ELSEVIER

International Journal of Food Microbiology 44 (1998) 207–217

International Journal of Food Microbiology

Salmonella spp. on pork at cutting plants and at the retail level and the influence of particular risk factors

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Received 26 February 1998; received in revised form 20 July 1998; accepted 6 August 1998

Abstract

This article describes the contamination of pork with *Salmonella* spp. in cutting plants and butchers' shops in The Netherlands and quantifies the influence of several risk factors. When contaminated carcasses are being processed, the main risk factors regarding cross contamination are inapt cleaning and disinfection (OR 12.8), manipulation of contaminated materials as such (OR 4.7) and (re)contaminated surfaces (OR 4.4). However, in the current situation, where contaminated carcasses are constantly being brought into cutting lines, interim cleaning and disinfection of surfaces and utensils during breaks and at the end of the working day will most likely prevent not more than about 10% of all cross contamination that takes place during a working day. Thus, as long as contaminated carcasses are being processed, about 90% of the cross contamination that occurs in cutting plants is practically unavoidable. It can therefore also be concluded that under these circumstances the implementation of codes of good manufacturing practices (GMP) and Hazard Analysis Critical Control Point (HACCP)-inspired production methods will only be marginally effective in the control of *Salmonella* spp. cross contamination in cutting lines. The same is more or less true for the processing of contaminated cuts or carcasses by butchers in shops and supermarkets. Furthermore, in contrast to the situation in cutting plants, it may be that up to 10% of butcher's shops or kitchens of restaurants become colonized for several weeks or months with their own endemic 'house flora' of *Salmonella* spp., which are originally introduced via the purchased contaminated products of animal origin. Though there are no hard data to substantiate this, it can be suspected that these shops and restaurants represent the more badly managed, i.e. poorly cleaned and disinfected, enterprises. However, several analytical limitations hinder an exact determination of the prevalence of *Salmonella* spp. contaminated pork and an exact quantification the influence of risk factors. The diagnostic value (i.e. the sensitivity, specificity, precision and predictive value) of the combination of swabbing of carcasses and cuts and the usually employed culturing methods, in particular, is largely unknown, and there are indications that it may be seriously questioned. Without a more thorough knowledge about the diagnostic value of current and future methods of sampling and identification, it is impossible to provide for more accurate estimations of the prevalence of *Salmonella* positive carcasses and cuts. Based on the research data, the incidence of contaminated cuts and retail-ready pork can not be estimated more precise than as somewhere between 5–40%. When compensating for the discussed methodological flaws, it must be assumed that currently the true prevalence of contaminated primal cuts and retail-ready pork in butchers' shops is about 25–30%, and that of minced pork and pork sausages about 50–55%. Lastly it is concluded that if carcasses were *Salmonella*-free, consumers could in principle be provided with virtually *Salmonella*-free pork. It is therefore recommended

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0168-1605/98/$ – see front matter
PII: S0168-1605(98)00122-6

that the EU allows for a decontamination step in slaughterhouses with a substance that is generally recognized as safe, provided that the producers strictly adhere to GMP-principles.

Keywords: *Salmonella* spp.; Cross contamination; Pork

1. Introduction

Current meat inspection increasingly fails to meet its objectives regarding the protection of public health (Anonymous, 1985, 1987, 1990; Berends et al., 1993). One of the most promising tools for both analyzing human health hazards associated with the production and consumption of meat and redirecting the current system towards a more risk assessment based approach, is the construction of elaborate descriptive epidemiological models of the fate of hazardous agents throughout the entire meat production chain (Rodricks and Taylor, 1983; Anonymous, 1985, 1987, 1990; Rodricks, 1993; Berends et al., 1996a,b, 1997).

In these descriptive epidemiological models are risks of contamination or infection reflected by their estimated incidence, and the influence of certain risk factors quantified by the measures odds ratio (OR) and attributable fraction (AF) (Armittage and Berry, 1987; Martin et al., 1987). The OR is the ratio between the odds of disease or contamination in the case that the factor is present or absent, and the with the OR connected AF an estimate of the proportion of cases that is really caused by the factor being present in a particular (sub)population. When the OR of a factor is significantly larger than 1 it is a definite risk, and when it is smaller than 1 it works preventive.

An elaborate description and analysis of the epidemiology of *Salmonella* spp. at pig farms, during transportation and in the slaughterhouses in The Netherlands are given in Berends et al., 1996b and Berends et al., 1997. This article continues the analyses made by describing the ecology and epidemiology of *Salmonella* spp. in cutting lines of Dutch cutting plants and in butcher's shops.

2. Materials and methods

The description of the ecology and epidemiology of *Salmonella* spp. throughout the entire pork production chain and the subsequent analysis of the influence of particular risk factors was defined as an implemented descriptive epidemiological model (Rodricks and Taylor, 1983; Anonymous, 1985, 1987, 1990; Rodricks, 1993). An extensive account of the terminology used, how and why to define different kinds of models, the actual construction of such models, the subsequent analysis of the data included in the different models, the further uses of the descriptive models and the limitations of such approaches is given in Berends et al., 1996a.

Briefly, the descriptive model for *Salmonella* tried to include all current knowledge about transmission routes, the extent to which *Salmonella* is present at certain stages in the entire pork production chain, factors that influence the presence or absence of *Salmonella* in these stages, and the dose-effect relationships in animals and humans. Subsequently these data were used to identify and quantify risks and risk factors of *Salmonella* contamination of pigs, pork and humans (i.e. an 'implemented formal descriptive epidemiological model'). Another important goal was to identify the areas where there is a lack of sufficient data, because this determines the validity of the analyses made and whether matters of crucial importance may be missed (Rodricks and Taylor, 1983; Anonymous, 1985, 1987; Tardiff and Rodricks, 1987; Berends et al., 1993; Rodricks, 1993; Berends et al., 1996b).

The data for this 'submodel' for the description and analysis of *Salmonella* contamination during cutting in plants and in butcher's shops were obtained both from the literature and from research of the Department itself, practically all of which is only published in confidential reports in Dutch (Gerats and Snijders, 1982a,b; Florjanc et al., 1992; Van Der Palen et al., 1992; Van Der Elzen, 1993; Johnson et al., 1992; Berends, 1993), or in specialized course books with a limited circulation (Berends et al., 1995). Furthermore, literature data were only included in the model if they themselves were an estimate of a risk or if they could be reprocessed for

estimating risks, which makes the descriptive epidemiological model more than a straightforward review.

In this submodel all odds ratios were assessed with two by two tables and all associations between risk factors and risks were tested for significance with the Chi-squared test (Armittage and Berry, 1987; Martin et al., 1987).

3. Results: summary of a descriptive epidemiological model for Salmonella spp. contamination of pork in Dutch cutting plants and butchers' shops

3.1. Salmonella spp. on pork in cutting plants

Human carriers, the air supply and droplets condensation do not constitute important sources of the *Salmonella* spp. contamination of pork cuts in cutting plants in The Netherlands (Florjanc et al., 1992; Berends, 1993; Berends et al., 1995). Permanent cooling of the air in the cutting rooms prevents *Salmonella* spp. colonizing certain ecological niches for longer periods. When the lines are properly cleaned and disinfected, e.g. during breaks and at the end of the working day, they become *Salmonella*-free again (Florjanc et al., 1992; Berends, 1993; Berends et al., 1995).

However, at the moment that contaminated carcasses enter the cutting line, the number of contaminated surfaces in the line will increase sharply to a maximum level (Florjanc et al., 1992; Berends et al., 1995). Particularly those parts of the line that constantly come into contact with carcasses and cuts of meat will remain positive throughout the working hours. These include the panels at the beginning and the end of conveyor belts, the panelling between the cutting boards and the conveyor belts and cutting boards themselves.

Once a point in a production line becomes contaminated, it can cross contaminate many tens to hundreds of primal cuts or carcasses before it is 'wiped clean' again (Oosterom and Notermans, 1986). In the current situation, however, the contaminated points in the cutting line become constantly replenished by the cuts that originate from contaminated carcasses; they will, therefore, not be wiped clean (Florjanc et al., 1992; Berends, 1993).

The effects of inadequate cleaning and disinfection are in practice only discernable during the first hour of production. Subsequently, the effects will become obscured by the more or less steady stream of *Salmonella* spp.-positive carcasses that is being processed. When cleaning and disinfection had been carried out in a satisfactory way, Gerats and Snijders (1982b) found 13/149 (9%) *Salmonella*-positive cuts during the first production hour. However, when cleaning and disinfection had been carried out incorrectly, they found 33/60 (55%) positive cuts. Based on these data, the OR of inadequate cleaning and disinfection of the line as a risk factor in 'cross contamination of meat with *Salmonella* spp. during the first hour of production' can be estimated at 12.8 (95% confidence interval (CI): 6.0–27.5; $P < .01$). The attributable proportion of inadequate cleaning and disinfection in these cases amounts to about 0.67, i.e. when the risk factor prevails it provokes about two thirds of the total cross contamination during the first production hour.

Furthermore, the data from Gerats and Snijders (1982b) also show that in about 30% of the cases cutting-plants make mistakes with regard to cleaning and disinfection. Since this is done 2–4 times a day, the probability that cleaning and disinfection is carried out incorrectly at least once a day can be set at 51–75% ($P_{(\text{faulty c and d})} = 1 - (1 - 0.3)^n$). When this is further extrapolated, the contribution of inadequate cleaning and disinfection on any given day is about 35–50% with respect to the cross contamination that occurs during the first production hours, and about 9–13% with respect to all cross contamination that occurs during a full working day of 8 h. Hence when *Salmonella*-positive carcasses are being processed, up to about 90% of all cross contamination during cutting is unavoidable, and the remaining 10% results from *Salmonella*-positive carcasses being processed earlier that day while interim cleaning and disinfection have been inadequate. The effects of the implementation of GMP codes in cutting plants on the total cross contamination with *Salmonella* may therefore be disappointingly marginal.

Table 1 displays a selection of the scarce data on percentages of (primal) pork cuts contaminated with *Salmonella* spp. The pilot-study of Gerats and Snijders (1982a) suggests a strong correlation between the number of *Salmonella*-positive carcasses that

Table 1
Prevalence of primal pork cuts* positive for *Salmonella* spp., and the calculated 99% confidence interval** of these assessments

Sampling method	No. of samples	Percentage positive	99% confidence interval
Samples of 1 kg, minced and then further investigated[a]	120	31	20–42
Cork borer method: 14 cm^2 sampled[b]	149	9	3–15
	60	55	4–14
	209	22	15–29
Cork borer method: 14 cm^2 sampled[c]	22	0	0–21
	22	5	0–29
	22	9	0–36
Moistened swabs: 100 cm^2 sampled[d]	60	10	0–20

Data from: (a) Banks and Board, 1983; (b) Gerats and Snijders, 1982a; (c) Johnson et al., 1992; (d) Van Der Elzen et al., 1992.
*The primal pork cuts investigated in The Netherlands were primarily bellies, and the investigations took place during the first production hour; Banks and Board (1983) investigated hams, bellies, flanks, shoulders, necks, fat trinimings and the meat from pigs' heads (see also the text of Section 4.2).
**These calculations are based on the sample size and do not take into account the discussed non-detection rate of the sampling methods (see text and the Table 2 and Table 3).

enter Dutch cutting lines and the number of *Salmonella*-positive pork cuts produced: 20% positive carcasses and at least 22% positive cuts. Since the data only refer to one group of pigs that could be followed from the end of a slaughter line to the end of a cutting line, a correlation coefficient and/or a regression formula could not be calculated. Data from Beran (1996) also suggest that the minimum number (i.e. the baseline) of contaminated cuts produced is ultimately determined by the number of contaminated carcasses that enter the cutting line.

Based on the calculated confidence limits in Table 1 and the results regarding the prevalence of *Salmonella* spp. on carcasses in Dutch slaughterlines (Berends et al., 1997), it can be estimated that, under routine conditions, the average percentage of *Salmonella*-positive cuts that leave Dutch cutting plants must be somewhere between 5 and 40%. The large interval is partly due to deficiencies of the sampling methods used, which will be discussed in Section 4.

3.2. Salmonella spp. on pork in butchers' shops

The composition of the bacterial flora on meat in retail outlets is the end result of the initial bacterial contamination and the colonisation occurring during slaughter, further processing and distribution. Cooling exerts a selective effect on the composition of this flora, because psychrotrophic species will outgrow the mesophiles (Lambert et al., 1991). However, though cooling or freezing prevents proliferation of *Salmonella* spp., the organisms do not become consistently devitalized.

In butchers' shops many opportunities for cross contamination with *Salmonella* spp. present themselves. The purchased primal cuts and/or carcasses are handled intensively during processing into retail-ready items. Primal cuts and finished items are often processed by the same persons with the same utensils, the same machinery and on the same cutting boards, without any interim cleaning and disinfection. Raw meats of different animal species, including poultry and cooked meat products, are often displayed on the same and/or directly adjacent counters.

Nortjé et al. (1990) concluded that during cutting, distribution and further processing meat was often not adequately refrigerated. Edel et al. (1977) and Banks and Board (1983) observed seasonal variation in the prevalence of *Salmonella* spp.-positive meat and meat products in butchers' shops, with the highest prevalences in summer, when, the *Salmonella* spp. will be able to proliferate on the machinery and chopping blocks to such an extent that more meat becomes cross contaminated with numbers above the detection limit.

The following studies provide some insight into

the extent of cross contamination that may occur in butchers' shops:

1. De Boer et al. (1983) investigated differences between the prevalence and serotypes of *Salmonella* spp. in feral fowl immediately after being shot and after being processed into 'retail-ready birds'. Only 5% of the feral fowl sampled carried *Salmonella* spp., and no bird was positive for more than one serotype. After being processed in the butchers' shops, however, 20% of the same group of birds were positive, practically all being contaminated with two or three serotypes. It can be assumed that the handling of the birds by the butchers was entirely responsible for this. Handling/processing as a risk factor for cross contamination with *Salmonella* can therefore be roughly estimated to have an OR of about 4.75. Therefore, roughly two thirds of all cross contamination took place as a result of the birds being handled (i.e. the AF);
2. From investigations of Garcia-Villanova et al. (1987) it can be inferred that in supermarkets and groceries about 70% of the cross contamination of vegetables with *Salmonella* spp. can be attributed to handling by staff and customers, thus having an OR of approximately the same magnitude as the manipulation of meat has in butchers' shops;
3. Edel et al. (1977) examined samples from chopping blocks and retail-ready meat. Approximately 10% (23) of 224 samples from the chopping blocks and 33% (75) of 224 meat samples were positive for *Salmonella* spp. In 15/23 cases (60%) of *Salmonella* spp. positive chopping blocks, the sampled meat contained exactly the same serotype. In 60/201 cases (30%) the meat samples were positive, but not the chopping blocks. A contaminated chopping block as a risk factor for cross contamination of meat during processing has thus an estimated OR of 4.41 (95% CI: 1,65–12.07; $P < .001$). In addition, a contaminated chopping block will contribute about two thirds of all cross contamination that occurs during processing (i.e. the AF). Considering all meat samples taken, an estimated 10% of all contamination was probably due to contaminated chopping blocks (i.e. the 'population-AF').

Data demonstrating the possibility that butchers' shops become colonised with their own endemic 'house flora' of *Salmonella* spp. are scarce. One Dutch study showed that in 54 of 55 (98%) butchers' shops that were repeatedly sampled during a period of three months *Salmonella* spp. were present on counters, chopping blocks, meat and in process waste water at one time or another (Edel et al., 1977). Furthermore, in about 9% of the shops the same serotype was consistently present on chopping blocks, counters, meat (products) and in the process waste water. The investigations did not reveal to which extent these shops represent the more badly managed, i.e. poorly cleaned and disinfected, ones. A Dutch case-study showed that kitchens of restaurants and caterers can also become colonized with their own endemic 'house flora' of *Salmonella* spp. (Beckers et al., 1982).

The percentages of *Salmonella*-positive retail-ready pork in butchers' shops and supermarkets, do not to appear to be much different from the percentages of positive primal pork cuts found at the end of cutting lines. Mostly, percentages between 10–40 for retail-ready pork and between 50–65 for minced pork and pork sausages are mentioned (Edel et al., 1973, 1977; Gerats and Snijders, 1982b; Banks and Board, 1983; Bentley, 1985; Beran, 1996). Again, the large interval for the prevalences of retail-ready meat can partly be explained by the imperfections of the sampling methods used (see Section 4).

4. Discussion

Due to a lack of valid data, it is impossible to identify and quantify all risks and risk factors involved comprehensively or to produce a precise estimate of the current prevalence of *Salmonella* positive pork in The Netherlands. Incidences can be estimated as fluctuating between 5–40%, and the percentage of positive minced pork and raw pork sausages as varying between 40–70%. Based on this descriptive submodel, the submodel for *Salmonella* in the abattoir (Berends et al., 1997) and the considerations to be discussed in 4.1 and 4.2, the best 'educated guess' (i.e. the assumption made) is that the true prevalence of contaminated cuts produced in Dutch cutting lines and of retail-ready pork in butchers' shops and supermarkets will probably be

about 25–30% and of contaminated minced pork and pork sausages about 50–55%.

4.1. Analytical limitations

One methodological shortcoming that may interfere with an exact determination of the prevalence of contaminated carcasses or meat is the fact that even the best combinations of enrichment and selective plating media have for the isolation of *Salmonella* spp. in naturally contaminated (refrigerated) meats have a sensitivity of only 50–60% when incubated during the routinely employed periods (Perales and Audicana, 1989; Aabo et al., 1995). Enrichment followed by more modern methods of identification, such as polymerase chain reaction assays (PCR), have in these cases sensitivities of 99–100% (Aabo et al., 1995). The detection limit in a direct PCR assay or enzyme linked immunosorbent assay (ELISA) on contaminated meat following pre-enrichment in buffered peptone water and enrichment in Rappaport–Vassiliadis broth, amounts to less than 0.1 per gram meat (Fluit et al., 1993; Myamoto et al., 1995; Aabo et al., 1995; Ng et al., 1996).

The surface area sampled is another methodological aspect that may interfere with an exact determination of the prevalence of contaminated carcasses or meat. There is reason to assume that the percentages of the *Salmonella*-positive cuts determined with the cork borer method and by swabbing a surface of about 100 cm^2 listed in Table 1, therefore, underestimate the true prevalence. As will be discussed further, both techniques may fail to detect bacteria that can be present in relatively low numbers and have an often somewhat clustered distribution, such as *Salmonella* spp. In this context swabbing is defined as all currently employed methods that evolved from the 'wet and dry method' as described by Kitchell et al. (1973) (Anonymous, 1996; Dorsa et al., 1996; Gill and Bryant, 1993; Hudson et al., 1996; Karr et al., 1996; Dorsa et al., 1997).

The larger the volume or surface area sampled, the greater the probability of detecting contamination with low levels of heterogeneously distributed pathogens (Jarvis, 1989; Siebert, 1993). Oosterom et al. (1985) found that it required swabbing of about 1000 cm^2 pork skin to determine that 75% of the contaminated carcasses contained maximally 0.1 colony forming units (cfu) *Salmonella* spp. per cm^2 and 25% between 0.1 and 1 cfu per cm^2. The cork borer method cuts out skin samples of in total 14 cm^2 and it is therefore not surprising that in comparison with swabbing a carcass surface of about 3000 cm^2, the cork borer method leads to 64% false negative results in the detection of *Salmonella*-positive carcasses (Berends, 1993).

Besides the question of how big the area to be sampled should be, it is important to know the sensitivity of the combination of the sampling techniques used and the usually employed culturing methods:. When bacteria are evenly distributed in numbers of at least 10^3 cfu per cm^2 swabbing recovers in general only between 5–50% of the cfu numbers that can be recovered by destructive methods. When counts are lower, and/or the distribution becomes more heterogeneous, the efficacy with which the bacteria can be recovered is even further reduced (Ingram and Roberts, 1976; Snijders et al., 1984; Van Der Palen et al., 1992; Kitchell et al., 1973; Dorsa et al., 1996; Sharpe et al., 1996). However, no traditional method, not even destructive ones, will be able to recover all the bacteria actually present on carcasses or meat surfaces (Carson et al., 1987; Lillard, 1988).

From the data of Snijders et al. (1984) it can be calculated that swabbing of pork carcasses recovers on average only 30% (20–40%) of the numbers of *Enterobacteriaceae* that can be recovered by sampling a comparable surface area with the destructive method. Also, the reproducibility of swabbing is poor and large variations in results are therefore common (Kitchell et al., 1973; Snijders et al., 1984; Zelleke et al., 1994; Dorsa et al., 1996; Sharpe et al., 1996). This has consequences for the non-detection rate of swabbing.

From the data of Dorsa et al. (1997), it can be calculated that with regard to detecting beef carcasses contaminated with *E. coli* or coliform organisms the sensitivity of swabbing a surface of 100 cm^2, when compared to excising 100 cm^2, is only between 30 and 40%, i.e. that between 60–70% false-negatives are obtained. Moreover, as demonstrated by Table 2, at the established levels of about 16 cfu coliforms/cm^2 the agreement between the results of the two methods is not impressive. Table 2 presents results of a field study by Dorsa et al. (1997) in the way this is usually done for the comparison of diagnostic tests or procedures in human and veterinary medicine (Armittage and Berry, 1987; Martin

Table 2
Swabbing compared with excision regarding the detection of carcasses with about 16 cfu coliform organisms per cm^2 (calculation with data from Dorsa et al., 1997)

		Detected with excision (100 cm^2)?		
		Yes	No	Total
Detected with swabbing (100 cm^2)?	yes	4	3	7
	no	7	16	23
		11	19	30
Relative sensitivity (4/11):				36%
Relative specificity (16/19):				84%
Relative predictive value of a positive result (4/7):				57%
Relative predictive value of a negative result (16/23):				69%
Relative precision ((4 + 16)/30):				67%
Apparent prevalence (7/30):				23%
True prevalence[a] (11/30):				37%
Observed agreement between methods (20/30):				.666
Positive agreement (yes/yes) by chance ((7/30)*(11/30)):				.086
Negative agreement (no/no) by chance ((23/30)*(19/30)):				.486
Total agreement by chance (*a*):				.572
Observed agreement minus total agreement by chance (*b*):				.094
Maximal agreement outside of chance (1 − *a*):				.428
Cohens' Kappa[b] (*b*/(1 − *a*)):				.220

[a]True prevalence as determined with excision.
[b]A Kappa between .4 and .7 is usual, and represents fair to good agreement. A kappa of .22 represents poor agreement.

et al., 1987). In these comparisons the measure of test-agreement is expressed as the Cohens' Kappa-value. The calculated Kappa-value of 0.22 means that there is rather poor agreement (see Table 2). Furthermore, Table 2 also demonstrates that at low levels of contamination even the destructive method is in practice not as consistently robust as might be expected. Table 3 is based on the same trial as Table 2 and presents an approximation of the 'absolute' sensitivity of swabbing and the destructive method under the assumption that the combined results represent the true prevalence of 14 of 30 (47%) beef carcasses contaminated with on average 16 cfu coliforms/cm^2. The estimated sensitivity of about 80% for the destructive method (11/14) is always better than the estimated sensitivity of about 50% for swabbing (7/14), but both techniques lead to an underestimation of the true prevalence. Furthermore, because of the poor test-agreement, the two methods identify different groups of carcasses as being contaminated. This explains also the difference between the calculated relative sensitivity of swabbing of 36% in Table 2 and the roughly estimated 'absolute' sensitivity of 50% in Table 3. In addition, when estimating a true prevalence on the basis of a test with a specificity of 100% and a sensitivity of 50% or 80%, the number of positive test results needs to be multiplied with a factor of 2 or 1.25, respectively.

Table 3
Diagnostic value of swabbing and excision with regard to the detection of carcasses with about 16 cfu coliform organisms per cm^2 (calculation with data from Dorsa et al., 1997)

		About 16 cfu coliforms/cm^2 actually present on carcasses?		
		Yes	No	Total
Detected with excision (100 cm^2)?	yes	11	0	11
	no	3	16	19
		14	16	30
Detected with swabbing (100 cm^2)?	yes	7	0	7
	no	7	16	23
		14	16	30
Method evaluation[a]:		Excision		Swabbing
Sensitivity		79%		50%
Specificity		100%		100%
Positive predictive value		100%		100%
Negative predictive value		84%		70%
Precision		90%		77%
Apparent prevalence		37%		23%
True Prevalence		47%		47%

[a]See Table 2 for calculations of sensitivity, specificity, predictive value, precision etc.

However, exact knowledge about the diagnostic value (i.e. the sensitivity, the specificity, the precision and the predictive value) of the still widely used 'classical' sampling methods does not really exist in the literature. The Tables 2 and 3 are, after all, only based on just one of the trials by Dorsa et al. (1997), and should thus more be seen as an important first clue than as an exact determination of the diagnostic value of swabbing and excision in practice. Nevertheless, it must be said that even this first assessment shows that the diagnostic value of swabbing, in particular, can be questioned. Meat scientists should thus make more of an effort to evaluate their methods in the manner as shown by these two tables.

In conclusion, in any future research regarding the prevalence of *Salmonella* positive carcasses or primal cuts it is necessary (i) to swab surfaces greater than 100–300 cm^2 (i.e., at least 1000 cm^2 and preferably about 3000 cm^2) and/or to design more effective/sensitive sampling methods (i.e., such as claimed by Sharpe et al., 1996) and (ii) to employ more sensitive methods of culturing and identification, such as PCR assays.

4.2. Impact for epidemiological surveys

Investigations on minced pork or sausages do not suffer from the disadvantages of swabbing or destructive methods, such as the cork borer method, and therefore may reflect the actual situation better. Banks and Board (1983) examined different categories of pork cuts by mincing and further investigating samples of one kilogram each. The cuts they examined stemmed from all parts of the carcass (i.e. the bellies and flanks, the neck and the head). They also examined sausages made from this meat. From their studies it can be inferred that: (1) there are no significant differences in the prevalence of *Salmonella*-positive cuts from different parts of the carcass; (2) no significant differences exist in the numbers of cfu *Salmonella* per cm^2 on these cuts of different origin; (3) mixing and mincing of different cuts leads to at least a doubling of the prevalence of positive samples (i.e. sausages that were 60% positive were produced from cuts which were 30% positive).

In addition, the data on the influence of handling on bacterial contamination of meat in general and the rarer quantitative data about *Salmonella* (cross) contamination (Ingram and Roberts, 1976; Roberts, 1980; Carson et al., 1987; Untermann, 1989; De Boer and Hahné, 1990; Gerats, 1990; Nortjé et al., 1990; Lambert et al., 1991; Schütz and Filip, 1991), make very clear that during processing in cutting lines and/or by butchers the percentage of contaminated pork can markedly increase. Inadequate cleaning and disinfection of cutting lines, handling of contaminated pork as such and processing on contaminated cutting boards and chopping blocks may lead, alone or in combination, to an approximate doubling or tripling of the prevalence of *Salmonella*-positive pork.

4.3. Management of the Salmonella hazard

It is quite certain that the incoming carcasses are currently the most important sources of *Salmonella* spp. in cutting lines. During processing of the carcasses the number of meat surfaces contaminated with *Salmonella* spp. will increase through direct and indirect contact, whereby the number of colony forming units per cm^2 will be reduced. Thus, the number of colony forming units may in many cases decrease to levels below the detection rate of our currently routinely employed detection methods (i.e. mostly swabbing of limited areas). Consequently, the finding of a relatively low number of contaminated cuts does not mean that *Salmonella* spp. are not present on many more cuts. Ultimately, the minimum number of contaminated cuts will be determined by the number of contaminated carcasses that enter the cutting line. *Salmonella* spp. present on the incoming carcasses will not disappear, but can be transferred to other surfaces and meat.

Cutting plants and butchers' shops appear to have much in common. In both situations the most important source of cross contamination with *Salmonella* spp. are the incoming contaminated materials. In both situations processing of these contaminated materials is unavoidable, resulting in the surfaces of chopping blocks, cutting boards, utensils, hands and machinery etc. also becoming contaminated. Since contaminated carcasses and/or cuts are constantly being brought into processes, interim cleaning and disinfection of surfaces and utensils during breaks and at the end of production hours will

probably prevent not more than about 10% of all cross contamination that takes place during the working day. The positive effects of GMP codes and process control based on the HACCP-concept (such as recently required by the EU) may therefore remain marginal as long as meat processing lacks steps that are designed to effectively prevent or reduce contamination with *Salmonella* spp.

Under prevailing legislation slaughterhouses may only apply steam, hot water or dry heat to reduce the contamination of carcasses with *Salmonella* spp., which is actually ultimately determined by the raising, transport and lairage of animals. Similarly, cutting plants and butchers do not possess the means of restoring deficiencies incurred in slaughterhouses without altering the organoleptic quality or appearance of the meat. Furthermore, it is not to be expected that Salmonella-free pigs are being delivered to the slaughterhouses in the near future (Berends and Snijders, 1994; Berends et al., 1996b, 1997). It is therefore advocated that the EU authorize more forms of terminal decontamination of pork carcasses, with the mandatory provision that producers strictly adhere to GMP-principles (Berends et al., 1997). Compliance with the latter approach will ensure that the application of a suitable substance which is generally recognized as safe, such as lactic acid or trisodium phosphate, will decontaminate the carcasses sufficiently to protect the public's health (Snijders et al., 1979; Epling et al., 1993; Van Netten et al., 1994, 1995; Dickson and Kunduru, 1995; Gorman et al., 1995; Hardin et al., 1995).

Acknowledgements

This study is part of a project carried out with the financial support of the Dutch Product Board for Livestock and Meat and the Dutch Ministry of Agriculture, Nature Management and Fisheries.

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