This observation differs from the report of Pearce *et al.* (unpublished observations) who noted four other serotypes (*Salm. typhimurium*, *Salm. infantis*, *Salm. hadar* and *Salm. derby*). It is not clear why these differences in 'live animal' serotypes were observed, although such differences may reflect a dynamic situation in which different strains/serotypes emerge to temporarily dominate environments, before being overtaken by successive strains/serotypes. The detection of multiple serotypes on live animals in lairage (Pearce *et al.*, unpublished observations) may be related to the fact that their study was carried out in a larger plant receiving a greater diversity of serotypes arriving at larger abattoirs, which draw animals from many widely dispersed farms.

In more general terms, the detection of *Salm. agona*, as in this study, is unusual. In most comparable studies, other serotypes are more frequently reported, e.g. in The Netherlands, *Salm. typhimurium* is the most common isolate from pigs and the detection of *Salm. agona* would be unusual (Huis In't Veld *et al.* 1992). Similarly, in Canada,

Salm. brandenburg (40·9%) is the most prevalent serotype in pigs and *Salm. agona* is restricted to the Quebec region (Letellier *et al.* 1999). The reasons for these patterns in the distribution of *Salmonella* serotypes are not clear and may be associated with seasonal, demographic or product-related factors (Ziprin 1994). In the light of such reports, the carriage of *Salm. agona* observed in this study may represent the transient status of the pigs being processed at that time. Alternatively, this observation may demonstrate a farm-related or regional pocket of *Salm. agona* carriage. The reasons underlying such temporal and/or regional differences in the dominant serotypes of *Salmonella* in pigs and other meat animals represent an important area of investigation. Information in this area would have considerable epidemiological value in tracking and controlling outbreaks of foodborne disease, in the accurate assessment of the risks posed to consumers by the emergence of more or less pathogenic strains and even in the targeted elimination or suppression of those strains/serotypes posing greatest risks to human consumers, within enhanced HACCP schemes.

This study clearly demonstrated that, once they enter the abattoir system, pathogens such as *Salmonella* could persist on carcasses and/or indirectly recontaminate meat during processing. The implications of such persistence/recontamination in terms of the presence of *Salmonella* on retail pork products has been established in a recent study by Duffy *et al.* (1999) which reported a 9·9% incidence of *Salmonella* on retail pork products in butcher shops in the Dublin area.

The current study noted apparent changes in the frequency of detection of strains of *Salmonella* on animals/carcasses during the course of the slaughter/dressing process. Thus, although *Salm. typhimurium* was not detected on live animals, it was detected after power-hosing the live animals and after bleeding, but not in samples taken at subsequent stages of processing. Such changes may reflect the methods used in the recovery and speciation of isolates in this study. While the overall incidence of *Salmonella* in samples could be accurately determined by standard means, during the process of speciation of presumptive *Salmonella* colonies it was not possible to recover and identify all colonies that developed on BGA and MLCB plates. Thus, serotypes recorded as absent at various stages of the process may, in fact, have been present as a small fraction of the overall *Salmonella* population. It is, therefore, possible that, for example, *Salm. typhimurium* was present on live animals but as a small proportion of the total *Salmonella* population, Similarly, *Salm. agona* may have been present after bleeding, although not detected by the methods used. Although it is, therefore, not clear whether or not the observations made during this study reflect partial or total reversals in the relative dominance of individual strains/serotypes of *Salmonella* at different stages of the slaughter process, the results confirm major changes in strain predominance.

A fuller understanding of such changes, and manipulation of the factors controlling these changes, should prove valuable in the exclusion of undesirable strains, species and genera from pork products emerging from commercial abattoir systems.

In more general terms, this study clearly demonstrated that elements of the slaughter/dressing process significantly change the incidence of *Salmonella* on carcasses. Thus, activities associated with stunning, shackling and bleeding involved considerable increases in the overall *Salmonella* contamination rate. Such increases may be related to contamination acquired when the stunned animal comes in contact with the slaughter house floor and is dragged to the point where it joins the rail. The role of the floor as an important source of pathogens such as *Salmonella* has been previously reported (Mafu *et al.* 1989; Hald *et al.* 1999). In the light of such information, it is clear that dragging stunned animals on the floor is poor practice and that carcass-handling practices should be changed to exclude or limit contamination at this point, within improved HACCP schemes.

The present study showed that the combined process of scalding and dehairing used in the examined abattoir led to a reduction in general bacterial numbers (TVCs) of approx. $1.5 \log_{10}$ cfu cm^{-2}, while the incidence of detection of *Salmonella* decreased from 50% to zero. Such decreases are probably primarily associated with the high temperature water treatment involved in these processes. As established in previous studies, the application of scald water at temperatures of 60–62°C destroys considerable numbers of enteric bacteria, including *Salmonella*, *E. coli* and *Campylobacter*, both on carcasses and those washed off into the scald tank (Sorquist and Danielsson-Tham 1990; Hald *et al.* 1999; Snijders 1975; Mafu *et al.* 1989; Davies *et al.* 1999; Bolton *et al.* 2002). General reductions in bacterial numbers of $2 \log_{10}$ cfu cm^{-2} have been reported (Gerats *et al.* 1981) during the scalding process. In more specific terms, the observation of this study that *Salmonella* numbers were reduced below the detection limit of the test method is in agreement with Berends *et al.* (1997), who failed to detect *Salmonella* in scald tank water at 60°C. Some indication of the scale of reductions in *Salmonella* numbers during scald tank treatments was given by Sorquist and Danielsson–Tham (1990) who reported a $6 \log_{10}$ cfu cm^{-2} reduction in *Salmonella* at 60°C after 1·7–2·2 min.

There is little doubt that the dehairing machine is a major source of bacterial contamination, including *Salmonella* (Yu *et al.* 1999; Morgan *et al.* 1989; Gill and Bryant 1993; Gill and Jones 1995; Davies *et al.* 1999). In a study by Gill and Bryant (1993), up to $5 \log_{10}$ cfu g^{-1} *Salmonella* spp. were obtained in 50% of debris samples taken from the dehairing machine. Rivas *et al.* (2000) found that bacterial counts in the dehairing equipment ranged from 4·4 to 6·2 $\log_{10}$ cfu cm^{-2} 3 h after slaughter had commenced. Morgan *et al.* (1989) suggested that contamination of the dehairing machine was due to faecal material escaping from the anus during this process. The application of a plastic cone (pushed into the anus), as is currently performed during lamb slaughter, prevents faecal contamination and should be used during pork slaughter to reduce faecal contamination of equipment and carcasses.

This study showed significant reductions (3 $\log_{10}$ cfu cm^{-2}) in TVCs during singeing which are similar to, but slightly larger than, previously reported reductions of $2 \log_{10}$ cfu cm^{-2} (Troeger 1993) and 2·5 $\log_{10}$ cfu cm^{-2} (Pearce *et al.*, unpublished observations). A number of authors have also reported similar reductions in the numbers of specific groups of bacteria during singeing, i.e. Pearce *et al.* (unpublished observations) obtained a 2·5 $\log_{10}$ cfu cm^{-2} decrease in total enteric counts and Gill and Bryant (1993) reported a $2 \log_{10}$ cfu cm^{-2} reduction in *E. coli* counts. Such reductions are not unexpected as the surface temperature of the pork carcass may increase to 100°C during the singeing process (Borch *et al.* 1996). The greater decontamination effect noted in this study may be related to the fact that hand-held singeing units, as used in this study, can be more comprehensively and consistently applied to all areas of the carcass, achieving greater reductions in bacterial numbers than the automated singeing machines used in larger plants.

In this study, polishing was not performed and thus cross contamination of the carcasses was avoided. Polishing is an important source of microbial contamination on pork carcasses (Pearce *et al.*, unpublished observations). This may be due to cross contamination from the polishing equipment (Huis In't Veld *et al.* 1992) and/or to redistribution of any bacterial contamination present on the carcasses after singeing (Snijders *et al.* 1984; Gill *et al.* 1995; Hald *et al.* 1999).

In this study, total bacterial counts on carcasses did not change during evisceration, although the incidence of *Salmonella* decreased from 7% to zero during this process. These results were unusual as evisceration has been frequently reported as a major source of contamination of pork carcasses. Thus, Gill and Bryant (1992), Berends *et al.* (1997), Hald *et al.* (1999) and Davies *et al.* (1999) reported increased incidence of *Salmonella* ranging from 4 to 32% after evisceration.

Some authors consider evisceration to be a CCP (Borch *et al.* 1996) while others suggest that the low incidence of gut rupture, and lack of corrective action when this does occur, means that evisceration is better controlled using Standard Operating Procedures and Good Manufacturing Practices (Anon 1996). Regardless of the programme used, the training of operatives is fundamental to ensure that pork carcasses are not contaminated during evisceration (Borch *et al.* 1996). In the present study, a single well-trained operative, working at

his own pace, performed evisceration. As a result, these operations were performed properly and there was no increase in the levels of bacteria on the carcasses. In addition to observing best practice such as operating a two-knife system, where one knife was being sanitized at 82°C while the other was in use, this individual was also responsible for carcass inspection and trimming. Any blemishes or stains, such as faecal stains, were trimmed and this may account for the decrease in *Salmonella* contamination.

In larger plants, where operatives are under pressure to achieve set production targets, evisceration may be used as a CCP if critical limits can be set and monitored effectively. These may be achieved by using the online monitoring system described by Bolton *et al*. (1999). This system has been scientifically validated in a commercial pork plant at Hatfield Quality Meats (Hatfield, PA, USA). Over a 52-month period, carcass contamination rates decreased from 7·6 to 1·08% and total bacterial counts decreased by over 99·8% (Bolton *et al*. 1999).

This study noted a slight increase in TVCs during chilling, which is in agreement with the results of Bolton *et al* (2002). However, other researchers have observed a reduction in the levels of Gram-negative bacteria during chilling (Gill and Bryant 1992). Such observations have led to the suggestion that chilling may be a CCP because it prevents the proliferation of bacteria on warm carcass surfaces. The validity and impact of such suggestions may well be modulated by a number of factors. Thus, valuable reductions may be achieved in relation to specific groups or species, for example in the case of *Campylobacter*, which are particularly sensitive to drying and low temperatures under aerobic atmospheres (Borch *et al*. 1996). Differences between the directions and scale of changes in bacterial numbers during chilling may also be related to differences in chilling parameters. Thus, factors such as air speed, air flow, relative humidity, temperature profiles for individual carcasses, carcass spacing, etc., although rarely detailed in most studies (Feldhusen *et al*. 1992), may significantly modulate the impact of chilling on the numbers and metabolic status of bacteria on chilled carcasses. Further studies to identify and implement conditions and combinations of conditions which consistently lead to reduction in carcass bacterial loads, without collateral damage to other carcass characteristics, could transform chilling and chill storage into an important CCP within enhanced HACCP systems.

This study has shown that there are major changes in total bacterial numbers and associated changes in genus/serotype profiles on animals/carcasses moving through the slaughter/ dressing process. However, the major reductions noted at some stages are significantly offset by (re)contamination at subsequent stages of processing. In principle, modifications of unit operations within an enhanced HACCP approach should allow the reductions gained to be sustained, such that the final products purchased by consumers carry lower numbers of spoilage and pathogenic bacteria. However, considerable work remains to be done in a number of important areas. For example, this study showed that processes which might intuitively have been expected to contribute to lower bacterial numbers, such as washing of the live animals and carcasses with cold water, were not in fact currently operating as effective CCPs. The study also noted that the efficiency of singeing as a CCP is modulated by the methods used, in that larger reductions can be achieved using hand-held units than have been previously reported in relation to commercial singeing machines. Again, improvements in the singeing systems could enhance their impact as a potentially useful CCP. For example, care in singeing could remove the need for extensive carcass polishing, limiting the (re)contamination of carcasses that the polishing process entails. Thus, polishing could usefully be replaced with hot water washing, turning a stage which currently involves (re)contamination of pork carcasses into a useful CCP where proper process control can lead to some carcass decontamination. This study also demonstrated that evisceration performed by a careful and well-trained operative, working at his own pace, will reduce the incidence of gut rupture and prevent contamination of the carcass. Finally, bad practices that allow contact between the carcasses and contaminated surfaces, such as the floor, should be prevented and faecal contamination of equipment and carcasses should be reduced or prevented through the application of a coning procedure similar to that used during lamb slaughter.

ACKNOWLEDGEMENTS

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