Journal of Food Protection, Vol. 65, No. 1, 2002, Pages 41–49

Assessment and Development of Procedures and Apparatus To Reduce Contamination of Lamb Carcasses during Pelt Removal in Low-Throughput Abattoirs

R. T. WHYTE,[1]* J. S. HOLDER,[2] D. B. TINKER,[1] V. M. ALLEN,[2] R. P. WHITE,[1] AND M. H. HINTON[2]

[1]*Bio-Engineering Division, Silsoe Research Institute, Wrest Park, Silsoe, Bedfordshire, MK45 4HS, UK; and* [2]*Department of Food Animal Science, School of Veterinary Science, Bristol University, Langford, BS18 7DU, UK*

MS 01-14: Received 8 January 2001/Accepted 2 July 2001

ABSTRACT

Two series of experiments were carried out to investigate methods of reducing contamination of lamb carcasses in low-throughput abattoirs, where cradle dressing is normally employed. In the first series, cradle design and pelt removal procedure were investigated, and a method was developed for assessing gross visible contamination. Significant improvements in microbiological and gross visible contamination ($P < 0.01$) were achieved by procedural changes only; modifications to the cradle design had no effect. In the second series of experiments, two improved methods of pelt removal and the effect of hand washing prior to carcass contact during the pelt removal procedure were investigated. The improved methods comprised a Frame system, in which the pelt was removed in a manner similar to that in a high-throughput inverted line, and a Hybrid system, in which the pelt was removed from the forequarters on a conventional cradle before the carcass was suspended in an "inverted" vertical position for removal of the pelt from the abdomen and hindquarters. The results of microbiological and gross visible contamination from these methods, with and without hand washing, were compared with the conventional Cradle method of pelt removal. Both the Hybrid and Frame systems had significantly less microbiological and gross visible contamination ($P < 0.01$). However, hand washing had no significant effect on the level of carcass contamination for all three methods of pelt removal. Greatest reductions in microbiological and gross visible contamination were achieved using techniques that minimized hand contact with the carcass during pelt removal by adoption of inverted dressing procedures. Equipment redesign did not reduce carcass contamination.

Microorganisms are present on the external surfaces of live animals, but healthy underlying tissues are considered to be sterile *(12, 26)*. Once these tissues are exposed, they can be contaminated with pathogens and spoilage bacteria arising from the normal flora of the skin as well as organisms of fecal and soil origin. Microorganisms on the hide, hooves, and hair at the time of slaughter are the most important sources of microbial contamination of the carcass surface *(17, 21, 25, 26)*. Pathogens isolated from these sites include the organisms *Clostridium perfringens, Staphylococcus aureus, Salmonella,* verotoxigenic *Escherichia coli, Campylobacter, Yersinia enterocolitica, Listeria monocytogenes,* and *Aeromonas hydrophilia,* which all cause enteric disease *(13, 29)*. Monitoring all these organisms on carcasses would be time consuming and is unlikely to yield meaningful data. Instead microbiological monitoring is confined to organisms that are presumed to be indicators of the possible presence of the organisms of concern. This is generally limited to the enumeration of total viable or aerobic counts, as a measure of hygiene performance and resulting storage life, and *E. coli* or *Enterobacteriaceae* as an indicator of fecal contamination, on the assumption that pathogens associated with meat are largely fecal in origin *(13)*.

During pelt removal, the few areas of the carcass that are contaminated heavily are commensurate with hide and hand contact. During subsequent dressing operations, handling of the carcass results in a redistribution of bacteria over its surface *(8, 13, 14),* with few bacteria being added.

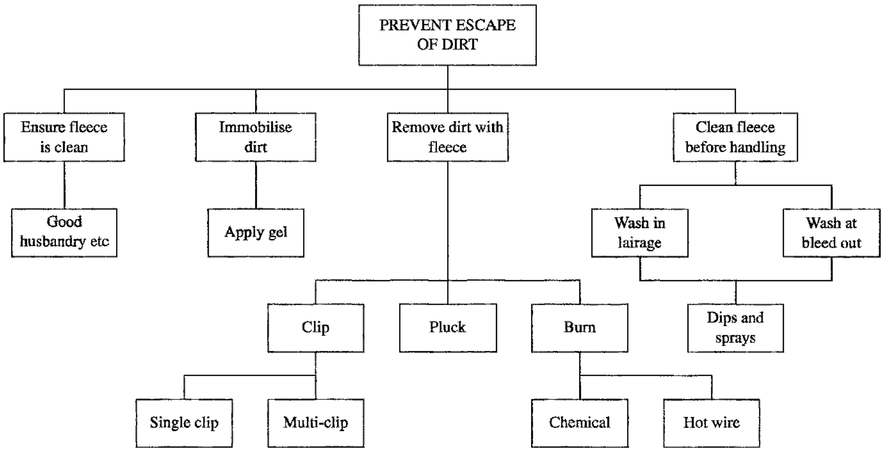
Typical levels found on the lamb carcasses for both total aerobic and *E. coli* counts have been reported, ranging from 3.93 to 4.44 and 0.96 to 1.51 log CFU/cm^2, respectively, at visibly clean sites following pelt removal. At sites visibly contaminated with fecal matter, these levels rose to 6.00 and 3.00 log CFU/cm^2, respectively, whereas tufts of wool gave 5.44 and 2.45 log CFU/cm^2, respectively *(5, 7)*.

The introduction of the United Kingdom Meat Hygiene Service cleanliness classification *(1)* of animals for slaughter has reduced the potential for gross contamination of the carcass. It contains five categories of cleanliness; the first two, the cleanest, are those into which animals must normally fall to allow slaughter. These categories were established from the correlation found between increasing carcass contamination and reduced animal cleanliness on presentation for slaughter *(18)*. These constraints have lessened the likelihood of carcass contamination from the pelt and, when coupled with improved techniques of pelt removal, will further reduce the risk of meat contamination. Gross, visible contamination of the carcass after pelt removal can comprise particles of dirt, straw, fecal material, coarse hair, and varying quantities of wool. However, there is little ev-

---

* Author for correspondence. Tel: 00 44 01525 860000; Fax: 00 44 01525 861735; E-mail: robin.whyte@bbsrc.ac.uk.

FIGURE 1. *Approach 1. Prevention of escape of dirt from the fleece.*



idence to support the concept that all sites of gross visible contamination also represent those of high levels of microbiological contamination *(7, 13).*

In the UK, the majority of sheep and lambs pass through large or high-throughput abattoirs on a continuous processing line at a rate of around 250 to 300 animals/h, the carcass dressing operations being carried out by around 25 operators. In addition to these abattoirs, there are approximately 155 low-throughput abattoirs that cater to limited-quantity kills, mainly for niche markets, including organic, specialist breeds, hobbyist, "farm shop" sales, and high-quality butchers. In low-throughput abattoirs, no more than 20 livestock units/week can be handled, with a maximum of 1,000 units/year. Ten sheep or lambs over 15 kg live weight make up one unit. The dressing operations are generally carried out by one or two operators.

In many low-throughput abattoirs, slaughtered sheep are dressed by first placing the carcass on a dished rigid frame, known as a cradle, for pelt removal. During the initial stages of pelt removal, gross visible contamination occurs primarily through the pelt either "tucking under" or from the dirty fleece hanging over the edge of the pelt onto the carcass. In addition to direct contact with the fleece, transfer of microorganisms also occurs via routes such as the tools, clothing, and hands of operatives and as dust or aerosol. The problem is exacerbated during the winter months, especially if the sheep have fed on root crops.

Abattoir workers use both hands on the carcass during pelt removal, especially in cradle dressing, where one man may carry out all the operations. In one process, known as "punching," the hand is pushed between the pelt and the carcass to free the pelt. It is not practical for the operator to clean his hands frequently during the pelt removal operation, so the level of cross-contamination is likely to be high.

A number of methods that aid pelt removal and at the same time reduce cross-contamination arising from handling of the carcass were investigated with the help of experienced slaughtermen. These methods were grouped into two approaches. The first aimed to prevent the dispersal of contaminants from the fleece either by removal or entrapment (Figure 1), and the second sought to minimize this risk (Figure 2). Specific measures ranged from removing or attempting to immobilize dirt in the fleece at the cut sites to the use of ultrasonic knives to aid pelt–carcass separation. In a series of investigative trials of methods suggested in Figure 1, ensuring the fleece was clean as a result of good husbandry, prior to slaughter, was the only successful approach. Other approaches either exacerbated contamination or damaged the pelt.

This research has concentrated on improving techniques of pelt removal following the methods grouped into the second approach. Where applicable, techniques used in high-throughput abattoirs have been adapted, such as the development of a low-cost system that allows inverted dressing of the carcass.

Air inflation, as a method of pelt removal, was not investigated because it is prohibited by EU regulations. It is thought to spread microorganisms over the surface of the carcass *(28)* and air infiltration of the tissues results in a white, opaque carcass, which is unacceptable to the meat trade. Research in Australia found that air inflation left large areas of attachment between the pelt and the carcass, requiring some, although reduced, manual effort to separate *(30).* Air was also found to penetrate between deeper layers of tissue, which increased the likelihood of deep tissue contamination.

A series of trials of pelt removal methods designed to minimize the escape and transfer of contaminants from the fleece resulted in the development of a pelt removal method that was effective in reducing gross visible contamination of the carcass. During this research, a mobile wash stand was built that allowed the slaughterman to clean his hands more readily during the pelt removal process and to pasteurize his knife more frequently. A method of scoring gross visible contamination on the depelted carcass was also developed that allowed rapid assessment of pelt removal methods. Major factors in reducing carcass contamination were identified in the first of two experiments described here. In the second experiment, these factors were investigated further by comparing three methods of pelt removal.

MATERIALS AND METHODS

Cradle design. The conventional cradle comprises a four legged platform made of galvanized steel rod, 1.2 m long, 0.7 m

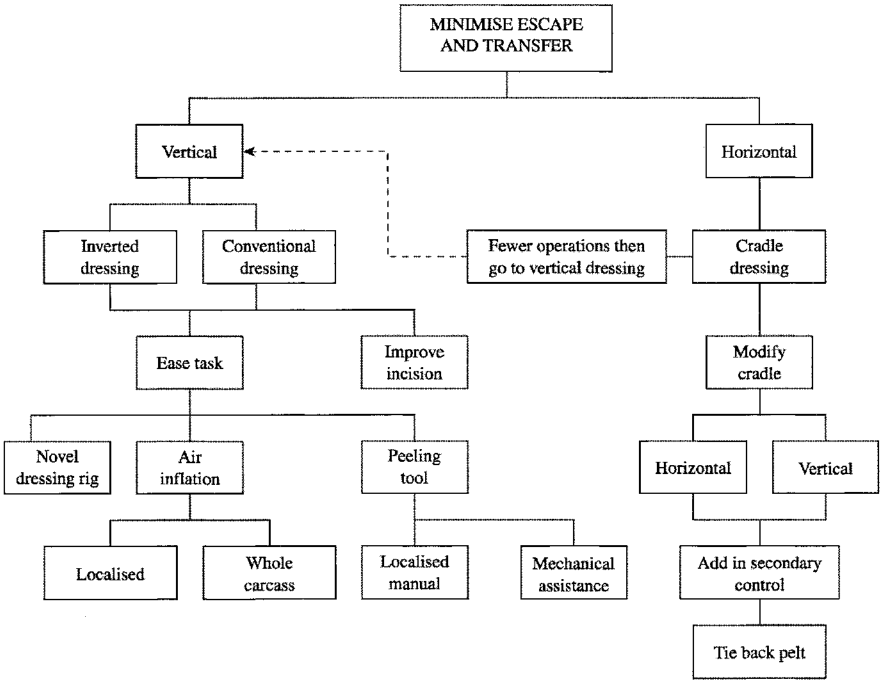


FIGURE 2. *Approach 2. Modification of pelt removal practices to minimize escape and transfer of contaminants.*

wide, and 0.8 m high with a platform typically made of seven crossbars dished laterally, on which the carcass is placed. The dishing of the platform is not sufficient to prevent the carcass from rolling, and its size does not allow the pelt to fall away from the carcass as it is released but increased the tendency of the pelt to roll back on to the tissue exposed. Improvements to the cradle and the pelt removal procedure were developed in conjunction with abattoir staff at Bristol University. A modified cradle was designed and built that allowed the weight of the loose pelt in the shoulder region to fall away from the carcass, while its platform curvature was more pronounced to provide more stability for the carcass. At the rear end of the modified cradle, a detachable vertical support bar was added to suspend the hind legs by means of a gambrel. However the support bar interfered with pelt removal and did not form part of subsequent trials.

Cradle pelt removal procedure. A range of pelt removal procedures were tried on sheep carcasses, in which most of the preparatory work of separating the pelt from the carcass was carried out on the cradle. The carcass was hung by the rear legs before the pelt was pulled off manually. By analyzing video recordings, the procedures were broken down to identify good and bad techniques, and the findings were discussed with the abattoir staff. Changes that formed a new, improved pelt removal procedure included delaying both the separation of the skin from the shoulders and the incision of the pelt along the ventral abdominal midline until the carcass is removed from the cradle and suspended vertically by the rear legs in the conventional Cradle method of dressing.

Modified cradle and modified pelt removal procedure trials. The effectiveness of the modifications to the cradle and to the pelt removal procedure was assessed experimentally. Two slaughtermen each skinned nine carcasses for each of four different treatment groups, including (i) conventional cradle–old method, (ii) conventional cradle–new method, (iii) modified cradle–old method, and (iv) modified cradle–new method. Each animal had been graded according to the cleanliness classification *(1)*. Immediately after skin removal, swab samples were taken from the shoulder and abdomen for enumeration of total viable counts (TVC) and *Enterobacteriaceae* counts using the wet- and dry-swab sampling procedure in ISO/CD 17604 *(3)*. These sites were chosen because they were likely to be contaminated by hand contact during the punching process to release the pelt from the carcass.

For each site, a 50-cm^2 area was defined using a sterile metal template. This area was sampled using a sterile, jumbo-sized swab (MW104J; Medical Wire, Corsham, UK) moistened with sterile maximum recovery diluent (MRD Oxoid CM733, pH 7.0 ± 0.2, Oxoid, Basingstoke, UK). To minimize variation, the area was first swabbed from left to right and then top to bottom *(22)*. This area was again sampled using a dry swab. Both swabs were added to 10-ml MRD and vortexed for 30 s using a Fisons Whirlimixer (Fisons, Loughborough, UK). Decimal dilutions were prepared from the resulting suspension and these were used to inoculate plate count agar (PCA Oxoid CM325, Oxoid) and violet red bile glucose agar (VRBG Lab88, LabM, Bury, UK) using a modification of the Miles and Misra technique *(24)*. The total viable microbial numbers and colonies of *Enterobacteriaceae* were enumerated on PCA and VRBG plates following incubation at 30°C for 48 h and 37°C for 24 h, respectively. The minimum detection level for plate counts was 1 CFU/2 cm^2.

Gross, visible contamination, which generally comprised straw, wool, dirt, and fecal matter, was quantified from the same regions of the carcass by a technique developed during this research. This method used sheets of colorless, clear adhesive plastic film, approximately 90 by 130 mm (3M Pat-it, 3M, St. Paul, Minn.), normally used to remove lint and pet hair from clothing. The adhesive sheets were applied to the carcass surface and then fixed to a light-blue (artists' electric blue) cartridge paper background. Earlier work on different background colors had shown that this color maximized contrast for observing and identifying different colors of hair, from white to brown to black, and particulate and fecal matter. This work also showed that leaving the samples for a minimum of 1 day before analysis allowed small particles of fat to diffuse into the cartridge paper, leaving a translucent stain that distinguished them from other foreign bodies.

Inverted dressing methods. New methods of pelt removal from lambs were investigated by visiting commercial abattoirs to study system design and the procedures used on high-throughput lamb lines. Based on the above results, processes were identified that offered scope for reducing the contamination of carcasses in small abattoirs, as well as reducing the overall work load on the slaughterman.

Ultimately, three methods of pelt removal were tested, the first of which was the traditional Cradle method described above. A summary of the sequence of slaughter and procedure used to remove the pelt for all three methods is shown in Figure 3.

The second, or Hybrid, method initially used the cradle to support the lamb while the pelt was released from the forelegs and brisket. The forelegs of the lamb were then placed in a fronting or foreleg iron, and the carcass was lifted to a vertical position at standing height using a cattle hoist, normally available in small abattoirs. In this position, the carcass is said to be inverted, its hind legs toward the floor. The pelt was pulled down from the back of the neck and shoulders to prevent in-rolling of the pelt. The flanks of the carcass were punched and the pelt released from around the shoulder so that the pelt draped downwards. A chain anchored to the floor was wrapped around the pelt, and the carcass was lifted by the hoist so that the pelt was pulled off the lower or hind end of the carcass.

The third, or Frame, method comprised a low-cost manual system that also made use of the hoist normally found in low-throughput abattoirs. The frame design allowed carcass manipulation at an optimum working position and encouraged a loose pelt to hang down and away from the carcass during the entire pelt removal procedure. The carcass was first suspended on parallel rails by the foreleg and hind leg of one side to allow the pelt to be loosened from the neck, the suspending foreleg and shoulder. The other foreleg was then hung in a second cleat, enabling the pelt to be removed from the second foreleg, neck, and brisket in the same manner. The hind leg was then released to allow the carcass to hang in the inverted position. It was then raised to an optimal working height, and the pelt was punched and allowed to hang down as in the second, Hybrid method. A chain was passed around the loose pelt, and the pelt was pulled off using a hoist via a pulley fixed to the floor.

Hand washing. The effect of hand washing to remove gross contamination from the slaughterman's hands on the final carcass appearance and on microbial contamination was examined in the second experiment. Hand washing was carried out at designated points indicated in Figure 3 for each of the three methods of pelt removal by both slaughtermen. Washing points were chosen when direct contact between the slaughterman's hands and carcass flesh was imminent, such as during punching. Hand washing, using the mobile wash stand, was carried out during pelt removal from half of the carcasses.

Inverted dressing trials. Two slaughtermen each skinned four carcasses for each of the six different treatment groups, including (i) Cradle method–no hand wash, (ii) Cradle method–hand wash, (iii) Hybrid method–no hand wash, (iv) Hybrid method–hand wash, (v) Frame method–no hand wash, and (vi) Frame method–hand wash. Before pelt removal, a swab sample of the pelt along the cut line between the foreleg and neck was taken to assess microbial contamination. Immediately after skin removal, swab samples were taken from the shoulder, abdomen (flank), and lateral surface of the rear leg for enumeration of TVC and *Enterobacteriaceae* counts, using the same microbiological techniques described above. These sites were chosen because they had a high likelihood of contact with the hide and the slaughterman's hands for the Cradle method, which would progressively decrease for the Hybrid and Frame methods. Gross, visible contamination was also assessed at the same sites using the same sampling techniques described above.

Statistical analysis. The enumeration of TVCs and *Enterobacteriaceae,* and measurements of gross visible contamination from the lambs were analyzed, and the treatments were compared by analysis of variance using the software package Genstat *(16).* In the first experiment, treatment factors were cradle designs and pelt removal methods, whereas in the second experiment, treatment factors were pelt removal methods and hand washing. The effects of using two different slaughtermen and of holding the trials over a number of days were considered in the analysis as treatment and blocking factors, respectively. Statistical significance was set at less than 0.05.

RESULTS

Carcass contamination arising from cradle dressing. The modified pelt removal procedure in the first experiment significantly reduced the mean TVC at the shoulder (Table 1) from 4.25 to 3.24 log CFU/cm^2 ($P < 0.01$) and at the abdomen from 3.36 to 2.88 log CFU/cm^2 ($P < 0.01$). The bacteria counts at the two sampling sites were also significantly different ($P < 0.01$). The cradle modifications and the slaughterman had no significant effect on the level of bacterial counts at the two sampling sites ($P > 0.05$). The counts of *Enterobacteriaceae* were low, in some instances below the minimum of 1 CFU/2cm^2 for detection, restricting the statistical analysis. The proportion of shoulder sites from which *Enterobacteriaceae* above the detection level of 1 CFU/2 cm^2 was isolated was reduced from 61 to 33% using the new dressing method. At the abdomen, the reduction was from 36 to 31%.

Quantification of the degree of gross visible contamination was based on the quantity of material adhering to the adhesive film. This was graded between 0 and 10, where 0 was equivalent to no visible contamination and 10 was the maximum seen. A graded scale was created between the two extremes using randomly drawn samples, which were subsequently used as standards in the grading. All samples, including the standards, were graded blind. Examples of the gross contamination transfer to the film and subsequent grading are shown in Figure 4.

The majority of gross visible contamination was hair; particulate matter was less common. Hair was evident either as curly, fine, loose abdominal hair or coarse hair that was cut or pulled mainly from the brisket and the legs. Measurements of gross visible contamination at the shoulder (Table 1) showed that the modified pelt removal procedure was significantly better than the conventional method ($P < 0.01$). The differences in contamination on the abdomen arising from the modified and conventional pelt removal procedures were not so marked but still significantly different ($P < 0.05$). The type of cradle used, conventional or modified, had no effect on the level of gross visible contamination both on the abdomen and shoulder ($P > 0.05$). No significant differences between the contamination scores arising from the two different slaughtermen or from the cleanliness scores of the carcasses were observed ($P > 0.05$).

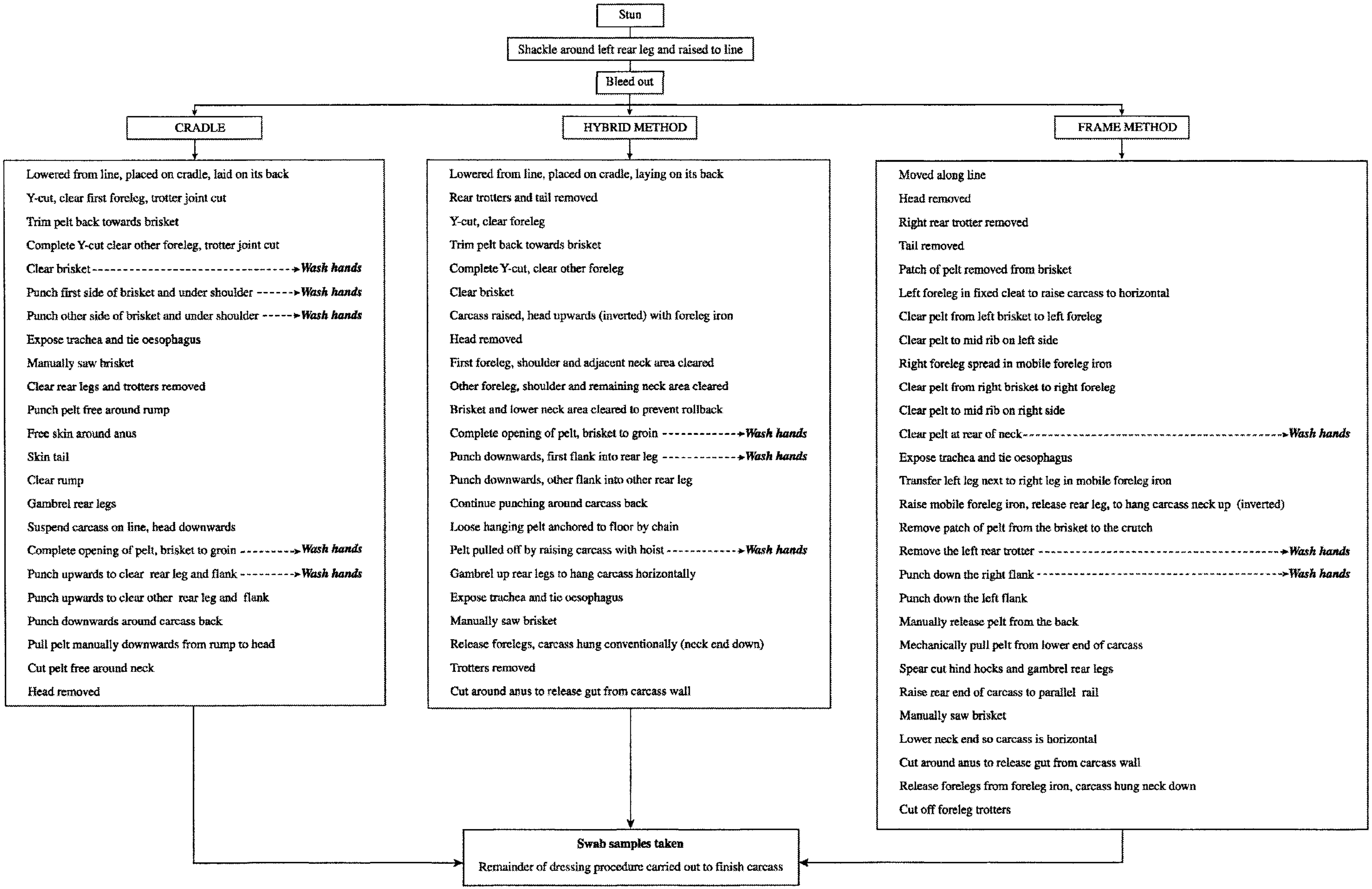


FIGURE 3. *General sequence of slaughter and dressing procedures using the Cradle, Hybrid, and Frame methods.*

TABLE 1. *Mean log total viable counts (log CFU/cm^2) and mean gross contamination scores (on a scale of 0 [no contamination] to 10 [maximum contamination]) from carcasses following pelt removal using a conventional and modified cradle according to sampling site and treatment*

	Mean log total viable counts (log CFU/cm^2)		Mean gross contamination scores	
Sample site	Old method	New method	Old method	New method
Shoulder	4.25 A[a]	3.24 B	6.8 D	1.9 EF
Abdomen	3.36 B	2.88 C	2.6 E	1.8 F
Standard error of the differences	0.1201		0.387	

[a] Means bearing the same letter are not significantly different ($P > 0.05$).

Carcass contamination arising from inverted dressing procedures. Levels of contamination along the incision lines on the carcass pelt ranged from 5 to 6 log CFU/cm^2 but had no significant effect on subsequent carcass contamination following pelt removal ($P > 0.05$). Carcasses that had their pelts removed by the Hybrid and the Frame methods had significantly lower mean TVCs of 3.65 and 4.00 log CFU/cm^2, respectively ($P < 0.05$) than those of the Cradle method, with a mean of 4.30 log CFU/cm^2 (Table 2). Moreover, the mean TVC for the Hybrid method was significantly less than that of the Frame method ($P < 0.01$). For each particular method of pelt removal, there were no significant differences between the TVCs from the three sampling sites ($P > 0.05$). Similarly, the counts of *Enterobacteriaceae* were significantly lower on the carcasses from the Frame and the Hybrid methods compared with the Cradle method, with means of 0.03, 0.14, and 0.47 log CFU/cm^2, respectively ($P < 0.01$). There was no significant difference between the mean *Enterobacteriaceae* counts on the carcasses where pelt removal was by the Frame and the Hybrid methods, nor were there significant differences between the *Enterobacteriaceae* counts from the three sampling sites for each particular method of pelt removal ($P > 0.05$). However, the counts of *Enterobacteriaceae* were low, in some instances below the minimum number of 1 CFU/2cm^2 for detection, restricting the statistical analysis.

Hand washing had no significant effect on contamination of the carcass in terms of both TVCs and *Enterobacteriaceae* for all three pelt removal methods ($P > 0.05$).

The procedure to quantify gross visible contamination was identical to that used for the first experiment, as described previously. The same standards were used again for the graded scale, and all samples were graded blind.

As before, the majority of gross visible contamination

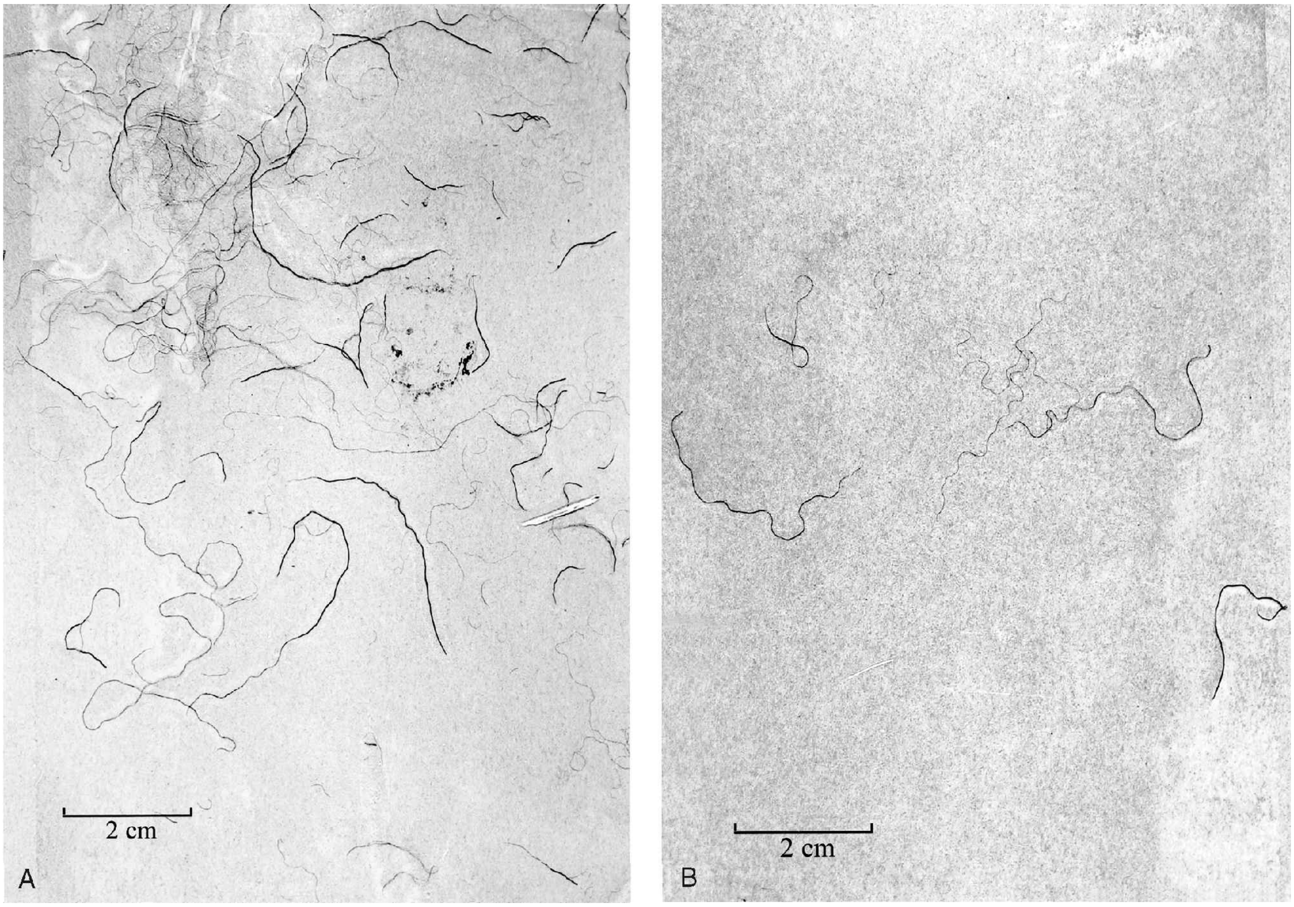


FIGURE 4. *Examples of gross contamination transfer to film. (A) High gross contamination, grading score 10 (maximum). (B) Medium gross contamination, grading score 4.*

TABLE 2. *Mean total viable and* Enterobacteriaceae *counts (log CFU/cm^2)*[a] *taken from selected sites on lamb carcasses after pelt removal using the Frame, Hybrid, and conventional Cradle methods*

	Mean total viable counts (log CFU/cm^2)			Mean *Enterobacteriaceae* counts (log CFU/cm^2)		
	Cradle	Hybrid	Frame	Cradle	Hybrid	Frame
Average for carcass	4.30 A[b]	3.65 B	4.00 C	0.47 D	0.14 E	0.03 E
Standard error of the differences		0.133			0.154	

[a] Minimum detection level is 1 CFU/2 cm^2.

[b] Means bearing the same letter are not significantly different ($P > 0.05$).

was hair, evident either as loose abdominal hair or coarse hair from the forelegs. The presence of particulate matter was less common. The best scores for the carcass flank ($P < 0.05$) and hindquarters ($P < 0.01$) were obtained using the Frame and the Hybrid methods (Table 3). The Frame method resulted in visibly less contamination of the shoulders and forelegs ($P < 0.01$) than the Cradle and Hybrid methods, although the Hybrid method resulted in less contamination of the forelegs than the Cradle method ($P < 0.01$). The Cradle method of pelt removal gave the most visibly contaminated carcass for all sites apart from the shoulder sampling site, which showed a similar contamination score to that of the Hybrid method ($P > 0.05$).

DISCUSSION

The effectiveness of slaughter hygiene can be judged by the total microbial load on the carcass at the end of carcass dressing. Counts of 3 to 4 log CFU/cm^2 are common on the carcass surface, but with care in pelt removal, counts of 2 to 3 log CFU/cm^2 can be achieved in high-throughput abattoirs *(23)*. However, counts can vary at a single abattoir from day to day and depends in the main on the cleanliness of the animal slaughtered *(18, 20, 23)*.

Pelt removal procedures. In the first experiment, significant differences were only found in microbiological and gross visible contamination resulting from a change in the pelt removal procedure, indicating that the method of handling the carcass by a single operator was the most important factor. The change of cradle design had no effect. The results obtained in this experiment are an improvement on earlier research *(18)* where alternative pelt removal techniques were only effective when soiled fleeces scoring 4 or more (as defined in the later Ministry of Agriculture, Fisheries, and Food guidelines *(2)*) were encountered.

TABLE 3. *Mean gross contamination scores (on a scale of 0 [no contamination] to 10 [maximum contamination]) taken from selected sites on lamb carcasses after pelt removal using the Frame, Hybrid, and conventional Cradle methods*

	Mean gross contamination scores		
Method	Cradle	Hybrid	Frame
Shoulder	4.3 A[a]	3.4 AB	1.7 DE
Flank	2.7 BE	1.4 D	1.6 DE
Hindquarters	5.6 C	0.8 D	0.7 D
Lower foreleg	9.0 F	6.3 CG	4.4 A
Standard error of the differences for different sites		0.580	

[a] Means bearing the same letter are not significantly different ($P > 0.05$).

Changes in procedures for pelt removal by other researchers have also been shown to be beneficial in reducing carcass contamination. The removal of a patch of skin from the perineal area was found to reduce visible as well as microbial fecal contamination but slightly increased wool contamination. This was also found to be more effective with shorn lambs, indicating the potential additive effect of different solutions *(8)*. This is supported by research that showed that shearing lambs prior to slaughter had a beneficial effect in reducing surface bacterial counts of the finished carcass *(27)*, and the authors go on to recommend shearing the carcass after bleed-out. However, our experience of this practice, when a single slaughterman carries out all the dressing procedures, was that the carcass became contaminated with fine particles of wool arising from the shearing process. In comparing the carcass surface bacteria counts from clean shorn and dirty unshorn sheep, researchers also found that washing unshorn sheep immediately before slaughter increased the total aerobic counts from a mean of 3.93 to 4.63 log CFU/cm^2 *(5)*. Washing shorn sheep was also found to increase the carcass surface bacteria counts *(6)*. Experiments elsewhere in a research abattoir showed no significant differences in contamination of the carcasses between lambs that had dry, short fleeces and dry, long fleeces, further indicating that the water content of the fleece is an important factor in microbiological loading and facilitation of cross-contamination *(11, 25)*.

Inverted dressing methods were examined in the second experiment. The major factors in the Hybrid and Frame methods that favored the production of a microbiologically and visually cleaner carcass during pelt removal were (i) the pelt removal operation started at the cleaner end of the carcass and moved downward to the more contaminated rear end, (ii) the inverted vertical position of the carcass using the Frame method allowed the pelt from around the shoulder region to hang down and away from the carcass, and (iii) the final removal of the pelt from the rear end of the carcass inverted the pelt, as a sock is removed, and avoided fleece–carcass contact.

The introduction of inverted dressing of sheep has been found to reduce carcass microbiological contamination compared to conventional dressing *(4),* but reductions in total aerobic counts were considered only to be of significance if the difference exceeded 0.5 log units *(15).* In this study, differences greater than 0.5 log units in total viable counts were found between the conventional Cradle dressing method and the inverted Hybrid method, but not for the Frame method. This result was surprising and could be due in part to less experience with the Frame method compared with the Cradle and Hybrid methods. In a study of conventional and inverted dressing of sheep carcasses at different abattoirs, the size of reduction in numbers of total aerobes after inverted dressing was found to vary between 0.5 and 1.0 log units for selected abdominal and chest ventral sites and greater than 1.0 log units for dorsal sites, including the perianal area. However, *E. coli* numbers were found to increase with inverted dressing *(4).* In contrast, inverting the carcass was considered to have an insignificant effect on the total aerobic count when random sites were selected according to a grid pattern applied to a carcass side, but 1.5 log unit reductions in coliform enumerations were considered significant *(15).* These contradictory results are attributed to the use of differing procedures in different abattoirs, the difficulty in making valid microbiological comparisons between different slaughter procedures, and the possible carcass-to-carcass variation arising from the differing levels of animal cleanliness prior to slaughter *(20).* As with the numbers of *Enterobacteriaceae* in the experiments reported here, the low numbers of *E. coli* detected reduced the reliability of analysis. The reductions in coliforms, most of which were *E. coli,* from the inverted dressing procedure were considered important because they were recovered from sites that would have been heavily contaminated at the rear end of conventionally dressed carcasses *(15).*

Gross, visible contamination assessment. The visual scoring system developed during the course of this series of experiments was a useful tool for measuring the gross visible contamination on carcasses when comparing different methods of pelt removal.

The degree of gross visible contamination at the carcass sampling sites closely reflected the contact that was likely to occur between the carcass and the hands of the slaughterman or the fleece. The lower foreleg was found to be the most grossly contaminated with cut coarse hair for each of the methods of pelt removal, and this reflected the difficulty in preventing the initial high levels of contamination that occurred when the first cuts were made through the fleece to penetrate the pelt. The removal of a patch of skin (“patching”) from the forelimbs during the early stages of pelt removal also resulted in contamination by cut hairs.

Similar procedures between methods, such as clearing the pelt from the shoulders during the Cradle and Hybrid methods, gave similar results of gross visible contamination at the shoulder. Similarly, pulling the pelt off mechanically in the Frame and Hybrid methods with the aid of a hoist eliminated the need for contact between the carcass and the slaughterman’s hands, resulting in similar low gross visible contamination scores.

Although a similar technique was used for both the Cradle and Hybrid methods to remove the pelt from the forelimbs, the skinned forelimbs were handled more during the Cradle method because more operations were carried out on the cradle. The Frame method steadied the foreleg by anchoring the foot in a cleat, removing the need for the slaughterman to touch the foreleg. This operation was also carried out at chest height, making the procedure physically easier and allowing the loose pelt to hang away from the carcass.

Recently introduced guidelines on cleanliness of animals presented for slaughter reduced the degree of pelt contamination allowed *(1),* which hindered the development of a full-range scale for gross contamination. Correlation between the microbiological contamination of the finished carcass and the level of gross contamination was not possible because minor changes in TVC and *Enterobacteriaceae* (i.e., less than 1 log CFU/cm^2) were accompanied by large changes in gross visible contamination scores from a partial-range scale (Tables 1 and 3). Whereas our scoring system gave equal weighting to all gross visible contamination, other research used a method of weighting contamination according to its origin and size, with fecal contamination scoring highly *(8).* Intuitively, this method would appear to improve the correlation between gross visible and microbiological contamination. However, the same authors warn against the use of gross visible contamination as a measure of microbial contamination, having found an inverse relationship between visible fecal contamination of the carcass and microbiological status *(5, 9).* In most of our samples, the major gross contaminant was wool; fecal material rarely was seen, which is consistent with the results of *Enterobacteriaceae* counts that we obtained.

Hand washing. Second to fleece, the slaughterman’s hands are considered to be a major source of carcass contamination and of carcass-to-carcass cross-contamination in low-throughput abattoirs *(4, 19).* Thorough cleaning of hands, arms, and apron before and during the pelt removal process has been shown to reduce carcass contamination with marker organisms *(19).* Investigations by others showed that although a 44°C hand rinse removed 90% of microbial contamination, the rinsed hands still carried a microbial population in excess of 4 log CFU/cm^2 *(4).* During pelt removal operations, slaughtermen were observed cleaning their hands by holding them under running water, to remove gross visible contamination, and shaking them, to remove the majority of the water. It is therefore no surprise that in the second series of experiments, no significant advantage was gained by hand washing in terms of microbiological contamination. Also, no significant advantage was gained in terms of gross visible contamination, probably because loose material readily adhered to the wet hand surfaces. The use of bactericidal soap and thorough drying of the hands is advocated to show improvement in hand cleanliness and a reduction in contamination source *(10).*

Changes in the procedure of pelt removal were the most effective method of reducing microbiological and gross visible carcass contamination for low-throughput abattoirs, mainly through the adoption of inverted dressing methods. These effects result from both the reduction of direct contact between the carcass and the slaughterman and the strategy of removing the pelt from the cleanest to the most contaminated end of the fleece. The Frame method used in these experiments offers the best results in terms of reduced gross visible contamination because it has the least amount of contact between the slaughterman and the carcass. The Frame method also offers greater potential for reducing contamination further. This can be achieved by carrying out the high- and low-risk operations separately; for example, if more than one slaughterman is available, the operations can be separated into left hand only and right hand only carcass contact, as is found on high-throughput inverted lines.

ACKNOWLEDGMENTS

This research was funded by the UK Ministry of Agriculture, Fisheries, and Food (now Department for Environment, Food, and Rural Affairs). Thanks are due to Mr. C. Goodland of Stourton Leaze Abattoir, Sherborne, Dorset, UK, for permission to use the Frame system design and to the abattoir staff at Bristol University.

REFERENCES

1. Anonymous. 1997. Clean livestock Policy. MHS Operations Manual, Chapter 4. Meat Hygiene Service, York, UK.
2. Anonymous. 1998. Clean sheep for slaughter. A guide for farmers. Ministry of Agriculture, Fisheries and Food PB 4103, London, UK.
3. Anonymous. 1999. Microbiology of food and animal feeding stuffs—carcass sampling for microbiological analysis. British Standards Institution ISO/CD 17604, London, UK.
4. Bell, R. G., and S. C. Hathaway. 1996. The hygiene efficiency of conventional and inverted lamb dressing systems. J. Appl. Bacteriol. 81:225–234.
5. Biss, M. E., and S. C. Hathaway. 1995. Microbiological and visible contamination of lamb carcasses according to presentation status—implications for HACCP. J. Food Prot. 58:776–783.
6. Biss, M. E., and S. C. Hathaway. 1996. Effect of pre-slaughter washing of lambs on the microbiological and visible contamination of carcases. Vet. Rec. 139:82–86.
7. Biss, M. E., and S. C. Hathaway. 1996. Microbiological contamination of ovine carcasses associated with the presence of wool and faecal material. J. Appl. Bacteriol. 81:594–600.
8. Biss, M. E., and S. C. Hathaway. 1996. The effect of different on-line dressing practices on microbiological and visible contamination of lamb carcasses. N.Z. Vet. J. 44:55–60.
9. Biss, M. E., and S. C. Hathaway. 1998. A HACCP based approach to hygienic slaughter and dressing of lamb carcasses. N.Z. Vet. J.. 46:167–172.
10. Brohagen, P. 1999. The danger of poor hand hygiene. Int. Food Hyg. 9(8):5–7.
11. Field, R. A., N. Kalchayanand, M. Rozbeh, and M. K. Andersen. 1992. Influence of a pelt puller on microbiological quality of lamb. SID Res. J. 7:24–26.
12. Gill, C. O. 1979. Intrinsic bacteria in meat. J. Appl. Bacteriol. 47: 367–378.
13. Gill, C. O. 1998. Microbiological contamination of meat during slaughter and butchering of cattle, sheep and pigs, p. 118–157. *In* A. Davies and R. Board (ed.), The microbiology of meat and poultry. Blackie Academic and Professional, London.
14. Gill, C. O., and L. P. Baker. 1998. Assessment of the hygienic performance of a sheep carcass during dressing. J. Food Prot. 61:329–333.
15. Gill, C. O., J. Bryant, and D. A. Brereton. 2000. The microbiological conditions of sheep carcasses from conventional or inverted dressing procedures. J. Food Prot. 63:1291–1294.
16. Genstat 5 Committee. 1998. Version 5 for Windows, release 4.1. Clarendon Press, Oxford, UK.
17. Grau, F. M. 1986. Microbial ecology of meat and poultry, p. 1–47. *In* A. M. Pearson and T. R. Dutson (ed.), Advances in meat research, vol. 2. AVI Publishing, Westport, Conn.
18. Hadley, P. J., J. S. Holder, and M. H. Hinton. 1997. Effects of fleece soiling and skinning method on the microbiology of sheep carcasses. Vet. Rec. 140:570–574.
19. Hudson, W. R., G. C. Mead, and M. H. Hinton. 1998. Assessing abattoir hygiene with a marker organism. Vet. Rec. 142:545–547.
20. Ingram, M., and T. A. Roberts. 1976. The microbiology of the red meat carcass and the slaughterhouse. R. Soc. Health J. 6:270–276.
21. Kelly, C., B. Lynch, and A. McLoughlin. 1982. The effect of spray washing on the development of bacterial numbers and storage life of lamb carcasses. J. Appl. Bacteriol. 53:335–341.
22. Kitchell, A. G., G. C. Ingram, and W. R. Hudson. 1973. Sampling—microbiological monitoring of environments, p. 43–61. *In* R. G. Board and D. W. Lovelock (ed.), Society for Applied Bacteriology Technical Series 7. Academic Press, London.
23. Mackey, B. M., and T. A. Roberts. 1990. Hazard analysis and critical control point programmes in relation to slaughter hygiene, p. 3–18. *In* J. Hannan and J. D. Collins (ed.), The scientific basis for harmonising trade in red meat. Proceedings of Round Table Conference of the World Association of Veterinary Food Hygienists, Dublin. University College, Dublin.
24. Miles, A. A., S. S. Misra, and J. O. Irwin. 1938. The estimation of the bacterial power of the blood. J. Hyg. 38:732–749.
25. Newton, K. G., J. C. L. Harrison, and A. M. Wauters. 1978. Sources of psychrotrophic bacteria in the abattoir. J. Appl. Bacteriol. 45:75–82.
26. Nottingham, P. M. 1982. Microbiology of carcass meats, p. 13–65. *In* M. H. Brown (ed.), Meat microbiology. Applied Science Publishers, London.
27. Schroder, B., and C. Ring. 1998. Minimising the bacterial count on lamb carcasses by means of slaughtering methods. Fleischwirtschaft 78:641–646.
28. Severini, M., M. Trevisani, and A. R. Loschi. 1994. Pelt removal in lambs: the issue of air inflation. Meat Focus Int. (November):449–451.
29. Sierra, M.-L., E. Gonzalez-Fandos, M.-L. García-López, M. C. G. Fernandez, and M. Prieto. 1995. Prevalence of *Salmonella, Yersinia, Aeromonas, Campylobacter* and cold- growing *Escherichia coli* on freshly dressed lamb carcasses. J. Food Prot. 58:1183–1185.
30. Smith, D. R., and G. Rogers. 1993. Trials on air assisted pelting of ovine carcasses. C.S.I.R.O. Meat Research Laboratory and Australian Meat and Livestock Corporation, Cannon Hill, Australia.