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Impact on human health of *Salmonella* spp. on pork in The Netherlands and the anticipated effects of some currently proposed control strategies

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Abstract

The impact on human health of *Salmonella* spp. on pork in The Netherlands is described. Subsequently, the effects of some currently proposed control strategies in the Dutch pork production chain are evaluated and quantified with the aid of a simple mathematical model. The estimated average incidence of cases of salmonellosis in the Netherlands is about 450 cases per 100,000 person years at risk (pyar). Some special risk groups for which the risks could be quantified are (1) persons with underlying diseases, such as neoplasms or diabetes mellitus (1200 cases/100,000 pyar); (2) persons with achlorhydria or who excessively use antacids (1100 cases/100,000 pyar); (3) persons who have recently been treated with antibiotics that disturb the normal gut flora (1700 cases/100,000 pyar); (4) nurses (900 cases/100,000 pyar); (5) caterers (900 cases/100,000 pyar); (6) slaughterline personnel (1800 cases/100,000 pyar). Furthermore, it is estimated that 15% (5–25%) of all cases of salmonellosis in The Netherlands are associated with the consumption of pork. Currently, proposed control measures regarding *Salmonella* in pigs and on pork in The Netherlands are codes of good manufacturing practices (GMP) that, in fact, formalize recommendations that can be found in many handbooks about pig breeding and pig slaughtering. When evaluated by a mathematical model constructed for this purpose, the proposed GMP codes from farm to cutting/retail could, at best, reduce the current levels of *Salmonella*-positive pigs and pork by 50–60%. If pigs were bred according to the rather costly specific pathogen-free concept (SPF), the prevalence of contaminated carcasses and pork could in total be reduced by 95% or more. However, implementing GMP codes from the transport phase up to the cutting/retail phase coupled with a decontamination step at the end of the slaughterline would be just as effective as GMP in combination with breeding using the SPF-concept. It is therefore concluded that the most efficient and cost-effective way of reducing the '*Salmonella* problem' entailed by the consumption of pork would be to decontaminate carcasses under the precondition that the entire production chain strictly adheres to GMP principles. Therefore, the EU should also allow for more possibilities regarding the decontamination of carcasses than is currently the case. It is also concluded that current EU regulations relying on hazard analysis of critical control points (HACCP)-inspired production in cutting plants will not be effective in reducing the prevalence of *Salmonella* spp. on pork. This is mainly because (1) there is currently an almost steady stream of *Salmonella*-positive carcasses that enter the cutting process; (2) when contaminated carcasses are being processed, further cross-contamination during working hours is unavoidable; (3) no steps in the cutting process are intentionally designed to

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effectively reduce the risks or consequences of cross contamination of cuts and retail-ready products.

Keywords: *Salmonella* spp.; Pork

1. Introduction

A future system of safety assurance for meat should be based on (i) continuous quantitative or semiquantitative assessments of consumer health hazards and (ii) modern principles of integrated quality control (IQC), good manufacturing practices (GMP) and hazard analysis of critical control points (HACCP) (Anonymous, 1985, 1987; Berends et al., 1993). A promising tool for achieving these goals is the construction of elaborate descriptive epidemiological models of the fate of hazardous microorganisms throughout the entire meat production chain, i.e. 'from stable to table'. Furthermore, if the prevalence of hazardous agents from stable to table can somehow be quantitatively modeled, the possible effects of envisaged control strategies can also be quantified in advance.

The *Salmonella* spp. contamination of Dutch finishing pigs at the farm, during transportation and lairage at the slaughterhouse and the influence of certain risk factors is described in Berends et al., 1996a. Berends et al. (1997), (1998) (MS 1907/98) discuss the main risks and risk factors regarding *Salmonella* spp. contamination of carcasses in slaughter lines in The Netherlands and of pork in cutting plants and butchers' shops, respectively. This article completes the analysis of the entire Dutch pork production chain by discussing the consequences for human health of the current exposure to *Salmonella* spp. contaminated pork, and by evaluating the effects of some currently proposed control strategies.

2. Materials and methods

The approach followed is inspired by the recommendations of the American National Research Council (Anonymous, 1985, 1987, 1990a; Rodricks, 1993). In this approach, the analysis of risks and risk factors is primarily based on a description of the ecology and epidemiology of hazardous microorganisms throughout the entire meat production chain. This description and subsequent analysis of the influence of particular risk factors is thereby defined as an 'implemented formal descriptive epidemiological model'. An extensive account of how and why to define different kinds of models, the construction of such models and the subsequent analysis of the data, and of the limitations of such approaches is given in Berends et al. (1996).

In short, the descriptive epidemiological model for *Salmonella* attempted 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., 1996).

In this submodel for the 'consumer phase', the analyses were performed almost exclusively with data from literature, supplemented by previously unpublished results (Van Leeuwen et al., 1990; Hoogenboom-Verdegaal et al., 1991, 1992; Edel, 1993a,b; Berends, 1993, 1997; Berends et al., 1995). The constructed mathematical model of the prevalence of *Salmonella*-positive pigs, carcasses and cuts is a straightforward numerical 'translation' of the three submodels mentioned (Berends et al., 1996a; Berends, 1997; Berends et al., 1998, submitted). In addition, literature data were only included in the model if they themselves were an indication of risk or if they could be reprocessed for estimating risks, which makes the descriptive epidemiological model more than a straightforward review.

In all submodels, the influence of risk factors is expressed as odds ratios (OR), i.e. the ratio of the odds of disease or contamination in the case that a particular factor is present to the odds when it is absent. When the odds ratio of a certain factor is statistically significantly greater than one, it is a definite risk. In this submodel for *Salmonella* spp. in the consumer phase, all odds ratios were estimated by means of two-by-two tables and tested for significance with the Chi-squared test (Armittage and Berry, 1987; Martin et al., 1987).

For the mathematical model from the end of the finishing phase up to cutting and retail, the simplest approach that would fit the (normally distributed) data was considered sufficient, resulting in an unweighted linear least squares regression with a zero intercept (Armittage and Berry, 1987).

3. Results: Summary of a descriptive epidemiological model of human salmonellosis via pork and an evaluation of the effects of certain proposed control strategies

3.1. Salmonella spp. on pork in The Netherlands and the consequences for human health

3.1.1. Human salmonellosis in The Netherlands

Infections with the non-typhoid *Salmonella* spp. are characterized by febrile gastroenteritis, i.e. diarrhoea, stomach ache, fever (up to 40°C), headache, nausea, vomiting and malaise. The first symptoms will appear after 12–24 h (range 5–72 h) and continue for about three–four (range 2–7 days) (Beckers et al., 1982; Flowers, 1988; Baird-Parker, 1990; Hoogenboom-Verdegaal et al., 1991). In approximately 5% of cases, sequellae arise, e.g. endocarditis, multiple abscesses, polyarthritis or osteomyelitis. In about 2% of these complicated cases, the patient dies. Death usually occurs as a result of dehydration, severe kidney failure and/or sepsis and shock (Kvenberg and Archer, 1987; Murray, 1987; Baird-Parker, 1990, 1994; Lester et al., 1991).

The incidence of disease can also be seen as a measure of the risk that groups of people (or animals) are at in a particular epidemiological setting (Armittage and Berry, 1987; Martin et al., 1987). With regard to human salmonellosis, the generally held view is that the official statistics grossly underestimate the real incidence (Genigeorgis, 1981; Beckers, 1987; Wheelock and Wright, 1989). A more accurate estimation of the incidence of food-borne salmonellosis in The Netherlands, however, can be made by combining the data from the following investigations: (1) In The Netherlands, about 5% of all identified cases of gastroenteritis in general practices are caused by salmonellosis (Hoogenboom-Verdegaal et al., 1991, 1994); (2) The estimated total number of persons in The Netherlands that suffer from gastroenteritis caused by all possible agents is about 2.5 million per year, while the estimated proportion that actually seeks medical attention for their complaints is about 10% (Hoogenboom-Verdegaal et al., 1992, 1994); (3) Furthermore, the nature and severity of symptoms of salmonellosis, as recorded in these studies (Hoogenboom-Verdegaal et al., 1991), resembles the nature and severity of symptoms as recorded in several outbreak studies. In the outbreak studies, it was observed that at least 20% of the exposed actually sought medical help (Blaser and Newman, 1982; Beckers et al., 1982; Smith et al., 1985; Wheelock and Wright, 1989). Thus, it can be estimated that, in The Netherlands, the average incidence of salmonellosis will be about 450 cases per 100,000 person years at risk. Based on the number of samples investigated in the aforementioned Dutch studies (Hoogenboom-Verdegaal et al., 1991, 1992, 1994), the annual incidence can be estimated within 95% confidence limits as being between 300 and 700 cases per 10^5 at risk. Incidence estimates of about the same magnitude can be made for other industrialized countries (Kvenberg and Archer, 1987; Lester et al., 1991; Baird-Parker, 1990, 1994; Bean and Griffin, 1990).

With regard to mortality, it can be estimated that, in The Netherlands, on average, about 65 people will (directly or indirectly) die from the infection annually. Taking into account that (complicated) salmonellosis is identified in only about 30% of the cases, by physicians and pathologists, as the sole and/or primary cause of death and, thus, is recorded as such, the official Dutch (long-term) statistics of about 20 to

30 deaths per annum confirm this last estimate (Beckers, 1987; Lester et al., 1991).

The very young and the very old are considered as being more at risk of an infection with *Salmonella* spp. than the average adult population. However, in The Netherlands, healthy elderly people do not seem necessarily to be more at risk than younger adults (Riley et al., 1984; Hoogenboom-Verdegaal et al., 1991, 1994; Anonymous, 1993). Based on these data, the estimate of 450 cases per 100,000 person years at risk in The Netherlands can actually be expressed in cases per 10^5 at risk of (i) 1800 for the group of zero–four years of age; (ii) 680 for the group of five–nine years of age; (iii) 300 for the group of ten years of age and older.

3.1.2. Risks of population subgroups that could be quantified

People already suffering from a disease or condition that may directly or indirectly affect their immunocompetence are more prone to an infection than people in good health, and their infection more often becomes complicated (Blaser and Newman, 1982; Baird-Parker, 1994; Ryan et al., 1997). Pavia et al. (1990) calculated an OR of 'underlying disease', such as neoplasms or diabetes mellitus, as a risk factor in 'becoming infected with *Salmonella* spp.' of 4.1 (95% CI: 0.7–25.0). From the data of Lester et al. (1991), it can be calculated that the OR of 'underlying disease' as a risk factor in 'arising sequellae' and as a factor in 'dying from this infection' are 3.8 (95% CI: 1.8–8.2; $P < 0.01$) and 3.6 (95% CI: 1.3–10.7; $P < 0.01$), respectively. From their data, it can be inferred that, in a group of 93 persons with an underlying disease that had been hospitalized for salmonellosis, sequellae arose in 47 (51%) cases, while in a group of 71 persons without any underlying disease that had been hospitalized for salmonellosis, sequellae developed in 15 (21%) cases. Furthermore, from the group of 93 patients, 23 (25%) died, and from the group of 71 patients, six (8%) died. Thus, the annual number of cases of salmonellosis per 10^5 at risk in the group of people with 'underlying diseases' may roughly be estimated at 1200, that of arising sequellae at 60 and that of death at 1.2, respectively.

Use of antacids or insufficient gastric acid production (achlorhydria) can also be a risk factor. From the data of Riley et al. (1984), it can be calculated that the OR of 'excessive use of antacids' as a risk factor in becoming infected with *Salmonella* spp. is 3.6 (95% CI: 1.1–10.4; $P < 0.01$). From a group of 20 excessive users, six (30%) became infected, while from a group of 419 non-users only, 45 (11%) became infected. The annual incidence of salmonellosis amongst those who use antacids almost daily, or who suffer from achlorhydria, can thus be estimated at about 1100 cases/10^5 at risk.

The administration of antibiotics with a disturbing effect on the normal gut flora, such as tetracyclines or broad spectrum penicillins, can lead to significantly more infections with *Salmonella* spp., both in animals and man (Pavia et al., 1990; Berends et al., 1996a). This effect is especially important in the first week after the last administration of these antibiotics. A stratified analysis of the data of several studies lead to a Mantel-Haenszel-corrected OR of the previous use of broad spectrum antibiotics as a risk factor in becoming infected with *Salmonella* spp. of 5.6 (95% CI: 4.4–7.5; $P < 0.01$) (Berends et al., 1996a). The annual incidence of salmonellosis amongst persons who have recently used antibiotics with an adverse effect on the composition of the gut flora may thus be about 1700 cases per 10^5 at risk. Since, in The Netherlands, antibiotics are prescribed to up to 10% of the population on average once a year (Berends, 1997), the impact on the total number of cases of salmonellosis is small. It can be estimated that in, The Netherlands annually, about 350 cases of salmonellosis result from being exposed to *Salmonella* spp. in the first week after the last administration of antibiotics, i.e. less than 0.5% of the total number of estimated cases.

People who come into close contact with (live) animals, animal excrement, animal products or patients suffering from salmonellosis are potentially more at risk of an infection then others (Williams, 1979; Flowers, 1988; D'Aoust et al., 1990; Barrow, 1992; Davies and Renton, 1992). However, no investigations could be found that quantify the higher risk incurred by farmers, slaughterline personnel, caterers or nurses.

Approximately 1% of those who have experienced an infection become a symptomless carrier of *Salmonella* spp. (Oostrom et al., 1979; Williams, 1979). Buchwald and Blaser (1984) found that eight of 600

(1.3%) examined members of the general population were symptomless carriers of *Salmonella* spp. Chau et al. (1977) established that six out of 78 (7.7%) pig slaughterhouse workers were symptomless carriers. From these studies, it can roughly be estimated that, as a risk factor in becoming infected and/or (afterwards) colonized by *Salmonella* spp., working at a pig slaughterhouse has an OR of 6.2 (95% CI: 2.1–18.3; $P < 0.01$). The annual incidence of *Salmonella* infections amongst pig slaughterhouse personnel can thus roughly be estimated at about 1800 cases per 10^5 at risk. In addition, although there are no data to confirm this, it may be the case that the risks incurred by farmers is about the same.

With respect to an estimate of the greater risk of an infection of caterers and hospital personnel in The Netherlands, only two, rather indirect, sources of information are available, viz. the official statistics of the Dutch Ministry of Health regarding cases of salmonellosis and demographic data from the Dutch Central Bureau of Statistics (Postema, 1990; Anonymous, 1993). Caterers and nurses have a more or less consistent share in the total number of registered cases amongst adults of about 20 and 5%, respectively (Postema, 1990). From the demographic data, it can be inferred that about 8% of the working population consists of people employed in the catering business and that about 2% of the working population consists of nurses (Anonymous, 1993). The ratio's between the proportion of cases of the groups caterers, nurses and the general adult population divided by their share in the whole working population can be written as 2.5:2.5:0.8. Thus, the incidence of salmonellosis amongst caterers and nurses appears to be about three times as high as amongst the general adult population. This leads to a rough estimate of the annual incidence of salmonellosis amongst caterers and nurses of about 900 per 10^5 at risk.

3.1.3. Foodborne salmonellosis and the associations with pork

In the industrialized countries, between 80 and 90% of all cases of salmonellosis are associated with the consumption of food of animal origin (Bryan, 1980; Schelner, 1985; Beckers, 1987; Kvenberg and Archer, 1987; Bryan, 1988; Anonymous, 1990b). With respect to The Netherlands, it can be inferred that, in general, 95% (90–97%) of all cases of salmonellosis are foodborne and 5% (3–10%) result from human-to-human transmission, e.g. to other family members (Edel et al., 1975; Hoogenboom-Verdegaal et al., 1991). However, in certain epidemiological settings, such as in nursing homes, human-to-human transmission may sometimes be between 30 and 70% (Williams, 1979; Joseph and Palmer, 1989; Anonymous, 1990a; Ryan et al., 1997). From analyses of Buchwald and Blaser (1984); Joseph and Palmer (1989), it can be inferred that, although in 30–50% of outbreaks of foodborne salmonellosis, food handlers also tested positive, only in 2–3.5% of these outbreaks could the *Salmonella*-positive food handlers also be identified as the actual source of the outbreak.

In industrialized countries, between 5 and 30% of all cases of foodborne salmonellosis will have pork as the actual source (Bryan, 1980, 1988; Baird-Parker, 1994). Although many types of *Salmonella* are not very selective in ‘choosing’ their host species, due to, amongst others, husbandry-associated ecological factors (Berends et al., 1996a), in many instances, very strong associations are observed between certain sero- and phage types of *Salmonella* spp. and the host species (Guinée and Valkenburg, 1974; Müller, 1986; Beckers, 1987; Murray, 1987, 1994; Baggesen and Wegener, 1994; Edel, 1994; Wegener et al., 1994). In The Netherlands, the types that are associated with pigs and pork over the past decade accounted for, on average, 15% of identified cases of human salmonellosis; about 50% of all *S. typhimurium* infections in humans have been with the pig-associated types (Van Leeuwen, 1991; Anonymous, 1992; Edel, 1993a,b). This more or less resembles the Danish situation (Baggesen and Wegener, 1994; Wegener et al., 1994). The average annual number of cases of salmonellosis associated with the production and consumption of pork can thus be estimated to be about 10,000, and within 95% confidence limits between 3000–23,000. This means that there is an average annual incidence of pig-associated salmonellosis in The Netherlands of about 70 cases per 10^5 at risk (30–165). Table 1 presents the average yearly risk of certain (sub)population members with regard to both salmonellosis transmitted via food of animal

Table 1
Estimated current average individual yearly risk of contracting salmonellosis from food of animal origin in general and from pork for a number of groups in the population in The Netherlands

Group	From food of animal origin in general	From pigs or pork
0–4 years old	1.8×10^{-2}	2.7×10^{-3}
5–9 years old	6.8×10^{-3}	1.0×10^{-3}
Aged 10 years and older	3.0×10^{-3}	4.5×10^{-4}
All ages	4.5×10^{-3}	6.7×10^{-4}
Chronically ill (adults)	1.2×10^{-2}	1.8×10^{-3}
Achlorhydria or (semi) continuous use of antacids (adults)	1.1×10^{-2}	1.7×10^{-3}
Caterers	9.0×10^{-3}	1.4×10^{-3}
Pig slaughterers	nc	1.8×10^{-2}

nc: not calculated.

origin in general and via pork (products) in particular.

3.2. Evaluation of the currently discussed control strategies

3.2.1. Outlines of a simple mathematical model for evaluation

To obtain an impression of the stage at which control measures would be most effective and to evaluate the actual effect of the control strategies that are currently being discussed in The Netherlands, a simple (deterministic) spreadsheet model for the presence of *Salmonella* spp. in pigs and on pork was developed. From the complete descriptive epidemiological model from stable to retail (Berends, 1993; Berends et al., 1996a, 1997, 1998, submitted), the following was used as input:

1. The current overall percentage of *Salmonella*-excreting pigs at slaughter weight in The Netherlands is about 13% (Berends, 1993; Berends et al., 1996a).
2. The Pearson's correlation coefficient of the percentage of *Salmonella*-excreting pigs before (X) and after (Y) transport is high (0.95; $n=10$; $P<0.01$). In the interval from 0 to 50% excreting pigs at slaughter weight, the relationship is sufficiently described by: $f(x)$ $Y=(1.72\pm0.18)X$ (F value 88.7 at 1 *d.f.*; $P<0.0001$). (Berends, 1993; Berends et al., 1996a).
3. Likewise, the Pearson's correlation coefficient of the percentage of positive pigs before slaughter (X) and the percentage of positive carcasses just before cooling (Y) is high (0.98; $n=14$; $P<0.001$), and the relationship is adequately described by: $f(x)$ $Y=(0.63\pm0.14)X$ (F value of 37.0 at 1 *d.f.*; $P<0.0001$). (Berends, 1993; Berends et al., 1997).
4. The baseline of positive cuts produced in cutting lines and butcher's shops is determined by the input of positive carcasses. Because of the lack of data, no precise correlations could be calculated. However, assuming the percentage of contaminated cuts (Y) to be a function of both the input of *Salmonella* spp. via the percentage of positive carcasses (X) and of the influence of inapt cleaning and disinfection lead to a satisfactory approximation of the prevalence of *Salmonella*-positive pork at retail level: $f(x)$ $Y=1.1(X+X(100-X)$ (Berends, 1993; Berends et al., 1998, submitted), provided that the proportion of *Salmonella*-positive carcasses that are being processed varies between 0 and 90%.

3.2.2. Evaluation of currently discussed control strategies

Apart from implementing EU regulations about HACCP-inspired production methods in cutting plants, a structured approach to the control of *Salmonella* spp. in the pig production chain in The Netherlands is still a matter of debate. Most of the discussions focus on the establishment of codes of good manufacturing practices for pig farmers, feed mills, pig transporters, slaughter houses and cutting plants. All the current designs are, in fact, an actual formalization of generally accepted rules about the production of *Salmonella*-free feeds; regular cleaning and disinfection of utensils, stables, trucks, machinery and rooms; training and hygienic conduct of personnel; pest control, many of which can already be found in any handbook about pig farming or slaughtering and dressing.

However, none of these codes effectively deal with all risks and risk factors identified in the model of transmission of *Salmonella* from stable to table in The Netherlands (Berends et al., 1996, 1996a, 1997, 1998, submitted). Consequently, they fail in totally controlling the *Salmonella* problem in pork.

The designed GMP codes for the farm phase, for example, do not take into account that, currently, about two thirds of the farms already have strong autonomous cycles with their own endemic 'house-flora' of *Salmonella* spp., and that breaking these cycles will require farm-specific measures that cannot be attained by a set of general rules about hygiene and bio-security. Moreover, as can be concluded from Berends et al. (1996a), 'improved hygiene practices' can reduce at best only about 50% of the *Salmonella* spp. infections that occur nowadays, whereas finishing according to the SPF concept will be able to reduce about 95% of currently occurring infections.

With respect to transport and lairage, it has been established that optimal hygiene can prevent only about 10% of the rise in the numbers of *Salmonella*-positive pigs that usually occurs nowadays (Berends et al., 1996a). Furthermore, if pigs could be transported and laired totally stress-free, which is currently not the case, the number of *Salmonella*-excreting pigs would, at best, not increase (Berends et al., 1996a).

Regarding the slaughterline, evisceration is the main risk factor for carcass contamination. Alternative procedures, such as the bagging of bungs, have proven that they can prevent on average 75% of the otherwise occurring carcass contamination with *Salmonella* spp. (Berends et al., 1997). Validation of the evisceration techniques used in a particular plant can be done by repeated bacteriological examinations for certain indicator organisms. For example, if the carcasses produced do not contain *Enterobacteriaceae* above the detection limit of 1.3 $\log_{10}$ colony forming units (cfu) per cm^2, it can be stated with about 97% confidence that the carcasses are practically free of *Salmonella* spp. (Berends, 1993). Currently discussed GMP codes, however, strive after a maximum of 25% of carcasses being contaminated with between 1.3–2.5 $\log_{10}$ cfu *Enterobacteriaceae*/cm^2. They can, therefore, not guarantee that, in the case that *Salmonella*-positive pigs enter the slaughterline, the *Salmonella* contamination of carcasses is maximally controlled. Furthermore, because much of the cross contamination with *Salmonella* spp. by the polishing machines and during processing after evisceration is practically unavoidable, GMP codes that do not include these special in-plant-validated evisceration techniques may thus only prevent 10–15% of the presently occurring carcass contamination with *Salmonella* spp. (Berends, 1993; Berends et al., 1995, 1997).

Within cutting plants and in butchers' shops, improved hygiene can only prevent up to probably 10% of the total cross-contamination that occurs during the processing of *Salmonella*-positive carcasses (Berends et al., 1998, submitted).

Fig. 1 presents the effects on the prevalence of *Salmonella* spp. of various scenario's regarding the implementation of codes of GMP in several parts of the pork production chain, as calculated with the simple mathematical model. It is obvious that the farm and the slaughtering phases constitute the most important targets in attempts to reduce risks for the consumer. Implementing GMP at the farm (scenario 3) will at maximum double the efficacy of GMP during transport and GMP during cutting and retail (scenario 2). If the GMP at the farm, during transport and during cutting and retail (scenario 3) were to be supplemented with GMP codes at the slaughterhouse that include the in-plant-validated 'special' evisceration techniques (scenario 4), the current exposure of the consumer via pork may be reduced at best by about 85%. In case the GMP codes during transport and cutting and retail were to be supplemented by breeding according to the SPF concept (scenario 5), the total reduction would be over 99%. When GMP codes are implemented from transport to retail, and supplemented by a terminal decontamination of the carcasses at the slaughterhouse (scenario 6), this would be just as effective as the combination of GMP and breeding according to the SPF concept.

4. Discussion

Descriptive epidemiology and some basic epidemiological methods of quantification can allow one to overcome the lack of data regarding dose–response relationships and the actual exposure of the consumer to certain numbers of *Salmonella* spp. and, thus, to quantify to a certain extent the influence of certain risk factors as well as the risks for certain subgroups of the population. This last aspect is important when priorities regarding the consumer risks that should be controlled are also set on the

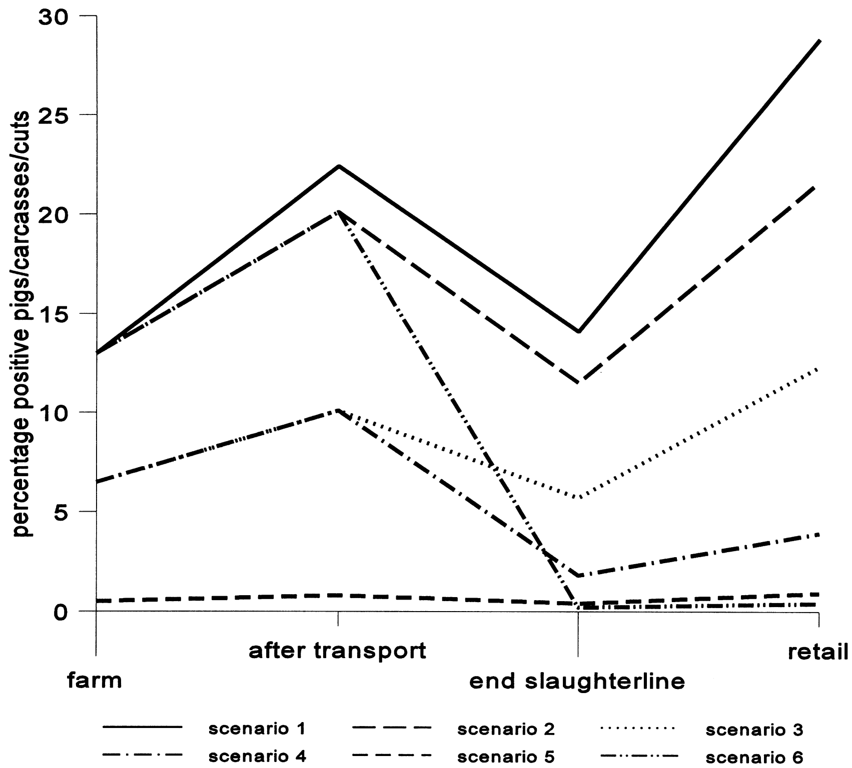

Fig. 1. Calculated effects of six different scenario's in the control of *Salmonella* spp. in the pork production chain in The Netherlands on the prevalence at the end of the finishing period up to retail level.

basis that a certain 'average risk' is acceptable, or rather that control efforts should be aimed at also protecting certain groups who are at elevated risk (Mossel et al., 1998). Furthermore, this analysis of the Dutch situation can now also serve as an example of how to assess risks for the consumer in other countries in Europe, in other microorganisms, and in other kinds of meat.

The higher risk for slaughter line personnel and chronically ill people in The Netherlands agree with existing assumptions. On an annual basis, the extra risk of antibiotic prescriptions for the 'average' consumer is negligible. Although not all of the persons who take antibiotics obtain them by prescription, the ~5.5 times higher risk of this situation prevails only for about a week. Healthy elderly people do not seem to be more at risk per se than younger adults. That elderly people are considered a group with a higher risk of infection can be explained by (1) a diagnostic bias because elderly people suffering from enteritis are usually more readily and more thoroughly examined by physicians than younger people with the same complaints; (2) over-representation of the elderly in official statistics because data from hospitals and nursing homes are more readily obtainable than those from general practitioners; (3) confounding of age with an often underlying chronic disease or condition, such as diabetes mellitus, neoplasms and/or achlorhydria.

A mathematical model is as good as the data it is fed with and, for the more accurate risk assessments and models required, further research is necessary. Nevertheless, even our rough approximation can be of help in translating complex situations into easy-to-depict evaluations of effective control strategies. Fig. 1 is in that sense a condensation of the many considerations and deliberations of the descriptive epidemiological model around the decisive role that the farm and, to a lesser extent, the slaughterhouse play in current consumer risks as well as in their future reductions (Berends et al., 1996, 1996a, 1997, submitted). It clearly underlines that (1) currently positive pigs and subsequently positive carcasses that are being brought into the chain constitute the main sources of *Salmonella* spp. ; (2) after evisceration, further cross-contamination is thus entirely determined by the *Salmonella*-status of the carcasses being processed; (3) when positive carcasses are being processed cross-contamination during working hours is unavoidable (Berends et al., 1996a, 1997, 1998, submitted).

In terms of efficient consumer protection, comparison of scenarios 2 and 3 (GMP codes from transport to retail and from farm to retail, respectively) with scenario 6 (GMP coupled with SPF-breeding) clearly illustrates that if virtually *Salmonella*-free pigs were produced, virtually *Salmonella*-free pork could be sold to the consumer (Berends et al., 1996a, 1997). Scenario 4 (scenario 3 supplemented with measures that are specifically designed to control *Salmonella* spp. contamination at the slaughterhouse) shows that, as long as *Salmonella*-positive pigs enter the slaughterhouses, there will always be transmission of *Salmonella* spp. to consumers, even when slaughterhouses, cutting plants and butchers work under the best of circumstances (Berends et al., 1997). Because there is a direct relationship between the prevalence of *Salmonella*-positive pigs, carcasses and pork and the number of pork-associated human cases in The Netherlands, reductions in the prevalence of positive pigs, carcasses and pork will lead to proportional decreases in pork-associated human salmonellosis.

The recently implemented EU regulations regarding HACCP-based production processes in cutting lines will, in all probability, be much less effective in *Salmonella* spp. control then assumed, because HACCP is implemented at the wrong time and in the wrong way. The former, because the unacceptable risks are already established in much earlier phases, viz. at the farm and to a lesser extent in the slaughter house. Procedural failure can be expected, because no steps at cutting lines are introduced that are intentionally designed to reduce risks. Where intervention is strived after, both the incoming materials, i.e. the carcasses, and the cutting process as a whole should be considered critical control points (Berends and Snijders, 1994; Berends et al., 1995). Moreover, there are no reasons to assume that the number of *Salmonella*-positive pigs and carcasses will soon be reduced substantially (Berends et al., 1996a, 1997).

Very high costs are entailed by breeding in accordance with the SPF-concept as well as in realizing considerable changes in current slaughtering practices. In many countries in Europe and elsewhere, these kind of changes in the pork production process are, therefore, an unrealistic option. Consequently, a similar approach to that adopted many years ago in the dairy industry of a mandatory strict GMP, from transport to retail, coupled with a terminal decontamination step in the slaughterhouse, will probably be one of the most efficient as well as cost-effective ways of controlling the *Salmonella*-problem on pork in The Netherlands and comparable countries. Besides the discussed in-plant-validated evisceration techniques, decontamination linked GMP will have to include, for example, (i) careful removal of all lymph nodes associated with the digestive tract that remain in the thoracic and abdominal cavity following evisceration (Berends et al., 1997); (ii) the exclusion of the pig's head meat for the production of products like minced pork (Berends et al., 1997). In addition, existing EU regulations offer too few options regarding the implementation of a decontamination step under the provisions, as discussed above, and should therefore be changed (Berends et al., 1997, 1998, submitted).

It should not be concealed that a substantial reduction in the number of pork associated cases of human salmonellosis will not necessarily mean that the total number of cases become negligible. Other sources of foodborne salmonellosis, such as poultry, eggs, international trade in staples and tourism, will remain important causal factors. The control of *Salmonella* spp. in food has to rely on a combined international effort, that at least includes all food products of animal origin that are currently associated with the problem, i.e. poultry, eggs, pork and veal. In all instances, perfect sanitary care at the farm, during transportation and lairage and slaughtering at abattoirs, linked to a terminal decontamination step, such as that practised in the dairy industry, may provide bacteriologically safe fresh materials that will no longer cause disease through consumption or as a result of cross contamination of other, initially safe, foods.

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