Observations on the distribution of salmonella in a pig abattoir

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A survey of 2211 pigs was carried out in a pig abattoir. Salmonella was isolated from 7·0 per cent of carcase swabs and from 11·6 per cent of 2205 samples of large intestinal contents. *Salmonella typhimurium* DT104 or DT104B was found in 3·2 per cent of the large intestinal samples (27·7 per cent of the salmonella isolates found) and in 2·7 per cent of the carcase swabs (38·7 per cent of the salmonella isolates from carcases). Within individual batches of pigs, the rate of isolation of salmonella ranged from 0 to 71·4 per cent from intestinal contents, and from 0 to 100 per cent on carcases. In a smaller subsurvey, salmonella was found in 9·1 per cent of intestinal contents, 5·8 per cent of mesenteric lymph nodes and 3·8 per cent of tonsils, but in no spleen samples. The rates of isolation of salmonella from pigs from different producer groups ranged from 0 to 21·9 per cent with 0 to 88·2 per cent of farm units within groups showing evidence of infection. *S typhimurium* DT104 or DT104B was isolated from large intestinal samples from 16·9 per cent of farm units. The number of salmonellae found in positive pigs ranged from 1·0 to 10^5 cfu/g intestinal contents and from 1·0 to 10^2 cfu per 0·1 m^2 dressed carcase surface. Sequential sampling during the slaughter process showed that 82·9 per cent of the carcases were contaminated after bleeding, a proportion which was reduced to 5·7 per cent after scalding; after singeing none were contaminated. Estimations of surface enterobacteriaceae revealed a similar pattern of reductions and resurgences of contamination to that observed with salmonella. The rate of isolation of salmonella from pigs which had been held in lairage overnight was less than that from pigs slaughtered within two to three hours of arrival.

SALMONELLA infections in people are responsible for considerable suffering and economic loss, worldwide (Murray 1994, Altekruse and others 1998). In most countries, the relationship between human cases and the contamination of pig meat is unclear, except in Denmark where *Salmonella typhimurium* DT12 constitutes approximately 15 to 20 per cent of human cases and is considered to be related exclusively to pig meat (Wegener and others 1994). There have also been occasional reports of large outbreaks of salmonella associated with pork products in the UK (Maguire and others 1993, Cornell and Neal 1998). The contamination of pig meat by salmonella has received more attention since a large outbreak of *Salmonella infantis* prompted the introduction of large-scale salmonella control measures in the Danish pig meat industry (Anon 1997, Mousing and others 1997a, Nielsen and Wegener 1997).

There have been several surveys of retail pig meat which suggest that a wide range of salmonellae may be present in fresh meat (Bozzano and others 1993, Fernandez-Escartin and others 1995) and pig meat products such as hot vacuum-packed pork (Van Laack and others 1993) and, particularly, those incorporating low-grade material such as mechanically recovered meat (Banks and Board 1983). Low-level contamination combined with bad food handling practice in kitchens, which is often automatic and unrecognised by food handlers, may allow salmonellae to multiply to levels which pose a hazard to consumers (Worsfold and Griffith 1997).

There have been several surveys of the prevalence of salmonella contamination of pig carcases and studies of the slaughter process. In Greece, 28 per cent of pork pig carcases were found to be contaminated with salmonella (Epling and others 1993). In Canada, 17·5 per cent of carcases were contaminated (Lammerding and others 1988). The prevalence in the Netherlands was 21 per cent (Osterom and others 1985), and in Belgium, 27 per cent (Korsak and others 1998).

In Denmark, large-scale action by the pig industry has reduced the rate of contamination of pork carcases to 1 per cent (Nielsen and Wegener 1997). The prevalence of salmonella in the intestine of individual pigs from different sources is extremely variable and individual animals may remain as carriers for at least 36 weeks (Wood and Rose 1992). In Denmark, 6·2 per cent of caecal samples were found to be positive, usually with one serotype or phage type predominating on each farm (Baggesen and others 1996). In the UK, a small survey found that 1·5 per cent of individual finishing pigs sampled on the farm were excreting salmonella (Pearce and Revitt 1998), but any sampling, especially by rectal swab, gives an underestimate of the level of infection (Bager and Baggesen 1993). This is also true of carcase sampling where only a fraction of the attached organisms can be identified by swabbing (Izat and others 1991) and where larger gauze swabs are more effective than smaller, more easily used swabs (Korsak and others 1998).

The pig industry is fortunate in that the scalding and singeing processes, if properly conducted, can reduce the level of contamination of the surfaces of carcases by salmonella to minimal levels before evisceration (Saide-Albornoz and others 1995). The spillage of material from the intestinal tract, mainly as a result of intestinal perforation during evisceration, is, therefore, the major source of carcase contamination. This problem can be reduced, but not totally eliminated, by careful technique (Berends and others 1997). This paper describes work carried out in one large abattoir to investigate the prevalence and distribution of carcase contamination with salmonella and enterobacteria during the slaughter process.

MATERIALS AND METHODS

Sampling procedure

Samples were taken in one large modern abattoir during eight visits made over a period of six months. They were taken from approximately 10 per cent of each batch of pigs slaughtered during the day. Between 5 and 10 g of large intestinal contents were collected, after evisceration, into sterile plastic containers and carcase swabs were taken from 0·1 m^2 of the carcase surface as a 10 cm band running up from the neck alongside the ventral incision in the carcase. The carcases were swabbed vigorously with a sterile surgical gauze swab (Number 63024; Robinson Healthcare). Surfaces of the fabric of the building and equipment were swabbed in a similar way but, in this case, approximately 0·5 m^2 of the surface was sampled. The samples were returned to the laboratory at ambient temperature, and culture begun on the day of collection.

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TABLE 1: Isolations of salmonella from large intestinal contents and carcase swabs of slaughter pigs

Visit	Number of farm batches positive for salmonella/number of farms sampled (%) (number of farm batches positive for STM DT104 or 104B [%])		Large intestinal samples: mean number positive for salmonella/ number of samples taken (%) <> = number of DT104 or 104B (range of salmonella prevalence in individual farm batches)		Carcase swabs: mean number positive for salmonella/number of samples taken (%) <> = number of DT104 or 104B (range of salmonella prevalence in individual farm batches)	
1	9/24 (37·5)	(5 [20·1])	31<6>/160 (19·4)	(0-64·7)	25<3>/160 (15·6)	(0-75·0)
2	10/23 (43·5)	(4 [17·4])	17<8>/279 (6·1)	(0-25·0)	9<7>/279 (3·2)	(0-36·4)
3	9/24 (37·5)	(5 [20·8])	28<15>/277 (10·1)	(0-50·0)	20<19>/277 (9·4)	(0-66·7)
4	7/14 (50·0)	(4 [28·6])	29<17>/227 (12·8)	(0-71·4)	12<11>/277 (5·3)	(0-42·8)
5	14/24 (58·3)	(3 [12·5])	35<9>/289 (12·1)	(0-44·4)	36<8>/289 (12·4)	(0-100·0)
6	17/29 (58·6)	(7 [24·1])	58<14>/270 (21·5)	(0-0·70)	21<11>/270 (7·8)	(0-62·5)
7	5/20 (25·0)	(1 [5·0])	22<1>/309 (7·1)	(0-35·7)	3<0>/309 (1·0)	(0-7·1)
8	12/27 (44·4)	(1 [8·3])	36<1>/394 (9·1)	(0-36·4)	29<1>/400 (7·2)	(0-50·0)
Total	83/185 (44·9)	(30 [16·2])	256<71>/2205 (11·6)	<3·2>	155<60>/2211 (7·0)	<2·7>

Culture media

Samples were pre-enriched in buffered peptone water (BPW) (Oxoid CM509) at 37°C for 18 hours, and 0·2 ml was then inoculated into a petri dish containing 20 ml of diagnostic semi-solid salmonella media (DIASSALM) (LabM; Lab 537). After 24 and 48 hours incubation at 41·5°C, subcultures were streaked on to Rambach agar (Merck 7500) using a 1 µl disposable loop. The Rambach agar plates were incubated for 24 hours at 41·5°C and suspect salmonella colonies were confirmed by full serotyping. Semi-quantative estimations of salmonella populations were made by vigorous shaking and decimal dilution of the sample in BPW immediately after sampling, and culturing each dilution for salmonella as above. Enterobacteriaceae were counted by standard plate counts on violet red bile glucose (VRBG) agar (Oxoid; CM485) or, when numbers were low, by decimal dilution in BPW, followed by incubation of all dilutions at 37°C for 24 hours and plating on VRBG agar.

Statistical analysis

The chi-square test (with Yates' correction) was applied by using Epi Info 6.03 (Dean and others 1991).

RESULTS

A summary of the salmonella isolation results from each of the eight visits to the abattoir is shown in Table 1. The proportion of batches of pigs from individual farms in which salmonella was found ranged from 25·0 per cent to 58·6 per cent, with a mean of 44·9 per cent. *S typhimurium* DT104 or DT104B was found in 30 (16·2 per cent) of the farm batches, that is 36·1 per cent of the salmonella-positive farms. Salmonella was found in 256 of 2205 (11·6 per cent) large intestinal samples and *S typhimurium* DT104 or DT104B was present in 71 (3·2 per cent) of samples, thus constituting 27·7 per cent of the salmonella isolates found. Salmonella was found in 155 of 2211 (7·0 per cent) carcase swabs and *S typhimurium* DT104 or DT104B was found in 2·7 per cent of the samples and thus constituted 38·7 per cent of the salmonellae found on carcases. The rate of contamination of carcases with salmonella was 60·5 per cent of the rate of isolation from intestinal contents. Within individual batches of pigs, the rate of isolation of salmonella ranged from 0 to 71·4 per cent of samples of large intestinal contents from individual pigs and from 0 to 100 per cent of swab samples from carcases.

A wide range of salmonella serotypes and definitive types of *S typhimurium* were found (Table 2). The predominant salmonella in large intestinal contents was *Salmonella derby* (24·2 per cent) followed by *S typhimurium* DT104 (23·4 per cent) and *S typhimurium* untypable (17·2 per cent). Some serotypes, such as *Salmonella manhattan*, *Salmonella kimuenza* and *S typhimurium* DT106, were associated with specific farms or producer groups but were also found on carcases of subsequent batches of pigs from other sources. Some serotypes, such as *Salmonella panama* and *Salmonella goldcoast*, were known to be common (data not shown) on some of the farms supplying the abattoir but were rarely found in the abattoir survey. *S typhimurium* DT104 was the most frequent isolate (34·8 per cent) from carcase swabs whereas *S derby* was less well represented (14·8 per cent of isolates). Salmonellae other than *S typhimurium* and *S derby* were also less frequently isolated from carcases than from intestinal contents.

An attempt was made to compare the rates of isolation of salmonella from different tissues (Table 3). Salmonella was found in 9·1 per cent of samples of large intestinal contents, and in 41·4 per cent of the batches of pigs sampled. The rates of isolation from mesenteric lymph nodes, tonsil and spleen were 5·8 per cent, 3·8 per cent and 0 per cent, respectively. Five batches of pigs were found to be carrying salmonella in the large intestine but not in the mesenteric lymph nodes, and in three batches, salmonella was found in mesenteric lymph nodes but not in the large intestine. The total number

TABLE 2: Number of isolates (% of total salmonella) of salmonella serotypes and phage types from samples from slaughter pigs

Sample type	*S typhimurium* DT104	*S typhimurium* DT104B	*S typhimurium* U302	*S typhimurium* DT193	*S typhimurium* DT208	*S typhimurium* DT106	*S typhimurium* other phage types	*S typhimurium* untypable	*S derby*	Other serotypes
Large intestinal contents	60 (23·4)	11 (4·3)	10 (3·9)	14 (5·5)	12 (4·7)	8 (3·1)	6 (2·3)[a]	44 (17·2)	62 (24·2)	29 (11·3)[c]
Carcase swabs	54 (34·8)	6 (3·8)	6 (3·8)	19 (12·2)	6 (3·8)	4 (2·6)	9 (5·8)[b]	26 (16·8)	23 (14·8)	2 (1·3)[d]

[a] *S typhimurium* DT29 x 2, *S typhimurium* DT120 x 2, *S typhimurium* DT12 x 1, *S typhimurium* DT181 x 1
[b] *S typhimurium* DT29 x 2, *S typhimurium* DT120 x 3, *S typhimurium* DT170 x 1
[c] *S kimuenza* x 13, *S kedougou* x 4, *S manhattan* x 4, *S goldcoast* x 1, *S panama* x 1, *S mbandaka* x 1, *S liverpool* x 1, *S bovis morbificans* x 1, *S yovokome* x 1
[d] *S manhattan* x 1, *S panama* x 1
DT Definitive phage type

TABLE 3: Isolations of salmonella from different tissues

	Large intestinal contents	Carcase swabs	Mesenteric lymph nodes	Spleen	Tonsil
Number of samples positive for salmonella/number of samples taken (%)	36/394 (9·1)	29/400 (7·2)	23/398 (5·8)	0/394	15/391 (3·8)
Number of batches of pigs positive (%)	12/29 (41·4)	16/29 (55·1)	8/29 (27·6)	0/29	8/29 (27·6)
Number of batches in which the specified tissue was the only positive sample	1 <5>	8	1 [3]	0	0

< > Number of batches positive in large intestinal contents but not in mesenteric lymph nodes
[ ] Number of batches positive in mesenteric lymph nodes but not in large intestinal contents

TABLE 4: Isolations of salmonella from pigs from different producer groups

Producer group	Number of units	Number of units positive for salmonella in large intestinal contents (%)	Number of units positive for STM, DT104 or 104B in large intestinal contents (%)	Overall isolation rate from large intestinal contents (%)	Overall isolation rate from carcase swabs (%)
1	13	1 (7·7)	0	13/116 (11·2)	12/118 (10·2)
2	1	1 (100·0)	0	1/19 (5·3)	3/23 (13·0)
3	30	23 (76·7)	13 (43·3)	84/499 (16·8)	49/499 (9·8)
4	38	16 (42·1)	7 (18·4)	30/489 (6·1)	42/486 (8·6)
5	17	15 (88·2)	2 (11·8)	87/397 (21·9)	26/399 (6·5)
6	6	0	0	0/32	2/32 (6·3)
7	21	7 (33·3)	1 (4·8)	21/368 (5·7)	6/369 (1·6)
8	1	0	0	0/33	4/33 (12·1)
9	5	3 (60·0)	0	2/50 (4·0)	2/50 (4·0)
10	3	0	0	0/34	0/34
11	1	0	0	0/8	1/8 (12·5)
12	3	1 (33·3)	0	2/22 (9·1)	1/22 (4·5)
13	1	0	0	0/4	0/4
14	6	4 (66·7)	2 (33·3)	11/71 (15·5)	3/71 (4·2)
15	2	1 (50·0)	0	5/63 (7·9)	4/63 (6·3)
Total	148	72 (48·6)	25 (16·9)	256/2205 (11·6)	155/2211 (7·0)

STM *S typhimurium*, DT Definitive phage type

of individual pigs in which salmonella was found was increased by 75 per cent to 63 of 400 (15·7 per cent) when the isolation results from the large intestine, lymph node and tonsil were combined. There was a poor correlation between the presence of salmonella in the various tissues from individual animals. Only seven of 23 (30·4 per cent) of the positive lymph node samples were from pigs in which the intestinal contents were also positive, and only two of 15 (13·3 per cent) pigs with positive tonsils were from pigs in which the intestinal contents or lymph node samples were positive. Only three of 29 (10·3 per cent) of the positive carcase swab samples were from pigs with salmonella in their intestinal contents, but seven of 29 (24·1 per cent) positive carcase samples were from tonsil-positive pigs. In no case was salmonella isolated from the intestinal contents, lymph node and tonsil of an individual pig.

There were considerable differences between the rates of isolation of salmonella from the pigs from different producer groups (Table 4), ranging from 0 per cent of pigs from several producer groups to 21·9 per cent of the pigs from producer group 5. However, the rate of isolation from the carcases of the pigs from producer group 5 was lower than that from several other groups. The proportion of infected pig units within each producer group ranged from 0 per cent to 88·2 per cent, with

TABLE 5: Semi-quantitative estimation of salmonella contamination of carcases and large intestinal contents

Sampling point	Number of carcases positive for salmonella/ number of carcases sampled (%)	Mean salmonella score per 0·1 m^2 carcase (maximum from individual sample)	Number of intestinal contents positive for salmonella/ number of samples taken (%)	Mean salmonella score (maximum from individual samples per 1 g faeces)
Postbleed	10/10 (100·0)	1·9 (max 3)	NS	NS
Postmeat inspection	8/17 (47·0)	0·5 (max 1)	NS	NS
Postmeat inspection	0/21	0	NS	NS
Postmeat inspection	2/15 (13·3)	1·0 (max 1)	8/15 (53·3)	3·4 (max 5)
Postmeat inspection	0/12	0	6/12 (50·0)	1·8 (max 3)
Postmeat inspection	0/4	0	0/4	0
Postmeat inspection	2/12 (16·7)	2·0 (max 2)	3/12 (25·0)	2·0 (max 3)
Postmeat inspection	0/16	0	0/16	0
Postmeat inspection	2/15 (13·3)	1·0 (max 1)	8/15 (53·3)	3·4 (max 5)
Postmeat inspection	1/41	1·0	3/41 (7·3)	1·0 (max 1)
Postmeat inspection	1/37 (2·7)	2·0	10/37 (27·0)	1·7 (max 3)

Salmonella scores: 0 = 0 organisms, 1 = 1-10 organisms, 2 = 10-10^2 organisms, 3 = 10^2-10^3 organisms, 4 = 10^3-10^4 organisms, 5 = 10^4-10^5 organisms
NS Not sampled

TABLE 6: Isolations of salmonella from carcases sampled at different points in the slaughter process (number of samples positive for salmonella/number of samples taken) on four visits

Sampling point	Visit 1	Visit 2		Visit 3		Visit 4		Totals
		am	pm	am	pm	am	pm	
Postbleed	9/10	10/10	10/10	1/10	10/10	8/10	10/10	58/70 (82·9)
Postscald tank	0/10	4/10‡	0/10	0/10	0/10	0/10	0/10	4/70 (5·7)
Postmain dehairing machine	0/10	10/10	1/10	0/10	1/10	2/10	0/10	14/70 (20·0)
Postsmall dehairing machine	NS	10/10	1/10	0/10	6/10	NS	NS	17/40 (42·5)
Postsinge	0/10	0/10	0/10	0/10	0/10	NS	NS	0/50
Postpolisher	0/10	0/10	0/10	0/10	0/10	1/10	0/10	1/70 (1·4)
Posteviscerator	1/10	0/10	0/10	1/10	0/10	NS	NS	2/50 (4·0)
Postsplitting	5/10	0/10	0/10	2/10	0/10	NS	NS	7/50 (14·0)
Postmeat inspection	25/160 (15·6%)	0/10*	0/10*	0/10†	0/10†	NS	NS	25/200 (12·5)
Entrance to chiller	1/10	0/10	0/14	0/10	1/10	NS	NS	2/54 (3·7)

*Overall carcase contamination rate for the day was 9/279 (3·2%)
†Overall carcase contamination rate for the day was 26/277 (9·4%)
‡Scald tank temperature 59°C
NS Not sampled

72 of 148 (48·6 per cent) units showing evidence of salmonella infection. *S typhimurium* DT104 or DT104B was isolated from only five producer groups, and 25 of 148 (16·9 per cent) units were infected. These figures are likely to underestimate the number of infected farms because, in most cases, relatively small numbers of samples were taken from each farm.

The numbers of salmonellae found in intestinal contents of a random selection of infected pigs ranged from 1·0/g to 10^4 to 10^5/g and from 1·0 to 10^1 to 10^2 per 0·1 m^2 carcase surface (Table 5). Higher levels of carcase contamination (10^2 to 10^3 per 0·1 m^2) were recorded immediately after bleeding.

Table 6 shows the rates of isolation of salmonella from carcases at various points in the slaughter process on four sampling visits. The overall carcase contamination rate was 82·9 per cent after bleeding but only 5·7 per cent after scalding. There were increases in contamination to 42·5 per cent of carcases after two dehairing operations but the contamination was reduced to 0 per cent after singeing. One isolate (1·4 per cent) was made after polishing and there were further increases in contamination after evisceration and carcase splitting. There was an apparent reduction in the contamination of carcases with salmonella at the entrance to the chiller but it is likely to have been due to sampling variation. The results of sampling the first batch of pigs to pass through the plant on two further occasions showed that two of 70 (2·8 per cent) carcases were contaminated after the singeing and polishing stages.

Table 7 shows a comparison of the rates of isolation of salmonella from large intestinal contents and carcase swabs from pigs which had either been held in lairage overnight or not been held in lairage overnight. The mean incidence of salmonella in the intestinal contents of the pigs which had been held in lairage was 9·9 per cent, compared with 12·0 per cent for the pigs which had not; a similar comparison of carcase swabs gave a mean incidence of 2·5 per cent for the pigs which had been held in lairage compared with 8·1 per cent for those which had not, a difference which was statistically significant.

There was widespread contamination of accessible surfaces and equipment beneath the slaughter line (Table 8) and in the lairage area. Salmonella was found in two of 10 samples taken from the exit ramp of the scald tank, but no salmonella was isolated from the floor around the singer. Contamination was again detected after polishing and increased along the slaughter line. The estimates suggested levels of 1 to 10^4 to 10^5 cfu per 0·5 m^2 surface area sampled, even in areas which had been disinfected with a glutaraldehyde-based foaming agent at the end of the previous day's production.

The contamination of carcases with enterobacteriaceae was assessed at various points in the slaughter process (Table 9). There was a reduction in surface counts from over 10^5 cfu/0·1 m^2 after bleeding to 10^2 to 10^3/0·1 m^2 after scalding, but there was then a 10-fold increase in contamination until singeing, when the numbers were again reduced to postscald levels. Further 10- to 100-fold increases in counts occurred during the polishing and evisceration stages, but there was little evidence of substantial further increases in contamination during splitting, trimming and grading, except in the single set of late afternoon samples.

DISCUSSION

The work described in this paper was carried out in one large abattoir, and the results cannot therefore claim to be representative of the whole of Great Britain. The fact that in individual pigs the rate of contamination of carcases was less than the carriage rate of salmonella, demonstrates the capacity of the slaughter process to limit the distribution of contamination. In most cases, the numbers of salmonellae on the carcases were also relatively low, and would only have been likely to cause a risk to people handling and consuming the meat if allowed to multiply during subsequent processing and storage.

Of greater concern is the high proportion of farms (at least 44·9 per cent) which showed evidence of the presence of infection in slaughter pigs; a third of these infected farms had either *S typhimurium* DT104, which is a multiple antibiotic-resistant strain which is widely isolated from animals and man (Ridley and Threlfall 1998) or *S typhimurium* DT104B, which has an even greater range of resistance. Multiple resistant strains of salmonellae are frequently isolated from pig carcases (Epling and Carpenter 1990). This problem appears to be associated with the regular use of antibiotics and is less

TABLE 7: Comparison of isolations of salmonella from pigs held in lairage overnight or not held in lairage overnight. Number of samples positive for salmonella/number of samples taken (%)

Visit	Large intestinal contents from pigs		Carcase swabs from pigs	
	Held in lairage	Not held in lairage	Held in lairage	Not held in lairage
1	NS	31/160 (19·4)	NS	25/160 (15·6)
2	3/60 (5·0)	14/219 (6·4)	0/60	9/219 (4·1)
3	3/68 (4·4)	25/209 (12·0)	1/68 (1·5)	19/209 (9·1)
4	13/61 (21·3)	16/166 (9·6)	5/61 (8·2)	7/166 (4·2)
5	10/62 (16·1)	25/227 (11·0)	1/62 (1·6)	35/227 (15·4)
6	12/79 (15·2)	46/191 (24·1)	2/79 (2·5)	19/191 (9·9)
7	3/87 (3·4)	19/222 (8·5)	1/87 (1·1)	2/222 (0·9)
8	0/28	36/366 (9·8)	1/28 (3·6)	28/372 (7·5)
Total	44/445 (9·9)	212/1760 (12·0)	11*/445 (2·5)	144/1766 (8·1)

*P <0·001
NS Not sampled

TABLE 8: Isolations of salmonella and semi-quantitative estimation from drip channels or floors beneath the line at different points in the slaughter process. Number of samples positive for salmonella/number of samples taken (mean salmonella score, maximum salmonella score in individual samples)

Sampling point	Visit 1	Visit 4	Pre-start	Visit 5 am	Visit 5 pm
Lairage reception	5/10	NS	NS	NS	NS
Lairage pens	8/10	NS	NS	NS	NS
Bleed channel	4/10	8/10 (0·8, max 1)	1/10 (0·1, max 1)	5/10 (0·5, max 1)	3/10 (ND)
Ramp postscald tank	2/10	NS	NS	NS	NS
Ramp postmain dehairing machine	5/10	NS	NS	NS	NS
Floor postsmall dehairing machine	NS	NS	NS	NS	NS
Floor postsinge	0/10	NS	NS	NS	NS
Floor postpolisher	7/10	NS	NS	NS	NS
Drip channel postevisceration	10/10	10/10 (1·8, max 4)	4/10 (1·0, max 5)	8/10 (0·8, max 1)	10/10 (ND)
Drip channel postsplitting	10/10	9/10 (1·5, max 4)	NS	NS	NS
Drip channel postmeat inspection	10/10	10/10 (2·7, max 3)	1/10 (0·1, max 1)	4/10 (0·6, max 3)	7/10 (ND)
Entrance to chiller	10/10	10/10 (2·5, max 5)	NS	NS	NS

Salmonella scores: 0 = 0 organisms per 0·1 m^2, 1 = 1-10 organisms per 0·1 m^2, 2 = 10-10^2 organisms per 0·1 m^2, 3 = 10^2-10^3 organisms per 0·1 m^2, 4 = 10^3-10^4 organisms per 0·1 m^2, 5 = 10^4-10^5 organisms per 0·1 m^2
NS Not sampled, ND salmonella score not determined

common when lower levels of therapeutic antibiotics are used (Baggesen and Aarestrup 1998). Antibiotic therapy for other conditions may also increase the shedding of salmonella because of its inhibitory effect on competitive bacteria in the gut (Holcomb and Fedorka-Cray 1997).

S derby, which is considered to be a partially host-adapted serotype in pigs, was the predominant serotype found in large intestinal contents but, in common with other minority serotypes, it was less frequent on carcases. In contrast, *S typhimurium* DT104 was predominant on carcases. This finding suggests either that *S typhimurium* may be more able to attach to carcase surfaces, or that when it is present, it may occur in larger numbers in the gut and so result in more generalised contamination.

The total absence of salmonella in the spleen was surprising, especially when it is compared with the results of diagnostic postmortem culture, when salmonella is often isolated from the spleen. It suggests that although salmonellae were found in lymph nodes and tonsils, in healthy carrier pigs, salmonella is carried in the alimentary tract and associated lymphoid tissue rather than systemically. The apparent correlation between the carriage of salmonella in the tonsils and carcase contamination requires further investigation.

The analysis of salmonella contamination among the producer groups showed that all of the large groups had evidence of salmonella infection on some of their units, but that *S typhimurium* DT104 or DT104B was found in only a third of the groups. Since it is possible only to contain, rather than to reduce, the contamination with salmonella resulting from an escape of intestinal contents during the slaughter process, the primary control measures should be established on farms, and particularly on problem farms. Secondary hazard analysis critical control point (HACCP)-style measures can then be applied to the whole chain of pig meat production, retailing and consumption (Smulders and Johnson 1990, Borch and others 1996). Studies of risk factors for salmonella in Danish pig herds have shown that large herds (Baggesen and others 1996) and farms which source pigs from dealers (Miller and others 1997) carry a higher risk. Liquid feed has been shown to be a protective factor, as is home-mixed feed (Dahl 1998), unless it is contaminated by infected wild birds during production, storage and feeding (Harris and others 1997). It is thought that the increasing genetic homogeneity of the pig population, with most replacement breeding stock originating from a small number of breeding companies, may also increase the opportunities for the dissemination of particular salmonella strains (Azsak and Hunter 1992). In Denmark, most pig breeding herds are self-contained and are limited in size by legislation on environmental pollution. This makes salmonella control more easy to achieve. It may also be difficult to control salmonella in outdoor breeding herds, which are becoming more common in the UK. The carriage rate of salmonella in breeding stock, especially replacement gilts placed in an infected farm, can be high (Davies and Wray 1997) and an isolation rate of 84 per cent was found in one survey of cull sows in the USA (Tay and others 1989). The prevalence of salmonella in suckling pigs is low, even when the dam is infected, so there is an opportunity to break the cycle of infection and increase pig performance by segregated weaning or split-site production (Dee and others 1996, Fedorka-Cray and others 1997, Nietfield and others 1998). However, these practices do not give full control over a long time (Dahl and Wingstrand 1996), and they must therefore also incorporate methods to minimise the mixing of litters, keep group sizes as small as practicable, operate on an all-in/all-out basis, thoroughly disinfect housing after each batch of pigs, and control rodents and wild birds (Muirhead 1993, Davies and Wray 1997).

In a well-managed pig abattoir, the slaughter process can reduce the level of surface contamination of carcases at the scalding and singeing stages (Saide-Albornoz and others 1995). Scalding temperatures of 61 to 62°C are commonly used because, although higher temperatures would be more effective, there is a danger of damaging the epidermis which leads to discoloration of the carcase and greater attachment of bacteria (Slavik and others 1995). Any salmonellae which do survive scalding or singeing can be spread between carcases by the dehairing equipment (Gill and Bryant 1993). Most of the final carcase contamination is due to the escape of intestinal contents during evisceration (Saide-Albornoz

TABLE 9: Assessment of carcase contamination with enterobacteriaceae at different points in the slaughter process (count per 0·1 m^2 carcase surface; mean of 10 carcases sampled)

Sampling point	Visit 2 am	Visit 2 pm	Visit 3 am	Visit 3 pm
Postbleed	$2·2 \times 10^5$	$1·8 \times 10^5$	$2·3 \times 10^5$	$3·4 \times 10^5$
Postscald	$<5·0 \times 10^3$	$<5·0 \times 10^3$	$5·0 \times 10^2$	$2·2 \times 10^2$
Postmain dehairer	$9·0 \times 10^3$	$7·0 \times 10^3$	$3·5 \times 10^4$	$4·2 \times 10^3$
Postsmall dehairer	$1·1 \times 10^4$	$1·3 \times 10^4$	$5·0 \times 10^3$	$3·4 \times 10^3$
Postsinge	$<5·0 \times 10^3$	$<5·0 \times 10^3$	$2·6 \times 10^2$	$2·4 \times 10^2$
Postpolisher	$1·0 \times 10^4$	$7·0 \times 10^3$	$5·5 \times 10^3$	$5·6 \times 10^3$
Postevisceration	$1·2 \times 10^5$	$8·0 \times 10^3$	$9·4 \times 10^3$	$4·3 \times 10^3$
Postsplitting	$7·0 \times 10^3$	NS	$1·7 \times 10^4$	$2·9 \times 10^3$
Postmeat inspection	$8·5 \times 10^3$	NS	$2·1 \times 10^3$	$4·6 \times 10^3$
Postgrading	$8·5 \times 10^3$	NS	NS	NS
Entry to chiller	$8·0 \times 10^3$	NS	$1·9 \times 10^3$	$1·8 \times 10^4$

NS Not sampled

and others 1995). Although some contamination is likely to occur during the removal of the oesophagus and rectum, in the authors' experience, the accidental rupture of the intestinal wall is responsible for most of the faecal contamination of carcases and equipment. There were marked differences in the frequency of these ruptures observed during different shifts, suggesting that the training of slaughterhouse staff and the monitoring of good evisceration techniques should receive a high priority in abattoirs. Similarly, production systems in which pigs are fed minimal dietary roughage and given little exercise should be discouraged because they tend to increase the frequency of intestinal rupture during slaughter (Miller and others 1997).

The results of these studies indicate that there was little increase in carcase contamination after the evisceration stage, but further increases during trimming and meat inspection procedures have been described by Mousing and others (1997b). The use of HACCP-style procedures has been widely adopted in abattoirs, but the level of microbial monitoring to identify the control points is often inadequate, and the procedures are often applied incorrectly (Von Langer 1995). Some benefit may also be obtained by applying procedures such as steam pasteurisation of pig carcases or acidic carcase washes (Epling and others 1993, Humphrey and others 1997, Morris and others 1997). However, there is a danger that the routine use of such measures may result in the relaxation of other hygiene practices and the adaptation of the organisms to the treatments.

It is commonly supposed that keeping pigs in lairage would increase the chance of cross-infection and contamination (Morgan and others 1987). It is known that any stress factor, including transport, may increase the rate of excretion of salmonellae by carrier pigs (Scheepens and others 1994, Berends and others 1996) but stress levels, and possibly salmonella excretion, are reduced by overnight lairage (Warris and others 1998). However, there appears to be little difference in the magnitude of this effect in relation to the distance travelled (Rajkowski and others 1998). In this study there was a reduced rate of intestinal carriage of salmonella and carcase contamination in pigs which had been held in lairage overnight compared with pigs slaughtered within two to three hours of arrival. This higher level of carcase contamination in the pigs not held in lairage may have been due to the heavier contamination of the slaughter equipment and the greater fatigue of the slaughterer for pigs slaughtered later in the day. The sources of the pigs selected for overnight lairage may also influence the contamination, if there is a regular pattern, but similar results have been found in a larger survey in Germany (Rabsch and others 1998). Although the experimental inoculation of pigs with larger numbers of salmonella may lead to the rapid dissemination of the organism throughout the body within hours (Blaha and others 1997), a more natural infection with small numbers of organisms may take two days to appear in the faeces (Fedorka-Cray and others 1994), so only prolonged lairage may result in an increased risk.

In recent years much attention has been focused on salmonella in pig meat. In most countries, the contribution of pig meat to human salmonellosis is unknown, particularly because variations in host preferences by different salmonella serotypes make direct comparisons of surveillance data difficult to interpret. More research into the molecular genetic basis of human and food animal salmonellosis is needed, but with the rapid improvements in salmonella control in poultry meat production, the opportunity for human infection via pig meat may increase in the future. It is clear that biosecurity and hygiene precautions to control salmonella should be improved throughout the chain of pig meat production and distribution, from nucleus breeders to hot dog stalls (Simonsen and others 1987). These precautions should also improve the control of endemic pig diseases and other food poisoning organisms (Weijtens and others 1997). Control measures should also cover wastes from potentially contaminated premises such as farms and abattoirs (Henry and others 1995). In Great Britain, the pig industry is large and diverse and, without the financial resources to invest in improved housing for all-in/all-out production, it will probably be necessary to use other aids for control, such as vaccination (Lumsden and Wilkie 1992, Meyer and others 1993) and the treatment of feed with formaldehyde.

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Notes