Review

Effects on the Microbiological Condition of Product of Decontaminating Treatments Routinely Applied to Carcasses at Beef Packing Plants†

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ABSTRACT

Reports on the microbiological effects of decontaminating treatments routinely applied to carcasses at beef packing plants indicate that washing before skinning may reduce the numbers of enteric bacteria transferred from the hide to meat. Washing skinned carcasses and/or dressed sides can reduce the numbers of aerobes and Escherichia coli by about 1 log unit, and pasteurizing sides with steam or hot water can reduce their numbers by >1 or >2 log units, respectively. Spraying with 2% lactic acid, 2% acetic acid, or 200 ppm of peroxacetic acid can reduce the numbers of aerobes and E. coli by about 1 log, but such treatments can be ineffective if solutions are applied in inadequate quantities or to meat surfaces that are wet after washing. Trimming and vacuum cleaning with or without spraying with hot water may be largely ineffective for improving the microbiological conditions of carcasses. When contamination of meat during carcass dressing is well controlled and carcasses are subjected to effective decontaminating treatments, the numbers of E. coli on dressed carcasses can be <1 CFU/1,000 cm². However, meat can be recontaminated during carcass breaking with E. coli from detritus that persists in fixed and personal equipment. The adoption at all packing plants of the carcass-dressing procedures and decontaminating treatments used at some plants to obtain carcasses that meet a very high microbiological standard should be encouraged, and means for limiting recontamination of product during carcass breaking and for decontaminating trimmings and other beef products should be considered.

Carcasses destined for human consumption have traditionally been subjected to washing and trimming treatments to remove visible contamination. In addition, at North American plants, it has long been the practice to remove hairs from some parts of skinned carcasses by vacuum cleaning or directed jets of air. It has generally been assumed that visible contamination indicates areas of the surface that carry relatively high numbers of bacteria and that the removal of visible contamination enhances the microbiological as well as the aesthetic condition of carcasses.

In recent years, North American beef packing plants that are subject to inspection by federal agencies have been required to implement hazard analysis critical control point (HACCP) systems for their processes to control微生物学, chemical, and physical hazards associated with their products (24, 94). Concerns about microbiological hazards in general and risks from Escherichia coli O157:H7 in particular have led to requirements for testing of carcasses for E. coli and Salmonella and for testing of ground beef and beef trimmings for E. coli O157:H7 (96).

To address those concerns and meet the microbiological criteria specified by the U.S. Department of Agriculture (USDA), the managements of beef packing plants have sought to enhance the microbiological safety of their products by implementing a variety of novel decontaminating treatments for carcasses as parts of their HACCP systems. All decontaminating treatments, both traditional and novel, that are currently employed have been shown to be effective for removing bacteria from, and/or inactivating bacteria that are currently employed have been shown to be effective for removing bacteria from, and/or inactivating bacteria on, meat under experimental circumstances (13). However, the efficacies of decontaminating treatments applied routinely in commercial practice may differ from those determined in experiments, often with inoculated product (59). Such differences can arise because the surfaces on which the bacteria are deposited, the physiological conditions of the organisms, and their disposition in the menstruum provided by the meat, as well as their numbers and the ways in which treatments are applied, can be very different in commercial and experimental circumstances. Thus, it cannot be assumed that results obtained when decontaminating treatments are applied under well-controlled conditions to heavily inoculated meat surfaces will necessarily be the same as those obtained with scaled-up treatments that are routinely applied to carcasses at beef packing plants.

Many of the factors that may give rise to differences in results obtained for decontaminating treatments applied under experimental and practical conditions may also give rise to substantial differences in the effects of apparently similar decontaminating treatments applied at different...
packaging plants. General conclusions about the effects in practice of any particular form of decontaminating treatments could then be drawn with confidence from only comparable data that identify the effects of similar decontaminating treatments at a number of representative plants. Unfortunately, such large quantities of the appropriate data are largely lacking. Nonetheless, the limited published findings for the effects of decontaminating treatments applied routinely to commercial beef carcasses do allow identification of effects that could be generally achieved in practice (36), without necessarily precluding the possibility of the effects being enhanced. Many of the available data are for indicator organisms, because in most commercial circumstances the study of the effects of decontaminating treatments on individual pathogens is not practicable (92). However, it is generally recognized that the effects of processes on pathogens can be usefully identified from the effects on appropriate indicator organisms (93). Thus, the available findings can indicate where future efforts should perhaps be directed for further improvement of the microbiological safety of beef.

The great majority of cattle slaughtered in North America are processed at large packing plants on high-speed lines at rates of >100 carcasses per h (70). The dressing processes at all such plants are broadly similar (14) and typically involve about 30 operations (Table 1). At some

### TABLE 1. Dressing operations in a high-line-speed beef carcass dressing process

<table>
<thead>
<tr>
<th>Step no.</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stun</td>
</tr>
<tr>
<td>2</td>
<td>Shackle</td>
</tr>
<tr>
<td>3</td>
<td>Bleed</td>
</tr>
<tr>
<td>4</td>
<td>Skin right, rear hock</td>
</tr>
<tr>
<td>5</td>
<td>Skin right butt</td>
</tr>
<tr>
<td>6</td>
<td>Remove right, rear hoof; hook right leg</td>
</tr>
<tr>
<td>7</td>
<td>Skin left, rear hoof</td>
</tr>
<tr>
<td>8</td>
<td>Skin left butt</td>
</tr>
<tr>
<td>9</td>
<td>Remove left rear hoof; hook left leg</td>
</tr>
<tr>
<td>10</td>
<td>Open brisket skin</td>
</tr>
<tr>
<td>11</td>
<td>Open tail skin</td>
</tr>
<tr>
<td>12</td>
<td>Skin rump</td>
</tr>
<tr>
<td>13</td>
<td>Skin tail</td>
</tr>
<tr>
<td>14</td>
<td>Remove horns, ears, and front hooves</td>
</tr>
<tr>
<td>15</td>
<td>Skin brisket</td>
</tr>
<tr>
<td>16</td>
<td>Skin back</td>
</tr>
<tr>
<td>17</td>
<td>Remove hide</td>
</tr>
<tr>
<td>18</td>
<td>Trim skin from the head</td>
</tr>
<tr>
<td>19</td>
<td>Split sternum</td>
</tr>
<tr>
<td>20</td>
<td>Free and wrap bung</td>
</tr>
<tr>
<td>21</td>
<td>Remove head; tie esophagus</td>
</tr>
<tr>
<td>22</td>
<td>Remove viscera</td>
</tr>
<tr>
<td>23</td>
<td>Split carcass</td>
</tr>
<tr>
<td>24</td>
<td>Change from dressing to main chain hook</td>
</tr>
<tr>
<td>25</td>
<td>Remove tail</td>
</tr>
<tr>
<td>26</td>
<td>Remove hanging tender</td>
</tr>
<tr>
<td>27</td>
<td>Remove mesenteric fat</td>
</tr>
<tr>
<td>28</td>
<td>Remove diaphragm remnants</td>
</tr>
<tr>
<td>29</td>
<td>Weigh</td>
</tr>
</tbody>
</table>

smaller plants more than one operation may be performed by a single worker, while at others more than one worker may be engaged in one of the operations. Trimming of carcass sides before weighing, which is a regulatory requirement, and washing carcass sides after they are weighed are treatments carried out at all plants (Table 2). At most plants, spot cleaning by vacuuming while surfaces are sprayed with jets of hot water from the vacuum head is used to clean hocks and sites along opening cuts in the hide, as such sites are often visibly contaminated by hairs and filth. At some plants the cleaned forehocks are inserted into a chamber in which they are sprayed with jets of steam. At many large plants skinned carcasses are now washed and sprayed with a lactic acid solution before they are eviscerated, and washed carcass sides are pasteurized with hot water or steam. The washed sides may be treated with a solution of peroxyacetic acid or stabilized chlorine dioxide before they are pasteurized or with a solution of lactic acid after pasteurizing. If carcasses are not pasteurized, they are instead usually sprayed with an antimicrobial solution. Washing carcasses before they are skinned is a treatment implemented only relatively recently at some plants, while dehairing of carcass before skinning might not now be a treatment routinely applied to carcasses at any plant.

### EFFECTS OF CARCASS-DECONTAMINATING TREATMENTS

**Washing or dehairing before skinning.** An apparatus for washing beef carcasses before they are skinned, which is manufactured by Chad (Olathe, KS), has been installed at the beef packing plants of at least one major North American meat-packing company. There appears to be only one published description of the apparatus and its effects on the
microbiological condition of carcasses (21). The reported treatment involved spraying carcasses for 10 s with a 1.5% solution of NaOH at a temperature of 65°C, with the solution being delivered at a nozzle pressure of about 50 bar and a flow rate of about 1,500 liters/min. The carcasses were then rinsed, for an unspecified time, with a solution of NaOCl containing 1 ppm of free chlorine at a temperature of 35°C, with the solution being delivered at a nozzle pressure of 50 bar and flow rate of about 900 liters/min. After the carcasses were washed, water was removed from the hide along the lines where opening cuts would be made, by application of a vacuum cleaning head. The treatment reduced the numbers of aerobes and Enterobacteriaceae on the hides by about 2 and 3 log units, respectively, but the numbers of those organisms on the skinned carcasses before evisceration were <1 log unit less on carcasses that had been washed before skinning than on carcasses that had not been washed. Nonetheless, the prevalence of E. coli O157:H7 on the carcasses that had been washed was only 2% compared with 17% on carcasses that had not been washed.

In another study, carcasses were washed before skinning in a cabinet for which the manufacturer was not identified, for between 25 and 97 s with potable water that apparently was not heated, which was delivered at a rate of about 900 liters/min (6). After being washed, the carcasses were sprayed with water containing chlorine at between 100 and 200 ppm. The reduction of the prevalence of E. coli O157:H7 on the hides was modest, from 98 to 90%, but the fraction of carcasses from which the organism could be recovered from the hides at countable numbers (≥0.4 CFU/cm²) decreased from 35 to 13%. The prevalence of Salmonella on carcass hides decreased from 95 to 69%, and the fraction of carcasses from which countable numbers of Salmonella were recovered from hides decreased from 40 to 7%.

Dehairing of carcasses before skinning apparently involved the carcasses being treated with two applications of a 10% Na₂S solution and then washing and treating them with two applications of a 3% H₂O₂ solution to neutralize residual Na₂S, with the carcasses being washed after each application of the H₂O₂ solution (85). When used in commercial practice, the treatment had no effect on the numbers of aerobes or Enterobacteriaceae recovered from the hides (74). However, the numbers of those organisms on skinned carcasses before evisceration were 2 log units less on carcasses that had been dehaired than on carcasses that had not been so treated. The prevalences of E. coli O157:H7 on the hides of treated and nontreated carcasses were 67 and 88%, respectively. The difference in the prevalences on skinned carcasses was far larger; the prevalence of E. coli O157:H7 on carcasses that had been treated was 1%, whereas on carcasses that had not been treated the prevalence was 50%.

It has been shown that washing animals before slaughter to remove visible contamination does not result in any substantial improvement of the general microbiological condition of dressed carcasses (17, 82, 83). Indeed, dressing carcasses with hides that are wet after washing can apparently result in dressed carcasses that are more heavily contaminated with bacteria than are the carcasses from animals that had not been washed and had dry hides (16). Thus, the finding that washing or dehairing of hides had little or no effect on the numbers of aerobes or Enterobacteriaceae on dressed carcasses could be expected. Despite that, the studies of carcasses with washed hides clearly showed reductions in the prevalences and numbers of E. coli O157:H7 and Salmonella on both hides and dressed carcasses.

The contrasting effects of hide washing on the contamination of dressed carcasses with bacteria in general as opposed to their contamination with enteric pathogens may be a result of the enteric pathogens being deposited mostly on hides shortly before cattle are slaughtered. Although it is often tacitly assumed that at slaughter enteric pathogens are present mostly on the hides of animals that are shedding the organisms (27, 33), most cattle presenting for slaughter may be contaminated with E. coli O157:H7 and Salmonella acquired during transport or in packing plant lairages from other animals or persistent sources of contamination in transport and holding facilities (4, 25, 88). Enteric pathogens have been found to persist in trailers and lairages after cleaning (79, 87), and recent studies have confirmed that the numbers of cattle contaminated with enteric pathogens greatly increase as a result of transport and holding in lairages (5, 34). Filth or dust carrying enteric pathogens that is deposited on hides shortly before animals are slaughtered is presumably superficial and attached only loosely to the hides. Such contamination and the accompanying pathogens would then likely be removed by washing, while contaminants more intimately associated with the hide could remain to be transferred to meat surfaces when carcasses are skinned.

Further work on the microbiological effects of commercial carcass hide washing treatments is obviously required, if only to ascertain if there are differences between the results obtained when hides with different types of gross contamination are washed. For example, are the microbiological results from skinned carcasses the same for carcasses with dry and dusty hides as for those with hides caked with dried mud when such carcasses are washed? In the latter instance, washing hides may be appropriate whether or not there are substantial direct microbiological benefits from the treatment. That is because in winter months in northwestern North America, the ventral surfaces and legs of cattle become coated with thick layers of dried mud that seriously impede skinning operations (98). Reliable removal of that material must greatly facilitate skinning operations and so might indirectly give rise to some improvement of the microbiological condition of skinned carcasses.

Washing of skinned, uneviscerated carcasses and carcass sides. It has long been a standard practice to wash beef carcass sides at the end of the carcass-dressing process, using hand-held sprays at smaller abattoirs and automatic spray cabinets at larger facilities. In recent years, at least at larger plants, the practice of washing carcasses after skinning but before evisceration has become widely established. There have been numerous studies that involved the washing of carcasses under experimental circumstances, to iden-
tify the effects of factors such as water temperature, nozzle pressure, time of washing, etc., on the microbiological conditions of naturally or artificially contaminated carcasses (10, 18). In addition, there have been a number of studies in which the combined effects of washing and one or more other decontaminating treatments applied routinely to beef carcasses were determined (31). However, there are only a few reports of the effects on the microbiological condition of beef carcasses of only routine washing, with either cold water or warm water applied at temperatures too low to inactivate any substantial fraction of the bacteria present on the carcasses (46).

A study of decontaminating treatments applied to beef carcasses at small abattoirs included examination of the effects of washing carcass sides, with low-pressure water at temperatures of >65°C or with high-pressure water at about 50°C, for durations of ≥70 s, using hand-held sprays (2). Of all the treatments used to reduce the numbers of aerobes, Enterobacteriaceae, coliforms, and E. coli on carcasses by about 1 log unit. Thus, although the waters delivered from spray nozzles at some plants were at temperatures at which most bacteria on meat would be rapidly inactivated, the microbiological effects were much the same as those achieved with cooler waters. This was probably because of the rapid cooling of the sprayed hot water during the travel of droplets from the nozzle to the carcass (29). The decontaminating effects observed with both hot and cooler wash waters were then likely due to only the physical removal of bacteria by the washing treatments.

In contrast, treatments for the automatic washing of beef carcass sides with cold water for about 5 s at three plants were found to redistribute bacteria on the carcasses, but not to remove them from the sides (15). Other, unspecified side-washing treatments at beef packing plants were also reported to have no substantial effect on the numbers of aerobes on beef sides or on the numbers of coliforms or E. coli (40, 77). Similarly, in each of two studies in which the effects of the automatic washing of carcass sides with water at temperatures of about 40°C for <40 s were examined, the numbers of aerobes on the sides were unaffected by the treatments (46, 64). However, in one of those studies the numbers of coliforms and E. coli on the sides as well as the numbers of aerobes were determined, and it was found that washing reduced the relatively high numbers of coliforms and E. coli on the sides by about 1 log unit. In a third study, the effects of automatic washing of beef carcass sides at three large plants were investigated (47). At two of the plants the numbers of aerobes on the sides were unaffected by the treatment, while apparent increases in the numbers of coliforms and E. coli indicated that bacteria were being redistributed on, but not removed from, the sides by washing. However, at the third plant the numbers of aerobes, coliforms, and E. coli were all reduced by ≥1 log unit as a result of washing. The divergent findings could not be explained by the temperatures of the waters, which were about 40°C at one but ≤18°C at two of the plants, including the one at which the numbers of bacteria were reduced, nor were they explained by differences in the water pressures at the nozzles, as those were similar. It was then suggested that the reduction in numbers at the one plant was because all parts of the sides at that plant were washed for 30 s, whereas at the other plants, the total treatment times were 12 and 26 s, respectively, and water was sprayed on only the upper parts of the sides for the first 6 or 13 s and subsequently on only the lower parts of the sides.

In a later study, the microbiological effects of treatments for washing skinned, uneviscerated carcasses and then spraying them with a solution of 2% lactic acid at three large beef packing plants and the treatments for washing carcass sides at those and another large plant were examined (50). The treatments of skinned carcasses reduced the numbers of aerobes on carcasses at one plant and the numbers of coliforms and E. coli on carcasses at another. The side-washing treatments did not affect the numbers of aerobes on sides at any of the plants in which uneviscerated carcasses were washed, but the numbers of coliforms and E. coli on sides were reduced at one of those plants. At that plant, the numbers of coliforms and E. coli on the carcasses had increased substantially during processing after the first washing treatment. At the plant where only sides were washed, the relatively high numbers of aerobes, coliforms, and E. coli were all reduced by the treatment. Those findings suggest that the effects of the combined carcass washing and lactic acid solution spraying treatments were largely if not entirely due to washing, and that washing treatments were effective for reducing the numbers of bacteria on carcasses by up to ≥1 log unit when the initial numbers were high, but not when numbers were relatively low.

Taken together, the various findings indicate that when carcasses or sides are relatively heavily contaminated with bacteria during skinning or subsequent operations, washing for relatively long times will substantially reduce the numbers of bacteria on the meat, probably by removing bacteria that are associated with particles that are flushed from the carcasses or sides. However, if the contamination of carcasses is well controlled throughout the dressing process, washing will have little or no effect on the microbiological condition of the meat. Thus, it seems that if contamination is not well controlled at only one stage of the processes, such as during skinning, the first wash after the contaminating operations will likely reduce the numbers of bacteria on the meat; repeated washing after that, or washing before the contaminating operations, will have no effect.

Spraying with antimicrobial solutions. The effects that solutions of various antimicrobials have on both the natural microflora on meat and the bacteria inoculated onto meat have been extensively investigated. The antimicrobials used have included chlorine, sodium hypochlorite, acidified sodium hypochlorite, and cetylpyridinium chloride; acetic, lactic, peroxyacetic, and other short-chain organic acids; and ozone, trisodium phosphate, nisin, and lactoferrin (1). Solutions of most of those antimicrobials have been shown to be effective for reducing the numbers of bacteria on meat. However, only lactic, acetic, and peroxyacetic acid
solutions appear to be routinely applied to carcasses at substantial numbers of North American beef packing plants.

At many large packing plants, a 2% solution of lactic acid is applied automatically as a misting spray to skinned but unevicerated carcasses immediately after they are washed and/or to carcass sides after they are washed or immediately after the washed sides are pasteurized with hot water or steam. In addition, chilled carcasses may also be sprayed with a lactic acid solution before they are broken.

When the effects of the treatments at three plants for washing skinned, unevicerated carcasses and spraying them with lactic acid solutions were investigated, it was found that one such treatment had no effect, one reduced the relatively high numbers of aerobes by \( > 1 \) log unit but had no effect on the numbers of coliforms and \( E. \, coli \), and one reduced the relatively high numbers of coliforms and \( E. \, coli \) by about 1 log unit but had no effect on the numbers of aerobes (50). Those findings suggested that the decontaminating effects at the two plants were due to the washing part of the treatment rather than any effect of the lactic acid solution, which would be diluted when sprayed as a mist onto the wet surfaces of carcasses. That conclusion was seemingly confirmed by a subsequent study of a treatment in which skinned carcasses were washed with water at 75°C for 5.5 s before being sprayed with 2% lactic acid (20). In that study, carcasses were treated with operation of only the washing or the acid-spraying part of the apparatus as well as with operation of both parts. The lactic acid spray alone reduced the numbers of aerobes and \( Enterobacteriaceae \) by \( > 1 \) log unit, but washing alone reduced their numbers by \( > 2 \) log units, and the reduction was no greater when carcasses were both washed and sprayed with the lactic acid solution. The large reductions obtained with washing may have been due in part to the relatively high temperature of the wash water. However, the large reductions might also reflect the relatively high numbers of bacteria present on the carcasses before washing, as those were \( > 4 \) and \( \approx 2 \) log CFU/cm\(^2\) for aerobes and \( Enterobacteriaceae \), respectively.

The findings with skinned carcasses probably apply equally to the spraying of carcass sides with lactic acid solution after they are pasteurized with hot water, as the reductions of bacterial numbers obtained with a combined treatment appeared to be no greater than those obtained by treatments elsewhere with hot water alone (50). It also seems likely that spraying carcass sides with 2% lactic acid after pasteurizing with steam or with 200 ppm of peroxyacetic acid before pasteurizing with steam does little to enhance the decontaminating effects of the pasteurizing treatments. However, that matter does not seem to have been investigated, presumably because of difficulties with sampling carcasses between the two stages of such combined treatments.

In one study, 2% lactic acid used as the sole treatment of washed carcass sides was found to reduce the numbers of aerobes and \( E. \, coli \) by about 1 log unit (30). Treatments of washed carcass sides with only 1.5 or 2.5% acetic acid, using automatic equipment or hand-held sprays, were also found to reduce the numbers of bacteria by about 1 log unit (2, 3). However, in another study, application of 2% lactic acid as the sole decontaminating treatment of carcass sides was found to be ineffective (51), and no substantial differences were found in the microbiological conditions of carcass sides between plants that sprayed both skinned carcasses and carcass sides with 1% acetic acid and those plants that did not apply such treatments (9). The routine treatment of chilled carcass sides with 2% lactic acid, using automatic spraying equipment, was also found to be ineffective for reducing the numbers of bacteria on the meat (11).

Although solutions of organic acids and other antimicrobials can certainly be effective against bacteria on meat (31), the results obtained with antimicrobial solutions applied to beef carcasses in commercial practice are evidently inconsistent. The lack of effect of some treatments with antimicrobial solutions is probably due to a variety of factors. Dilution of solutions on wet carcass surfaces has been mentioned already. Antimicrobial solutions are generally not applied in large volumes, if only for reasons of cost, so uniform coverage of all surfaces with sufficient solution to be effective may be difficult to achieve even when surfaces are dry. Moreover, spraying carcasses with an antimicrobial solution immediately before or after another consistently effective decontaminating treatment such as pasteurizing may achieve little. That may be because of faulty application, or because bacteria that survive the consistently effective treatment may be mostly those that are physically protected from any treatment of the surface. If the latter is the case, then even if the numbers of bacteria are reduced by a treatment that precedes one that is consistently effective, the initial treatment will only inactivate bacteria that would have been inactivated by the second treatment anyway, whereas if a treatment is applied immediately after one that is consistently effective, the second treatment will not affect any of the remaining, protected organisms.

Evidently the beneficial effects of antimicrobial solutions applied to carcasses in commercial practice cannot be assumed, so determination of the effect of each such treatment in any process would be advisable.

**Trimming and vacuum cleaning.** Visible contamination has traditionally been and continues to be removed from carcasses by cutting away the contaminated tissues. Hair and associated visible contamination has been in the past and may sometimes still be removed from specific parts of beef carcasses, such as the hocks, by vacuum cleaning. In recent years visible contamination has increasingly been removed by vacuum cleaning with cleaning heads that contain outlets from which hot water or steam is sprayed onto the meat surface that is being cleaned. All such treatments are effective for removing visible contamination and bacteria associated with it (68, 78). However, there is no necessary relationship between visible and microbiological contamination (35). That is, sites that are not visibly contaminated may carry large numbers of bacteria, while sites that are visibly contaminated may carry few. The effectiveness of trimming and cleaning treatments will then depend on the extent to which the microbiological conditions of
Carcasses are improved by the removal of bacteria associated with visible contamination.

Carcass sides are routinely inspected during the later stages of the dressing process by workers who remove any visible contamination from them by trimming or vacuum cleaning, with or without the application of hot water or steam. Such treatments may improve the microbiological conditions of the trimmed or cleaned areas. However, the treated areas are small and carcasses are not treated uniformly. Consequently, the microbiological conditions of populations of carcasses undergoing dressing were found to be not noticeably different before and after all the trimming and cleaning operations had been applied to them in several processes (40, 50). Moreover, the vacuum and hot-water cleaning of specified areas of carcass surfaces did not result in any improvement of the microbiological conditions of those areas on the population of carcasses that passed through the process (43). The effects of routine trimming or cleaning treatments might be greater if they were applied uniformly to all carcasses irrespective of whether the sites specified for treatment were visibly contaminated (55). However, the effects of trimming or cleaning treatments applied in such a manner do not appear to have been studied.

Trimming may be relatively effective when applied to carcasses that have been detained because of extensive visible contamination. Even so, the overall reductions in numbers of aerobes and E. coli at trimmed sites may often be only about 1 log unit (52). It therefore appears that improvements of the microbiological conditions of carcasses by removal of visible contamination are modest at best and often trivial. Trimming and cleaning treatments are evidently needed for aesthetic purposes, but it should be recognized that their contributions to the microbiological safety of meat will at most be small.

**Pasteurizing of carcasses with steam or hot water.** At most large North American beef packing plants, beef carcass sides are pasteurized with steam or hot water after they are washed at the end of the carcass-dressing process. Sides that are pasteurized with steam must be free of detritus and dry when they are treated; otherwise, contaminated surfaces will not be heated to pasteurizing temperatures by steam condensing upon them. A widely used type of steam pasteurizing apparatus, therefore, includes a pair of manifolds from which air is blown over carcass sides that pass between them in order to dry the sides before they enter the steam treatment chamber (76). Drying and scrupulous removal of detritus is not necessary when carcasses are pasteurized with hot water, as any remaining cold water is mixed nearly instantaneously with excess hot water while detritus is at least moved upon if not removed from surfaces by the washing action of the water.

Steam pasteurizing treatments used in commercial processes for which microbiological effects have been reported in the literature have involved the use of steam at temperatures that ranged from 75 to 105°C and treatment times that ranged from 6 to 11 s. In most of the studies it was found that the numbers of aerobes were reduced by ≥1 log unit and that the prevalences of E. coli were reduced, although some were still detected at numbers >1 CFU/cm² (26, 75, 76). In one study the steam temperature was varied, but the treatment time was consistently about 11 s because of the rate of carcass processing at the plant (80). The findings of that study were that the maximum reductions, with elimination of detectable E. coli at a level of 0.4 CFU/cm², were obtained only when the steam temperature was ≥85°C. In an earlier study of a treatment in which carcass sides were exposed to steam at 105°C for 6 s, the numbers of E. coli were found to be reduced by >2 log units, with the organism being detected in few samples at a level of 1 CFU/100 cm² (43). There has been one report of a steam pasteurizing treatment being ineffective (71). However, that was not a routine treatment, and it involved the use of steam at a temperature of 90°C and a treatment time of 10 s, which are conditions that other studies have indicated to be adequate for effective treatment. In that case, treatment of wet carcasses or some other misapplication of the treatment must be suspected.

Two studies of the decontaminating treatments applied to carcasses at beef packing plants included investigation of the effects of pasteurizing treatments that used steam. One of the three treatments was preceded by treatment of the carcass sides with 200 ppm of peroxycetic acid, and the others were followed by treatment of sides with 2% lactic acid (46, 50). The carcasses could not be conveniently sampled between the spraying and pasteurizing treatments. With such combined treatments, the numbers of aerobes were reduced by ≥1 log unit, and the numbers of E. coli were reduced by >2 or >3 log units, with none being detected at the level of 1 CFU/100 cm² in 74 of 75 samples from treated carcasses. The effects of the spraying treatments are uncertain, but as previously discussed, they may be trivial. Thus, the effects of the combined treatments probably were mostly due to the pasteurizing treatments.

Sprayed hot water will cool rapidly with increasing distance from the spray head because of the large surface area-to-volume ratio for water in the form of droplets (28). Decontamination of carcasses with hot water will then be effective only when water is distributed over all parts of the carcass surface while the water remains at a temperature sufficient for rapid inactivation of enteric pathogens. In one type of apparatus, hot water is recirculated and delivered onto carcasses as sheets of water that spread to cover all surfaces of the carcass (42). The optimum water temperature and time for the treatment of beef carcass sides in apparatus of that type were found to be 85°C and 11 s, respectively (44). Under such conditions the numbers of aerobes and E. coli on carcass sides were reduced by >1 and >2 log units, respectively. Similar reductions occurred with carcass sides that were sprayed with water at 85°C for 10 s and then with 2% lactic acid for 5 s (50). As discussed before, it is likely that the decontaminating effect achieved with that combined treatment was largely due to the treatment with hot water.

The available data indicate that when apparatus for pasteurizing carcasses with either steam or hot water are used appropriately, the numbers of aerobes and E. coli are
reliably reduced by at least 1 and 2 log units, respectively. Pasteurizing is then an effective means of controlling the microbiological conditions of carcasses.

**Microbiological conditions of dressed carcass sides.** In 1996 the USDA introduced performance standards for the control of the microbiological contamination of product from carcass-dressing processes. The standard for *E. coli* on beef carcass sides at the end of the process, which is in the form of a three-point attributes acceptance plan (63), stipulated upper limits for wholly acceptable and marginally acceptable samples of 5 and 100 CFU/cm², respectively (94). With the recommended procedures, *E. coli* recovered from the sides on carcass sides likely to be most heavily contaminated would be detected at a level of 1 CFU/12 cm². In studies of seven beef packing plants at that time, it was found that the fractions of carcasses that gave samples with *E. coli* at numbers >5 CFU/cm² varied widely between plants and with the season, from about 1 to 10% (90). The mean log numbers of aerobes on the carcass sides ranged from 2.0 to 3.2 log CFU/cm², and the mean numbers of *E. coli* were between about 1 and 3 CFU/cm² (89). The plants involved in the study had mostly implemented hot-water or steam vacuum cleaning treatments, in addition to trimming and washing carcass sides, and some were operating systems for spraying sides with 2% lactic acid.

At about the same time, similar results were obtained for beef carcass sides at 11 other plants, with mean log numbers of aerobes ranging from 1.7 to 3.3 log CFU/cm² (48, 65). For 10 of those plants, the log mean numbers calculated from the values for the means and standard deviations for sets of 25 counts ranged from 2.0 to 4.9 log CFU/cm² (48). The mean numbers of *E. coli* were ≤1 CFU/cm², with the mean numbers at four plants being <1 CFU/10 cm², and the mean numbers at one small plant being <1 CFU/1,000 cm². The decontaminating treatments used at the times of sampling at those plants were not identified, but none were then washing carcasses before or after skinning, nor were they pasteurizing carcass sides.

In recent years, the microbiological conditions of beef carcass sides have been greatly improved by the introduction of both carcass-dressing practices that reduce contamination of the meat (52, 86) and novel treatments for decontaminating carcasses. Thus, at one plant the prevalence of *E. coli* at a level of ≥1 CFU/12 cm² in samples routinely collected in compliance with regulatory requirements was about 3%, while at two other plants *E. coli* was detected in only 16 of 7,775 or 1 of 2,111 samples (49). In a study of decontaminating treatments at four plants, the final log mean numbers of aerobes on carcass sides were <2 log CFU/cm² at one plant and <1 log CFU/cm² at two plants in which sides were pasteurized but >4 log CFU/cm² at a plant where carcass sides were sprayed with 2% lactic acid but not pasteurized (50). No *E. coli* organisms were recovered from 2,500 cm² of carcass surfaces at two plants where carcasses were pasteurized with steam; but *E. coli* was recovered at levels of 1 CFU/100 cm² or 1 CFU/cm² at plants in which carcasses were pasteurized with hot water or not pasteurized, respectively. Log mean numbers of aerobes of <1 log CFU/cm² and *E. coli* numbers of <1 CFU/1,000 cm² were also found on carcass sides at the end of the dressing process in another study (46).

Very low numbers of aerobes and *Enterobacteriaceae* on carcass sides at two other plants have also been reported (7). At those plants, the prevalence of *E. coli* O157:H7 in samples of >2,000 cm² of carcass side surfaces was about 1% or less (7, 12, 81).

These various findings show that with appropriate design and control of a beef carcass-dressing process that includes effective decontaminating treatments, the numbers of *E. coli* and enteric pathogens on carcasses can be consistently reduced to disappearing low levels. For such processes the mandated routine testing for *E. coli* with detection of the organism at the level of 1 CFU/12 cm² is of questionable value. Obviously, not all plants have attained such a high microbiological standard for their carcasses. However, it is evident that this level of microbiological control with a correspondingly high level of microbiological safety is attainable, and there is no obvious reason why it should not be attained at all plants. It is unlikely that this will happen as long as regulatory authorities continue to regard much lower standards as wholly acceptable and require inappropriate testing. Testing could be readily enhanced by, for example, stipulating that carcass surfaces be sampled by swabbing a large but undelimited area, say, of 5,000 cm². The samples could be processed as in current practice to enumerate *E. coli* at a level of 1 CFU/500 cm². Performance standards could then be structured to take into account the results obtained at the best plants as well as the average performance by, for example, reducing the testing requirements when consistently superior results are obtained. By such means regulatory activities and requirements could be restructured to encourage at all beef packing plants the implementation and validation of the highly effective control measures that are currently in place at some.

**MICROBIOLOGICAL CONDITIONS OF BEEF CUTS AND TRIMMINGS AND GROUND BEEF**

In a study of the microbiological conditions of ground beef produced at federally inspected plants in the United States before decontaminating treatments other than washing, trimming, and vacuum cleaning were used, the log mean numbers of aerobes in the product were found to be 3.9 log CFU/g, and *E. coli* was recovered from about 80% of samples at mean numbers of 54 CFU/g (95). In other studies during the same period, there were comparable findings for the numbers of aerobes and *E. coli* cells in trimmings produced at a beef packing plant (54) and in boxed beef and trimmings from chilled carcass quarters delivered to a beef processing plant (32).

At a somewhat later time, when spraying with antimicrobial solutions and/or pasteurizing treatments had been implemented in some carcass-dressing processes, the microbiological conditions of beef trimmings and ground beef produced at eight packing plants were examined (84). The log mean numbers of aerobes, calculated from mean log numbers and standard deviations published in the report (23), ranged from 2.3 to 6.9 log CFU/g and from 2.7 to 6.9
log CFU/g for trimmings and ground beef, respectively. The numbers of E. coli cells in trimmings and ground beef ranged from about 10 to 60 CFU/g and 10 to 80 CFU/g, respectively; it was stated that E. coli counts were “relatively low, and often below the detection limit” of 10 CFU/g. The findings for aerobes and E. coli in ground beef produced in federally inspected plants in Canada at about the same time were similar, with log mean numbers of aerobes ranging from 3.7 to 6.8 log CFU/g and numbers of E. coli ranging from 5 to 160 CFU/g (61).

The improvement of the microbiological conditions of trimmings and ground beef at some plants indicated by those studies is now probably general. The findings of a recent study were that the mean log numbers of aerobes on trimmings from multiple plants were 2.5 log CFU/g, while with a level of detection of 10 CFU/g, E. coli cells were recovered from only 7% of samples and the mean number of E. coli in positive samples was little more than 10 CFU/g (19). The current, improved microbiological condition of beef trimmings from North American plants that is indicated by those findings is likely largely due to the operation of effective carcass-decontaminating treatments at most larger beef packing plants. However, the microbiological conditions of frozen trimmings from Australia and New Zealand continue to be superior to that of U.S. product (19), although in those countries most carcasses are not pasteurized or treated with antimicrobial solutions (67). Moreover, the finding of E. coli at numbers ≥10 CFU/g on 7% of samples from trimmings is seemingly at variance with the observation of E. coli numbers being reduced to <1 CFU/1,000 cm² on carcasses subjected to the most effective pasteurizing treatments. Those discrepancies may be due in part to some plants applying decontaminating treatments ineffectively, but they may also arise because of growth of bacteria on, or recontamination of, product during carcass-cooling and -breaking processes at some North American plants.

Increases in the numbers of aerobes, by up to 1 log unit, during the cooling of carcasses are apparently common (51, 89). However, the numbers of E. coli on carcasses did not increase during carcass cooling at eight plants (11, 89), while the increases were 0.5 log unit or less at three other plants, and the numbers decreased during cooling at a fourth plant (51). Carcass-cooling processes can then apparently be expected to have some effect on the numbers of aerobes on beef trimmings but can be operated to have little or no effect on the numbers of E. coli.

In a study on the microbiological conditions of cooled carcass sides entering and primal cuts leaving four carcass-breaking processes, the numbers of aerobes and E. coli on the meat were unaffected by one of the processes. However, in the other three processes the numbers of aerobes on cuts were about 1 log unit more than the numbers on carcasses, while the numbers of E. coli on cuts were 1, 2, or 4 log units more than the numbers on carcasses (41). In two other studies, the numbers of aerobes and E. coli on trimmings were found to be 1 and 3 log units more, respectively, than the numbers on carcasses entering carcass-breaking processes (46, 56). The possibility that such findings were due to bacteria being redistributed from a few heavily contaminated sites on some carcasses during carcass-breaking processes was addressed by sampling the whole surface of each of the hindquarter portions arriving at a processing line and each of the primal cuts leaving the line during a 1-h period at the beginning of processing for the day (59). The numbers of E. coli recovered from the cuts were 2 log units more than the numbers recovered from the hindquarter portions. The source of the contaminants added to meat during carcass-breaking processes was evidently detritus that was not removed from fixed or personal equipment during routine cleaning (8, 56–58).

A major objective of the implementation of HACCP systems and carcass-decontaminating treatments at beef packing plants is the elimination of E. coli O157:H7 from ground beef. Consequently, U.S. regulatory authorities have in recent years routinely tested ground beef to determine the prevalence of E. coli O157:H7 in the product. Since 2000, that testing has involved the enrichment of 325-g samples and recovery of E. coli O157:H7 from the enrichment medium by immunomagnetic separation. With such sensitive procedures, prevalences of about 0.8 were found for each of the years 2000, 2001, and 2002, but the prevalence subsequently declined to 0.4 and 0.2% in 2003 and 2004, respectively (72). The prevalence of about 0.2% was maintained in 2005 and 2006, but it increased somewhat in 2007 (73, 97). E. coli O157:H7 was not detected in samples from 1,200 subprimal cuts from five packing plants that were sampled in 2004 (66). However, prevalences of the organism of 0.3 and 0.2% were found for groups of >1,000 cuts sampled before or after that time (62, 91).

The decline in the prevalence of E. coli O157:H7 in ground beef as determined by the USDA would seem to coincide with the period when pasteurizing and antimicrobial spraying treatments for carcasses had been or were being implemented at most North American beef packing plants. The prevalence of E. coli O157:H7 in large samples from comminuted or intact beef now appears to be stable at about 0.2%. The 75% reduction in the prevalence of E. coli O157:H7 is relatively small in view of the numbers of E. coli on carcasses in some processes being reduced by up to 4 orders of magnitude as a result of effective carcass-decontaminating treatments being operated as parts of HACCP systems. The limited reduction of E. coli O157: H7 contamination obtained after wide adoption of carcass decontaminating could be accounted for by relatively ineffective application of decontaminating treatments at some plants, enhanced resistance of the organism on meat to acid or other stresses imposed by decontaminating treatments, and/or recontamination of product during carcass breaking and, possibly, grinding at others. The modest effects of the general implementation of carcass-decontaminating treatments on both E. coli and E. coli O157:H7 contamination of the products dispatched from beef packing plants would then seem to be closely comparable, as would be expected. Thus, the possible full benefits of carcass-decontaminating treatments appear to be as yet unrealized.
FURTHER IMPROVEMENT OF THE
MICROBIOLOGICAL SAFETY OF BEEF

The available information shows that beef carcass-
dressing processes that include effective carcass-decontam-
inating treatments can be operated to routinely produce car-
casses that carry E. coli at numbers <1 CFU/1,000 cm². The pro-
bability of E. coli O157:H7, other verocytotoxigenic
E. coli, or Salmonella being present at detectable num-
bers on such carcases would then be disappearingly small.
However, it is clear that not all plants produce carcases of
such a superior microbiological condition and that the meat
may be recontaminated with E. coli and also, presumably,
with associated pathogens, possibly during the handling and
transporting of carcases and certainly during carcass-
breaking processes. It would then be desirable for the beef
packing industry to generally adopt practices that would
ensure the best possible microbiological condition for
dressed carcases and maintenance of that microbiological
condition of the meat during all further handling and pro-
cessing.

The microbiological conditions of carcases will not be
moved toward the highest possible standard if appropriate
data by which their microbiological conditions can be iden-
tified are lacking. While enumeration of E. coli can provide
data suitable for assessing the safety of meat with respect
to contamination with enteric pathogens, the detection level
with current procedures is far too high for determining the
microbiological conditions of carcases of very high micro-
biological standards. Therefore, procedures for the routine
sampling of dressed carcases for enumeration of E. coli
should be modified. Product should also be sampled at the
beginnings and ends of carcass-breaking processes to de-
termine if numbers of E. coli on products increase as a
result of those processes.

If product surfaces are maintained at or little above
chiller temperatures during processing, significant growth of
E. coli cannot occur (60), but product can evidently be
recontaminated during carcass breaking by bacteria that
grow in detritus that persists in personal or fixed equipment
after routine cleaning. The flora of such detritus can include
mesophilic organisms, such as E. coli and related enteric
pathogens, because the equipment is exposed to warm tem-
peratures during cleaning periods and because parts of
equipment may be warmed by frictional heating when it is
being operated. The presence of E. coli in cleaned equip-
ment can be demonstrated by appropriate sampling of non-
meat-contacting as well as meat-contacting parts of equip-
ment. The presence of E. coli in or on non–meat-contacting
parts of equipment is relevant to product safety, because
detritus will be moved from non–meat-contacting to meat-
contacting parts of many types of equipment, such as con-
veyors, when the equipment is operated.

Contamination of meat from persistent detritus in per-
sonal equipment can be controlled by improved cleaning of
the equipment. At present, cleaning of personal equipment
at most meat plants is left to the discretion of the worker
who uses it, so cleaning is variably effective; some equip-
ment, such as that made of steel mesh, cannot be freed of
all detritus by washing (57).

Many parts of equipment in carcass-breaking facilities,
such as drive mechanisms and hinges of jointed conveyor
belts, cannot be thoroughly cleaned without disassembly of
the equipment (69). When the equipment is operated, de-
tritus, or water contaminated by it, is squeezed or thrown
from moving parts to spread or settle on meat-contacting
surfaces. However, the spread of detritus from uncleanable
parts of equipment and growth of bacteria in persisting de-
tritus can be controlled if the equipment is thoroughly dried
after cleaning and it is kept dry during meat processing
(53).

Chilled beef in any form, before or after carcass break-
ing, is not as yet generally subjected to decontaminating
treatments in beef fabricating facilities. However, the use
of antimicrobial solutions for treatment of chilled carcass
sides or quarters and beef subprimal cuts and the use of pasteurizing of beef trimmings could be considered. Bacon
et al. (11) found that treatment of commercial carcass sides
and cuts with 2% lactic acid reduced the numbers of E. coli
on the products by <0.5 log unit. Similarly, Gill and Ba-
doni (39) found that solutions of peroxyacetic acid and
acidified sodium chlorite and 2% lactic acid generally re-
duced the numbers of E. coli on commercial carcass quar-
ters by ≤1 log unit, with the results differing somewhat for
quarters from different slaughtering plants. Those treat-
ments were also found to be more effective against bacteria
on the mostly fat tissue of distal surfaces than on the serous
membranes covering most medial surfaces of carcass fore-
quarters. Bosilevac et al. (22) similarly found that acidified
sodium chlorite solution was less effective against bacteria
on low-fat-content than on high-fat-content trimmings.
However, treatment of quarters with 4% lactic acid gave
consistent reductions of ≥2 log units in the numbers of E.
coli (39), as did pasteurizing trimmings with water at 85°C
for ≥45 s (45).

Harsh decontaminating treatments such as effective
pasteurizing can cause gross discoloration of the treated
surfaces. That is apparently not an important consideration
when the product to be treated is trimmings or other man-
ufacturing beef that is to be ground, because grinding dis-
tributes the discolored tissue throughout the meat mass.
Thus, the initial color and appearance, eating qualities, and
organoleptic qualities during display of ground beef pre-
pared from trimmings pasteurized with water at 85°C for
60 s differed little or not at all from those of ground beef
prepared from unpasteurized product (37, 38). Surface dis-
coloration would, however, be a major commercial concern
if the discolored surfaces remained and were exposed on
the final product, as would likely be the case with steaks
cut from decontaminated primal cuts. At this time there has
been no report in the literature of a treatment applied to
commercial primal cuts that is reliably effective for en-
hancing the microbiological condition of the product and
exerts no effect or an acceptable effect on product appear-
ance.

The limited information currently available suggests
that the microbiological safety of all forms of beef could
be greatly enhanced by better control of the recontamination of meat from decontaminated carcasses and by implementation of effective decontaminating treatments for trimmings and cuts. While it should be possible to largely prevent recontamination, and effective decontamination of beef destined for grinding would seem to be commercially practicable, a suitable decontaminating treatment for other forms of beef has yet to be clearly identified.

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