Importance of Airborne Contamination during Dressing of Beef and Lamb Carcasses

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ABSTRACT

Carcasses along slaughter lines were exposed to normal slaughterhouse air or ultraclean air provided from a unit fitted with a HEPA filter. In cattle slaughterhouses, aerobic viable counts were measured by sponging the brisket at the end of the line to determine whether the slaughterhouse air had led to contamination of the carcasses. Furthermore, a replica cattle carcass with settle plates attached was exposed to similar conditions. The greatest contamination of the plates occurred at the hide puller (P < 0.01). The use of ultraclean air reduced the deposition of organisms onto settle plates (P < 0.01). The airborne route contributed to contamination in cattle slaughterhouses, but other vectors were more important. Further study of contamination of the brisket, at the time that it was first exposed, showed that knives transfer contamination from the hide. The use of ultraclean air at this position showed that the airborne route was a contributor to contamination (P < 0.1), but it was not the greatest vector. In lamb slaughterhouses, the highest counts on settle plates were found at the fleece puller (P < 0.05). The highest counts on the lamb carcasses were found on the brisket exposed from the start of the line to just after the fleece puller (P < 0.05). There was no clear relationship between the measured counts and the concentration of organisms in the air, indicating that the airborne route in lamb slaughterhouses contributes less to carcass contamination than do the surface contacts.

The role of the airborne route in the contamination of beef and lamb carcasses during dressing is unclear. For cattle, Newton et al. (7) concluded that “the bacterial load on hides had an overwhelming influence on (the load on) carcasses after dressing,” but they did not state whether the airborne route or surface contacts were transferring the contamination. Roberts (10) reasoned that the deposition rate of airborne particles is so low, compared to the numbers on equipment and operatives, that the air is not the main route of contamination during dressing unless there is no contact between contaminated surfaces and carcasses. Vel-lacott (13) also concluded that the highest rate of contamination on settle plates (2.0 log CFU cm⁻²) would be insufficient to produce a significant rise in surface counts on carcasses as they pass along the line. Fournaud and Beraud (2) measured total aerobic viable counts on beef carcasses and settle plates and found no correlation between them. They also concluded that the airborne route was not the main vector of contamination but that it could become more important if the concentration of airborne organisms was high and the flesh was not previously contaminated. More recently, Prendergast et al. (8) found a poor correlation between air and carcass counts, and they suggested that it was difficult to demonstrate the contribution of the airborne route to carcass contamination. However, these views are not supported by Rahkio and Korkeala (9), who concluded that “airborne bacteria have an important role in (beef) carcass contamination,” and they found a strong association between carcass and air contamination. They also reported on an article by Sirami (11), who also found associations between airborne and carcass contamination.

For lamb, Grau and Smith (3) concluded that the fleece is a significant source of contamination of lamb carcasses. Salmonellae found on the brisket were thought to come mostly from the wool during the opening of the fleece. They also concluded that “presumably” the contamination of the rib area was from dust shaken out of the fleece during pulling. Bettelheim (1) found different strains of Escherichia coli at the beginning and end of a lamb dressing line. Strains found at the end of the line were typical of human sources, but the route of contamination—direct contact with operators, indirect contact with surfaces contaminated by operators, or airborne transfer—was not identified. Roberts (10) stated that shearing the crutch of lambs did not necessarily decrease carcass contamination if good practices were used. Hadley et al. (4) suggested that contamination can be transferred by many routes, including the air. They found that total aerobic counts increased with the amount of soiling on the fleece. Most authors conclude that the fleece is the greatest source of contamination, but none, to our knowledge, define the contribution of the airborne route to lamb contamination.

Previous studies have generally measured the numbers of microorganisms on carcass flesh and the concentration

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of organisms in the air, and a correlation has been sought between them. The problem with this approach is that the concentration of organisms in the air does not always vary greatly, and so finding a high level of statistical correlation between air and surface counts is difficult. Furthermore, the microbial counts on carcasses are highly variable, although some workers have used settle plates to achieve more reproducible measurements of deposition rates.

In this study, ultraclean air from a HEPA unit was directed onto a carcass as it moved along the dressing line. The aim was to produce much lower concentrations of airborne organisms than usual near the carcass during dressing and to assess whether this had an effect on the microbial counts on the carcass. In addition, a dummy carcass with settle plates attached was treated in the same way to provide reproducibility, and its surfaces were not touched by operators as it passed along the line. If the plates were contaminated, even though ultraclean air had been applied, then it is likely that the contamination would have arisen from large ballistic particles passing through the clean air zone. Tests were carried out with and without the use of ultraclean air to provide a range of microbial concentrations in the air. Studies were carried out in two cattle slaughterhouses and two lamb slaughterhouses. Studies in one of the cattle slaughterhouses also aimed to identify the position at which the brisket was contaminated and to assess the role of knives in the transfer of contamination.

The present study did not propose that ultraclean air be used in practice to reduce airborne contamination in slaughterhouses. Such air was used solely to provide a difference in the concentration of airborne organisms for the experimental approach. More practical methods of reducing airborne contamination could be proposed if the airborne route were found to be significant.

**MATERIALS AND METHODS**

Tests were carried out on two beef (CS1 and CS2) and two lamb (LS1 and LS2) dressing lines. The dressing line of CS1 was a straight-line system with all operations at one level, including the following: removal of the hooves, first incision of the hide, further opening of the hide, hide pulling (upward puller), evisceration, carcass splitting and light washing of the split, and final trimming. Slaughterhouse CS2 was much newer, but it had the same operations and was also a straight-line system. On dressing line LS1, carcasses were suspended horizontally by all four legs during hand punching and subsequent mechanized fleece pulling when the fleece was pulled from head to tail. The dressing line rose to a high level immediately downstream of the fleece puller. The carcasses were suspended by just the forelegs about 5 m downstream of the fleece puller, where the line height dropped to normal level. The line reversed back on itself (serpentine line) several times along its length. On dressing line LS2, some initial patching and freeing of the brisket were carried out before the carcasses were transferred from a static line to an indexed line. The carcasses were then suspended horizontally, and operators began to free the fleece and clear the legs. The carcasses were suspended from the forelegs just before power punching and mechanized fleece removal, again from head to tail. The carcasses were then rehung from the rear legs prior to evisceration and final inspection. The line was all on one level and in a fairly straight run.

Figure 1 shows the position of the HEPA unit used in cattle slaughterhouse CS1 as it moved along the dressing line, directing ultraclean air toward the carcass ahead of it. The unit (Portable Vertical Microvent Unit, Filtration Engineering, Sandbach, Cheshire, England) delivered ultraclean air at 1 m s\(^{-1}\) through a diffuser measuring 0.75 by 0.75 m. Figure 2 shows the dummy half-carcass that was produced by measuring the dimensions of a real carcass and creating a replica from Styrofoam, which was then covered in industrial cleaning cloths, coated with polyvinyl alcohol glue, and finally painted. A steel eye at the end of the upper, rear leg allowed the replica to be hung on the shackles line.

A smaller HEPA unit (Fig. 3) was used in cattle slaughterhouse CS2 to deliver ultraclean air closer to the brisket than was possible with the larger unit, and it was also used in the lamb slaughterhouses. This unit (Portable Vertical Microvent Unit, Fil-
FIGURE 3. Photograph of small HEPA unit with flexible ducting attached.

Measurements along the dressing line with ultraclean air in CS1. These tests were similar to those just described, except that the carcass under test was followed down the line by the HEPA unit. Seven tests were carried out with the replica, and nine tests were carried out with the real carcasses. These were the maximum numbers of tests that could be carried out in the time available. The tests alternated between the replica and real carcasses, and all tests were carried out in cattle slaughterhouse CS1.

Measurements at the hide puller in CS1. Some further tests were carried out in CS1 to assess carcass contamination at the hide puller. The brisket of a carcass was sponged (four areas measuring 10 by 10 cm) just before the hide puller, and the opposite brisket was sponged as soon as the carcass was released from the hide puller. These tests were repeated five times. For further tests at the hide puller, as the hide was being removed, an area of the flank that had not been touched by anything was sponged. The carcass in this region would therefore have had no direct surface contamination and little exposure to airborne contamination.

Tests to assess the roles of air and knives in carcass contamination in CS1 and CS2. Tests to assess the roles of air and knives in carcass contamination were carried out in both cattle slaughterhouses. Ultraclean air was delivered closer to the brisket than before with the smaller HEPA unit. Also, unlike during the earlier tests, the briskets were sponged immediately upon exposure. The tests were carried out prior to the hide puller at the position of the operator, who made the first incision of the centerline of the hide and the first knife movements along the brisket. The tests were carried out with and without the use of ultraclean air and with knives that belonged to the slaughterhouse (slaughterhouse knives) or with presanitized knives provided by us.

In the tests with slaughterhouse knives and no ultraclean air, the operator used a slaughterhouse knife to make the first incision along the centerline of the carcass and then used a second knife to expose the left- and then the right-side brisket. A sterile sponge was then wiped along both faces of this knife. The sponges were treated as in earlier tests (transported [with more diluent added], stomached, and plated). The concentration of airborne organisms was measured near the brisket, around 20 to 30 cm from its surface, with the impaction sampler, with plates exposed for 10 s. Each test was carried out 10 times.

For the tests with sanitized knives and no ultraclean air in cattle slaughterhouse CS1, the operator was provided with knives that had been washed and then soaked for 24 h in a disinfectant (7% solution of Quattet Clear, DiverseyLever, Nottingham, UK). After soaking, the knives were rinsed in sterile water, put in a sanitized bucket, and placed in a sterile plastic bag. The knives used for the tests in cattle slaughterhouse CS2 were sanitized by autoclaving with a pressure of 105 Pa in sealed wrappers. A sanitized knife was used to make the first incision along the centerline of the carcass, and the knife was sponged. A second sanitized knife was then used on the left side of the carcass, and it was sponged after the operator had finished using it. The left-side brisket was also sponged immediately upon exposure. A third sanitized knife was then used on the right side of the carcass, and the knife and brisket were sponged as for the left side. The concentra-
tration of organisms in the air was also measured as for the tests with slaughterhouse knives. All tests were carried out 10 times.

**Tests with slaughterhouse air in LS1 and LS2.** A 9-cm-diameter settle plate containing nutrient agar was attached by Velcro pads to a region of the dummy carcass representing the brisket. The plate cover was removed at a position where the brisket of a real carcass would have been exposed. The dummy carcass was held by a person and moved along the line as if the replica were a real carcass. The plate cover was replaced just before the fleece puller, and the exposure time was recorded. This plate was removed and replaced with one that was immediately uncovered and exposed until just after the fleece puller. A further plate was then located at the position of the rump. The plate was exposed until the end of the line, just before the final wash and inspection. The plates were placed in a cool box, and for tests in LS1, they were incubated at a laboratory later that day. For tests in LS2, which was a long distance from the laboratory, the plates were taken to the laboratory in a cool box and then stored overnight at 2 to 4°C prior to incubation. During the tests, the concentration of airborne organisms next to the replica was measured at four positions: where the brisket was first exposed, just before and just after the fleece puller, and just before the final wash and inspection. The 55-mm-diameter sample plates contained nutrient agar and were exposed for 5 s.

For tests with real lamb carcasses, the left-side brisket was sponged just as the brisket was exposed, and the right-side brisket was sponged just after the fleece puller. The left-side rump was sponged just after the fleece puller, and the right-side rump was sponged at the end of the line prior to the final wash and inspection. These specific sides were chosen, as opposed to the tests alternating between the left and right sides, because of the limited access to the sides at certain points along the lines. The sponges were treated as for tests with cattle but were used over an area measuring 7 by 7 cm. For the first test in LS1, the replica was used, and for the second test, a real carcass was used. For all further tests in LS1 and LS2, the replica and adjacent real carcass were simultaneously tested in each run. Ten runs with the replica and 10 runs with the real carcasses were carried out in each slaughterhouse.

**Tests with ultraclean air in LS1 and LS2.** These tests were the same as those just described, except that the small HEPA unit was moved alongside the line to direct ultraclean air at the replica or real carcass. In LS1, it was impossible to provide clean air directly onto the carcass along the entire length of the line because of the line layout. About 5 m beyond the fleece puller, the dummy and real carcasses were exposed to slaughterhouse air for 20 s because of the extra height of the line and location of equipment. Ten tests with the replica and 10 tests with the real carcasses were carried out in LS1. Eight tests were carried out with the replica, and nine tests were carried out with the real carcasses in LS2.

**RESULTS AND DISCUSSION**

**Measurements along the dressing line in cattle slaughterhouse CS1.** Figure 4 shows the aerobic viable counts from the settle plates and sponges. Although comparisons should not be made between settle plate and sponge data, this figure does allow the information to be shown on one graph. Much of the data measured during tests with the HEPA unit and settle plates cannot be shown on this logarithmic scale, as no organisms were detected in many of those tests. Of the 28 measurements of deposition onto settle plates at the hide puller, only five showed a detectable presence of organisms, and in the measurements beyond the hide puller, organisms were detected on only 9 of the 28 plates.

The settle plate data form into groups, with the lowest counts and airborne concentrations found when the ultraclean air had been used after the hide puller. The next highest counts were found with the ultraclean air applied before and at the hide puller, and the next highest were found...
TABLE 1. Average total aerobic viable counts on the brisket, and the concentration in the air, in cattle slaughterhouses CS1 and CS2; the measurements were made after exposure with or without the use of the HEPA unit and with slaughterhouse or presanitized knives

<table>
<thead>
<tr>
<th>Condition</th>
<th>Avg count, log CFU/sponge ± 1 SD</th>
<th>Avg concn, log CFU m⁻³ ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>No HEPA, slaughterhouse knives</td>
<td>3.0 ± 1.1</td>
<td>4.9 ± NA³</td>
</tr>
<tr>
<td>No HEPA, presanitized knives</td>
<td>3.3 ± 0.8</td>
<td>4.9 ± NA³</td>
</tr>
<tr>
<td>HEPA, slaughterhouse knives</td>
<td>2.5 ± 0.7</td>
<td>3.8 ± 0.2</td>
</tr>
<tr>
<td>HEPA, presanitized knives</td>
<td>2.1 ± 0.7</td>
<td>3.6 ± 0.3</td>
</tr>
<tr>
<td>Flank immediately after exposure and no contact with knives</td>
<td>1.1 ± 1.0</td>
<td>—</td>
</tr>
</tbody>
</table>

Values are averages ± standard deviations; n = 10 in all tests, except for measurements on the flank in CS1, when n = 20.

a These tests included plates in which all of the holes were positive, and therefore, the concentration was 87,600 CFU m⁻³ or greater; the exact concentration is unknown. NA, not available.

b In CS1, 6 of the 20 sponges showed no organisms. In CS2, 4 of the 10 sponges showed no organisms. In these cases, the CFU per sponge was taken as log(minimum number of organisms detectable/2), i.e., log(½).

dposthide puller without the use of ultraclean air. The settle plate counts reduced with decreasing airborne concentrations of organisms, indicating that the airborne route will contribute to contamination. Statistical analysis (Genstat, VSN International Ltd., Hemel Hempstead, UK) showed that the use of ultraclean air reduced the rate of deposition (P < 0.01), and the rate of deposition from the start of the line to just before the hide puller was significantly greater than after the hide puller (P < 0.01).

There is a large spread in the concentration of airborne organisms measured at the hide puller during the tests with the dummy carcass, with counts of up to 4.7 log CFU m⁻³. This is the highest concentration that could be measured with the impaction sampler at the exposure time used in the test; higher concentrations may have occurred. The cause of the particularly high counts in some tests is not known, but it is possible that the hide puller can, on some occasions, release very large numbers of organisms from the hide. The deposition rates on the plates exposed from the start of the line to just after the hide puller were around 10-fold greater than beyond the hide puller. These deposition rates range upward to about 1.3 log CFU cm⁻² h⁻¹, but beyond the hide puller, the maximum count was about 0.5 log CFU cm⁻² h⁻¹. Fournaud and Bertaud (2) measured slightly higher rates of 1.4 to 1.9 log CFU cm⁻² h⁻¹ at the dressing site and 0.8 to 1.7 log CFU cm⁻² h⁻¹ at the evisceration site.

Figure 4 shows the total aerobic viable counts recovered from sponges versus the average of the three measurements of airborne organisms measured along the line. The use of ultraclean air has clearly reduced the airborne concentration, but it has had no clear effect on the sponge counts. No statistically significant difference was found between the counts obtained with or without the use of ultraclean air. This may have been due to the HEPA unit having failed to greatly reduce the concentration of airborne organisms, possibly because the hide acted as a source of organisms within the clean air zone created by the HEPA unit. Sponge counts ranged from 1.2 to 4.7 log CFU cm⁻² h⁻¹, with an average of around 3 log CFU cm⁻² h⁻¹. The exposure time of the brisket in one test was 54 min, but in all other tests, the time was between 14 and 20 min, with an average of 16 min. On the basis of the average count and exposure time, the average deposition was 2.4 log cm⁻², which is similar to the average values found by Prendergast et al. (8) (2.5 and 2.6 log cm⁻²) on cattle brisket at the end of the line.

Measurements at the hide puller (brisket in slaughterhouse CS1). No significant difference was found between the sponge counts taken just before and after the hide puller in CS1. The average counts pre- and post-hide puller were 3.4 and 2.8 log CFU cm⁻² h⁻¹, respectively, with standard deviations of 0.8 and 1.3. This suggests that the brisket became contaminated as soon as it was exposed.

Tests to assess the roles of air and knives in carcass contamination prior to the hide puller (CS1 and CS2). Table 1 shows the average total aerobic viable counts taken from the brisket with and without the use of ultraclean air and with slaughterhouse or presanitized knives in both slaughterhouses. Table 1 also shows the counts taken from the flanks of the carcasses as soon as the flank was exposed and not touched. These results indicate that the airborne route is important at this point along the dressing line; however, there is considerable scatter in the data. Statistical analysis of the data from the tests in CS1 was carried out, considering the sampling completely randomized, and this showed a significant difference (P < 0.05) between the counts on carcasses treated with and without ultraclean air. However, for logistical reasons in slaughterhouse CS1, tests could only be carried out in blocks (with or without ultraclean air and with or without slaughterhouse knives). With the tests not being randomized, no true “replication” was available to give an independent estimate of residual variability. Analyzing the results together from the two slaughterhouses allowed an estimate of residual variability. This analysis showed a significant effect of the use of ultraclean air but only at the level of P < 0.1. Had it been possible to carry out fully randomized experiments, then the differences would likely have been found with greater confidence.

The use of presanitized knives, compared to slaughter-
house knives, did not have an obvious effect on the sponge counts in CS1. In CS2, the average counts on the brisket after the use of the presanitized knives were higher than those found after the use of the slaughterhouse knives. The line speed during those tests was quite high, and the operator often struggled to use the presanitized knives with ease.

Table 1 shows the average concentrations of airborne aerobic viable counts. In the tests without the use of the HEPA unit, most of the plates from the air sampler showed all of the holes of the sampler as positive, indicating that the concentration of organisms was 4.9 log CFU m$^{-3}$ or greater. The exact value could not be determined, and no standard deviation can be given. The results do, however, show that the use of the HEPA unit successfully decreased the concentration of organisms in the air.

Figure 5 shows the total aerobic viable counts recovered from the sponges used on the knives in CS1. The data for sanitized knife 1 and the first factory knife are shown together because they are the first knives used. Similarly, sanitized knife 3 and the second factory knife are shown together, being the last knives used. The first knife used was the most contaminated. The average counts on the knives were lower after the tests with ultraclean air, but the difference was not significant and would not be expected to be so, because it is likely that more contamination of the knives would come from the hide than from the air.

Figure 6 shows the microbial counts at various positions along the line. Those counts at first cut, pre- and post-hide, and end of line were obtained from the brisket, whereas those labeled “No Contact” were obtained from the flank just after exposure. Apart from two cases, counts from the flank were below 100 CFU per sponge (<1 cm$^{-2}$). For the two cases in which higher counts were found, it may be that some larger (ballistic) airborne particles had landed on the surface being swabbed. The counts on the brisket increased up to just before the hide puller and then remained almost constant. This indicates that the brisket became contaminated prior to the hide puller. Further contamination was not detected, because the counts on the carcasses were already high, and the air or surface contacts did not add sufficient organisms to be noticeable. Alternatively, it may be that the sampling method could not recover higher numbers. Mackey and Roberts (6) suggested that swabbing gives an adequate assessment of carcass contamination, whereas Ingram and Roberts (5) found that swabbing recovers a variable percentage, with recoveries as low as 1%.

The first incision of the hide led to contamination of the flesh, and further research, such as that described by Small et al. (12), should focus on reducing the transfer of contamination from the hide to the flesh. If procedures could be found to reduce the contamination of the brisket before the hide puller, then it is likely that significant increases in contamination from the airborne route would be found at the hide puller.

Measurements along the dressing line in lamb slaughterhouses LS1 and LS2. Table 2 shows the average rates of deposition of organisms onto the settle plates on the replica carcass in the two lamb slaughterhouses. In both cases, the highest counts were found at the fleece puller, and statistical analysis showed that the rate of deposition at the fleece puller was greater than elsewhere ($P < 0.05$). However, there was no significant effect of the use of the HEPA unit. In many of the tests when the HEPA unit was used, the deposition rates on settle plates were low, but occasional plates would show a very high count. These high counts could result from larger ballistic particles, containing organisms, passing through the clean air zone and landing on the plates.
Table 2 also shows the organism deposition onto carcass flesh assessed with sponges in the two slaughterhouses. The rate of deposition was greater between the start of the line and just after the fleece puller than from just after the fleece puller to the end of the line ($P < 0.05$), on the basis of an analysis of the data from both slaughterhouses. The counts from the brisket, exposed from the start of the line to just after the fleece puller in LS1, are 1.5 log greater than from the briskets exposed in LS2. This could result from the carcasses in LS1 being changed from a four-point to a two-point suspension at the fleece puller, leading to the carcasses swinging violently. Also, carcasses with their fleeces still on were passing along the line close to exposed carcasses, because of the serpentine layout of the dressing line in LS1.

In LS1, the average count from the start of the line to just after the fleece puller, when the HEPA unit was not used, was $3.5 \log \text{CFU cm}^{-2} \text{h}^{-1}$. The average exposure time from the start of the line to just after the fleece puller was 228 s, and so the approximate average count was $2.6 \log \text{CFU cm}^{-2}$. Hadley et al. (4) found average values within the range from 2.2 to $5.5 \log \text{CFU cm}^{-2}$. In LS2, the average count was about $1.1 \log \text{CFU cm}^{-2}$. Although the average exposure time was 496 s, the first five carcasses...

Table 2. Average total aerobic viable counts on settle plates, the briskets of carcasses, and the concentration in the air in lamb slaughterhouses LS1 and LS2; the measurements were made after exposure with or without the use of the HEPA unit$^a$

<table>
<thead>
<tr>
<th>Condition</th>
<th>Avg count, log CFU cm$^{-2}$ h$^{-1}$/sponge $\pm$ 1 SD</th>
<th>Avg concn. log CFU m$^{-3}$ $\pm$ 1 SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slaughterhouse LS1</td>
<td>Slaughterhouse LS2</td>
</tr>
<tr>
<td>No HEPA, dummy carcass, before fleece puller</td>
<td>$1.0 \pm 0.3$ (10)</td>
<td>$0.1 \pm 0.6$ (10)</td>
</tr>
<tr>
<td>No HEPA, dummy carcass, at fleece puller</td>
<td>$1.7 \pm 0.6$ (10)</td>
<td>$0.6 \pm 1.0$ (10)</td>
</tr>
<tr>
<td>No HEPA, dummy carcass, after fleece puller</td>
<td>$0.6 \pm 0.2$ (10)</td>
<td>$-0.4 \pm 0.4$ (10)</td>
</tr>
<tr>
<td>HEPA, dummy carcass, before fleece puller</td>
<td>$0.3 \pm 0.5$ (10)</td>
<td>$0.0 \pm 0.6$ (8)</td>
</tr>
<tr>
<td>HEPA, dummy carcass, at fleece puller</td>
<td>$1.1 \pm 0.9$ (10)</td>
<td>$0.4 \pm 0.7$ (8)</td>
</tr>
<tr>
<td>HEPA, dummy carcass, after fleece puller</td>
<td>$0.4 \pm 0.8$ (10)</td>
<td>$0.3 \pm 0.7$ (8)</td>
</tr>
<tr>
<td>No HEPA, real carcass, start of line to just after fleece puller</td>
<td>$3.5 \pm 0.9$ (10)</td>
<td>$2.0 \pm 0.3$ (10)</td>
</tr>
<tr>
<td>No HEPA, real carcass, just after fleece puller to end of line</td>
<td>$2.2 \pm 0.9$ (10)</td>
<td>$2.0 \pm 1.1$ (10)</td>
</tr>
<tr>
<td>HEPA, real carcass, start of line to just after fleece puller</td>
<td>$3.5 \pm 1.0$ (10)</td>
<td>$2.3 \pm 0.3$ (9)</td>
</tr>
<tr>
<td>HEPA, real carcass, just after fleece puller to end of line</td>
<td>$1.1 \pm 1.3$ (10)</td>
<td>$1.5 \pm 1.0$ (9)</td>
</tr>
</tbody>
</table>

$^a$ Values are averages $\pm$ standard deviations; the number of tests is shown in parentheses.
FIGURE 7. Total aerobic viable counts from settle plates on the replica carcass (dummy) and from sponges of real carcasses (real) in lamb slaughterhouses. (a) Slaughterhouse LS1 and (b) slaughterhouse LS2. Dummy/Start, replica from start to just before fleece puller; Dummy/Fleece, replica from just before to just after fleece puller; Dummy/End, replica from just after fleece puller to end of line; Real/Start, real carcass from start of line to just after fleece puller; Real/End, real carcass from just after fleece puller to end of line.
were exposed for 670 to 813 s from the start of the line to just after the fleece puller, whereas the next five carcasses were exposed from 244 to 294 s. There was no indication that increasing the line speed increased the contamination. The higher line speed was planned, and extra staff members were working on the line.

No significant effect of the HEPA unit was found at either lamb plant. Use of the HEPA unit had a less obvious effect on the concentration of organisms in the air than in the cattle slaughterhouses. The presence of fleece within the clean air zone restricted the effectiveness in reducing the airborne concentrations.

Figure 7 shows the settle plate, sponge count, and airborne concentration data. This graph illustrates further that there is no clear relationship between the counts measured on the plates or sponges and the concentration of organisms in the air close by. This indicates that the airborne route is not the main contributor to carcass contamination in lamb slaughterhouses. Observations during the tests showed that the flesh is often contacted by the operators’ hands, by the knives, and by the fleece as the carcass moves along the line.

Overall, this study has shown that the airborne route is not the main contributor to the contamination of cattle and lamb carcasses during dressing.

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