Transfer of *Listeria monocytogenes* during Slicing of Turkey Breast, Bologna, and Salami with Simulated Kitchen Knives

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ABSTRACT

In response to continued concerns regarding *Listeria* cross-contamination during the slicing of deli meats, a series of specially prepared grade 304 and 316 stainless steel kitchen knife blades was inoculated with a six-strain *Listeria monocytogenes* cocktail (10^6, 10^5, and 10^3 CFU per blade) composed of two weak, two medium, and two strong biofilm-forming strains. The blades were then attached to an Instron 5565 electromechanical compression analyzer and used to slice whole chubs of delicatessen turkey breast, bologna, and salami to entirety (30 slices) at a cutting speed of 8.3 mm/s. Homogenates of the slices in University of Vermont Medium were surface or pour plated with modified Oxford agar and then enriched. *Listeria* transfer from knife blades inoculated at 10^8 CFU per blade was logarithmic, with a 2-log decrease seen after 8 to 12 slices and direct counts obtained thereafter out to 30 slices. However, blades containing 10^5 and 10^3 CFU per blade typically yielded direct counts out to only 20 and 5 slices, respectively. Normalizing data on a log scale for the first 10 slices resulted in significantly greater *Listeria* transfer and “tailing” from grade 304 as opposed to grade 316 stainless (*P* < 0.05) for all three products. After 1 year of use, surface roughness values as determined by surface profilometry were significantly greater (*P* < 0.001) for grade 304 than for grade 316 stainless blades. Cutting force and blade sharpness were not significantly different (*P* > 0.05) within stainless steel grade (*P* < 0.05) for each product. However, significant differences in cutting force were seen between salami and turkey (*P* < 0.05) for grades 304 and 316 stainless, respectively. In addition to compositional differences in the deli meats and knife blades, wear and scoring on the blade likely affected *Listeria* transfer during slicing.

Cross-contamination of cooked and ready-to-eat (RTE) foods with *Listeria monocytogenes* has been identified as a serious public health concern (11, 12, 34–36), with delicatessen meats posing the highest per annum risk of listeriosis among 20 RTE food categories examined in a 2001 draft risk assessment (39). Four nationwide RTE meat-related listeriosis outbreaks were documented in the United States from 1998 to 2002, three of which were traced to delicatessen-sliced turkey (9, 13, 27). These three outbreaks were responsible for a combined total of 100 listeriosis cases, including 12 deaths and 6 miscarriages and the recall of 48.7 million lb of product (37). In 2003, the U.S. Department of Agriculture, Food Safety and Inspection Service provided three alternatives for controlling *Listeria* in delicatessen meats: (i) postpackage pasteurization and product reformulation to prevent *Listeria* growth, (ii) product reformulation to prevent *Listeria* growth, and (iii) increased product and environmental testing (35).

Food-processing environments continue to be major harbors for foodborne pathogens (30, 31) and specifically *Listeria* (20), with the extent of *Listeria* cross-contamination between equipment and RTE foods in delicatessens still poorly understood (7, 19). Humphrey (15) recovered *L. monocytogenes* from 10 of 32 slicer blades in the United Kingdom, with Uyttendaele et al. (40) isolating *L. monocytogenes* from 4.9% of cooked meat products obtained from Belgian markets. In a 2003 large-scale survey of retail RTE foods in Maryland and Northern California (12), 0.4 and 2.7% of manufacturer- and deli-sliced luncheon meat samples yielded *L. monocytogenes*, respectively. These findings, along with two reports of extended *Listeria* transfer from artificially contaminated slicing machines to luncheon meats during slicing (19, 42), clearly support the need to minimize cross-contamination during the slicing of RTE meats.

Routes of cross-contamination in home and commercial kitchens have been well documented through various assessments of bacterial survival on cutting boards (1, 2, 31), sponges (25, 30), oven mitts (23), pot holders (23), cloth towels (23, 24, 31), and food contact surfaces manufactured from stainless steel (5–7, 11, 12, 18, 20, 21, 26) or other materials (10, 30). Ak et al. (1) showed an increased transfer of *Listeria, Escherichia coli*, and *Salmonella* with scored or scratched plastic cutting boards as opposed to wooden boards. In addition, Montville et al. (24) reported bacterial transfer rates of 0.01 and 10% from contaminated chicken meat to previously uncontaminated chicken meat from food workers with and without vinyl gloves, respectively. Because of sampling difficulties and wide variations in both design and use, bacterial transfer from knife blades has received minimal attention.

*Listeria* can attach to stainless steel in as little as 20
min (26), with the extent of attachment dependent on both the grade of stainless steel and the type of surface finish (14, 33). By means of scanning electron and atomic force microscopy, Arnold and Bailey (5) measured biofilm formation and surface morphology of grade 304 stainless steel having a 2B, sandblasted, sanded, or electropolished finish. When all four surfaces were exposed to a mixed bacterial culture obtained from a poultry carcass rinse, bacterial attachment was at least 1 log lower on electropolished stainless steel than on the other three surfaces. These findings have important ramifications in the manufacture of stainless steel knife blades, delicatesen slicer blades, and other food contact surfaces found on processing equipment, as well as in retail delis.

In a limited study by King (17) with an Instron electromechanical compression analyzer, a lightweight high-speed knife sustained less damage during the slicing of lamb rib bones than the traditional knife blades used for processing, with fewer meat particulates being generated. This study suggests that cross-contamination and subsequent contamination of the processing environment from aerosols and meat particulates can be decreased by improvements in knife blade design.

Recognizing the need to improve current Listeria risk assessments (12, 36), the three primary objectives of this study were to quantify L. monocytogenes transfer from (i) inoculated knife blades to turkey, salami, and bologna, (ii) inoculated turkey, salami, and bologna to knife blades, and (iii) inoculated product to a knife and then to uninoculated product. As a secondary objective, stainless steel grade, surface roughness, knife sharpness, and cutting speed were also assessed for their impact on Listeria transfer during the slicing of deli meats.

MATERIALS AND METHODS

L. monocytogenes strains. Six strains of L. monocytogenes (previously obtained from Dr. Catherine W. Donnelly at the University of Vermont, Burlington)—CWD 205 (source unknown), CWD 578 (dairy plant environment), CWD 701 (cheese), CWD 730 (dairy plant environment), CWD 845 (dairy plant environment), and CWD 1002 (pork sausage)—were chosen from more than 190 strains on the basis of their ability to form weak biofilms in a microtiter plate assay (16). All strains were maintained at −80°C in Trypticase soy broth (TSB; Difco, Becton Dickinson, Sparks, Md.) containing 10% (vol/vol) glycerol. TSB containing 0.6% (wt/vol) yeast extract (TSB-YE; Difco, Becton Dickinson) was inoculated from the frozen stock cultures and incubated at 37°C for 24 h. After a second transfer in TSB-YE, each culture was pelleted by centrifugation at 9,700 × g for 10 min at 4°C (Sorvall Super T21, Sorvall Products, L.P. Newton, Conn.), resuspended in 9 ml of 0.1% peptone (Difco, Becton Dickinson), and combined in equal volumes to produce a single six-strain cocktail containing approximately 10⁸ CFU/ml. Cell concentration was verified by measuring optical density at 600 nm and spiral plating (Autoplate 4000 Spiral Plater, Spiral Biotech Inc., Norwood, Mass.) an appropriate dilution on modified Oxford agar (MOX; Difco, Becton Dickinson) and then incubating at 35°C for 48 h.

Delicatessen meats. One retail brand each of restructured roast turkey breast, Genoa hard salami, and bologna (2.5 to 3.5 kg each) was purchased as intact chubs from a local retailer (Gordon Food Service, Lansing, Mich.), held at 4°C, and used within 20 days of purchase. On the basis of the package label, product compositions were as follows: (i) turkey breast—turkey breast, turkey broth, and <2% (each) salt, dextrose, and sodium phosphates; (ii) salami—pork, beef, salt, and <2% (each) dextrose, water, natural spices, sodium ascorbate, lactic acid starter culture, garlic powder, sodium nitrite, BHA, BHT, and citric acid; and (iii) bologna—beef, pork, water, salt, and <2% (each) dextrose, potassium lactate, sodium diacetate, sodium erythorbate, sodium nitrite, and oleoresin of paprika. Fat, moisture, and crude protein content were determined in triplicate for two lots of each product according to AOAC International methods 991.36, 950.46, and 992.15, respectively (4).

Knife blades and slicing. A series of sharp and medium-sharp electropolished grade 304 and 316 stainless steel knife blades measuring 12 by 5 cm (product contact area of 60 cm² for each side of the blade) with a thickness of 1.4 mm were manufactured by ProAxis, Inc. (Lafayette, Ind.). Sharp knives were machined to a sharp point by milling at a 45° angle 10 mm from the end of the blade. Medium-sharp blades were machined with a blunt end (0.5 mm from tip) to simulate a broken knife blade. Each knife blade had a built-in flange (1 by 2 cm) at each end so that the blade could be attached to a custom-made knife support bracket (Fig. 1).

Surface profiling of knife blades. Knife blade roughness values and overall surface profiles were obtained through the University of Illinois Center for Microanalysis of Materials (Urbana, Ill.) with a Sloan Dektak 3 ST stylus surface profilometer (Veeco Instruments Inc., Woodbury, N.Y.). Initially and after 1 year of use, surface profilometer measurements were taken along six defined 10-mm lines on the front and backsides of the blade. Surface roughness values were obtained by recording the stylus height 40 times per second as the stylus traveled toward the edge of the blade along each 10-mm line at predetermined intervals. Measurements were stopped when the stylus came within 0.5 mm of the blade edge. Average roughness (Ra) was calculated in micrometers according to the standard guidelines of the American National Standards Institute (3). Surface scoring images were taken.
with the surface profilometer after 6 months of use for both 304 and 316 knife blades (Fig. 2).

**Knife blade inoculation.** A turkey slurry was prepared for knife blade inoculation by diluting 25 g of uncured roast turkey breast 1:10 in sterile deionized water and then homogenizing it in a model DFP2 blender (General Electric, Bridgeport, Conn.) at high speed for 1 min. The slurry was then filtered through five layers of sterile cheesecloth, heated in an 80°C water bath for 20 min, transferred to 50-ml sterile centrifuge tubes, and stored at −20°C. Before use, 50 ml of turkey slurry was thawed overnight at 4°C, after which 1 ml of the six-strain cocktail was inoculated into 9 ml of turkey slurry. One face of the ethanol (75% [vol/vol]) flame-sterilized knife blade was then inoculated with 100 µl of turkey slurry. After uniformly spreading 100 µl of inoculum on the 60-cm² blade surface with an inoculating needle so as to contain 10⁸, 10⁵, or 10³ CFU per blade, the blades were dried for 1 h in a laminar flow cabinet at 23°C and 30 to 40% relative humidity. Temperature and humidity were verified with a hygrometer (Fisher Scientific, Hampton, N.H.), after which the inoculated blades were immediately mounted on the Instron 5565 electromechanical compression analyzer for slicing.

**Transfer of *L. monocytogenes* from inoculated grade 304 and 316 stainless steel knife blades to uninoculated product.** In a replicated study (n = 3), uninoculated chubs of turkey breast, salami, and bologna were sliced with knife blades containing 10⁸ and 10⁵ or 10³ *L. monocytogenes* CFU per blade so as to obtain 30 or 20 slices, respectively. These unrealistically high inoculation levels were necessary to quantify the numbers of *Listeria* in consecutive slices for subsequent modeling of *Listeria* transfer. For knife blades containing 10⁸ CFU per blade, all slices were diluted 1:5 (wt/vol) in phosphate-buffered saline (PBS), homogenized in a Stomacher 4000 (Seward, Norfolk, England) for 1 min, and spiral plated (50 µl) on MOX. For inocula of 10⁵ and 10³ CFU per blade, each slice was diluted 1:5 (wt/vol) in University of Vermont Medium (UVM; Difco, Becton Dickinson) and similarly homogenized for 1 min. Duplicate 5-ml aliquots of the homogenate were poured plated in 25 ml of MOX with 150-mm-diameter petri dishes (Fisher Scientific, Chicago, Ill.) and incubated at 35°C for 48 h, with populations determined as the number of *listeriae* per slice. When *Listeria* was not detected by direct plating, MOX plates streaked after enrichment were examined for the presence or absence of *Listeria* following 48 h of incubation at 35°C, with mean *Listeria* populations calculated at the limit of detection for positive enrichments.

**Cleaning and sanitizing of knife blades.** Knife blades were removed from the support bracket after use, soaked in 75% ethanol (vol/vol), wiped with a 1-ply composite tissue (CT) (Kimwipe Ex-L 1-ply white tissue, Kimberly-Clark Corp., Roswell, Ga.), and rinsed with deionized water. Adequacy of this cleaning and sanitizing regimen was confirmed by the CT surface sampling method developed by Vorst et al. (41). Before use, knife blades were rinsed with sterile deionized water and dried with a CT. To prevent surface oxidation during storage, all blades were coated with a thin layer of mineral oil that was previously removed with 95% ethanol and given a final rinse in sterile deionized water.

**Quantification of injured *Listeria* on knife blades.** Five unused grade 304 and 316 stainless steel knife blades were inoculated at 10⁵ CFU per blade as previously described. All blades were sampled by the CT method of Vorst et al. (41), with 1 ml of PBS added to the CT before swabbing. After adding the CT to 9 ml of PBS and homogenizing in a stomacher for 1 min, 50-µl aliquots were spiral plated in duplicate on tryptose phosphate agar (Difco, Becton Dickinson) containing ferric ammonium citrate (0.5 g/liter) and esculin (1 g/liter) (mTPA), for the recovery of healthy and injured cells, and on mTPA with sodium chloride (40 g/liter) (mTPAN) and MOX, for the recovery of healthy cells as previously described (22). All plates were counted after 48 h of incubation at 35°C. Percent injury was determined by the following equation:
<table>
<thead>
<tr>
<th>Product</th>
<th>Grade 304</th>
<th>Grade 316</th>
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<tr>
<td>Turkey</td>
<td>34 ± 4 A</td>
<td>21 ± 3 B</td>
</tr>
<tr>
<td>Bologna</td>
<td>11 ± 3 C</td>
<td>8 ± 1 C</td>
</tr>
<tr>
<td>Salami</td>
<td>57 ± 5 D</td>
<td>50 ± 7 D</td>
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</table>

*Values are expressed as pounds (1 lb = 0.45 kg).*  
*Means with different letters are significantly different (*P* < 0.05).*  

% injury = [(nonselective count - selective count) ÷ nonselective count] × 100

### Statistical analysis

All *Listeria* transfer experiments were replicated three times. *Listeria* transfer to and from knife blades and direct and sequential transfer from inoculated blades to product and inoculated product to un inoculated product via the knife blade were analyzed by a general linear model and analysis of variance for least significant differences in mean recovery (29). Mean differences in surface topography of grade 304 and 316 stainless steel blades were replicated five times and analyzed by a general linear model at each of 5,000 points for six defined areas across both sides of the blade (29).

### RESULTS

#### Proximate analysis

On the basis of proximate analyses, turkey breast, salami, and bologna contained 78, 43, and 60% moisture, <1, 36, and 27% fat, and 19, 17, and 10% protein, respectively.

#### Knife blade surface profiling

The initial roughness values for new knife blades prepared from grades 304 and 316 stainless were 0.105 and 0.070 μm, respectively. After 1 year of use, a significant difference (*P* < 0.0001) in surface topography was seen for both sides of the grade 316 blades, with *R*ₚ values of 2.083 and 3.079 μm, whereas no such difference (*P* > 0.05) was seen for grade 304 blades. The total *R*ₚ values of 7.409 and 2.581 μm (front and back) for grade 304 and 316 blades, respectively, were significantly different (*P* < 0.0001).

#### Effect of stainless grade, product, and sharpness on transfer

Significant differences in cutting force were seen between salami, bologna, and turkey (*P* < 0.05) for grades 304 and 316 stainless steel (Table 1). The average cutting force (1 lb = 0.45 kg) for turkey and salami was 22 ± 3 lb and 48 ± 5 lb for grade 316 and 21 ± 3 lb and 50 ± 7 lb for grade 304 stainless steel blades, respectively. Bologna had the lowest average cutting force for both stainless steel grades at 8 ± 1 lb. Preliminary data showed no significant differences (*P* > 0.05) in *Listeria* transfer with inoculated sharp and medium-sharp 304 grade stainless knife blades inoculated at 10⁸ CFU per blade.

#### Transfer of *L. monocytogenes* from inoculated grade 304 and 316 stainless steel knife blades to uninoculated product

*Listeria* transfer from inoculated knife blades (10⁸ CFU per blade) was generally logarithmic for all three products, with populations on the blade decreasing 2 log after 8 to 12 slices and the initial slices decreasing linearly (Fig. 3). The total number of *Listeria* CFUs transferred was not significantly different (*P* > 0.05) between products. At an inoculation level of 10⁵ CFU per blade, *Listeria* was quantifiable in slices 13 to 20 by direct plating for all three products (Fig. 4). Enrichment results were typically negative for turkey and bologna after 26 slices and positive for salami out to 30 slices (Table 2). Low-level inoculation (10³ CFU per blade) identified a weak logarithmic association (0.35 < *R*² < 0.65) for bologna and no association for turkey or salami (Fig. 5).

Differences in transfer between stainless steel grades 304 and 316 were compared for turkey, bologna, and salami. With a concentration of 10⁵ CFU per blade, stainless steel grade did not significantly affect (*P* > 0.05) numbers of *listeriae* transferred during the first 20 slices. *Listeria* was quantifiable in the first five slices by direct plating, regardless of stainless steel grade or product type. Direct counts were obtained out to five slices for all products and both grades.

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**TABLE 1. Average slicing force for turkey, salami, and bologna with medium-sharp (MS) and sharp (S) knife blades manufactured from grades 304 and 316 stainless steel**

<table>
<thead>
<tr>
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*Values are expressed as pounds (1 lb = 0.45 kg).*  
*Means with different letters are significantly different (*P* < 0.05).*
TABLE 2. Number of samples yielding Listeria by direct count and enrichment (n = 3) for blade-product (BP) and product-blade-product (PBP) transfer for turkey (T), bologna (B), and salami (S).

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a Number of samples positive by direct plating/number of samples positive by enrichment.
b NT, not tested.

grades of stainless. Normalizing data on a log scale for the first 10 slices resulted in significantly greater (P < 0.05) transfer for grade 316 stainless. For slices 10 through 15, more direct counts were obtained from grade 304 than from grade 316 stainless. For slices 10 to 15, total numbers of Listeria transferred were greater with grade 304 than with grade 316 stainless steel blades, resulting in significant differences (P < 0.05) for mean recovery as a function of total CFUs transferred.

Sequential transfer of L. monocytogenes from inoculated product to a grade 304 stainless steel knife blade and then to uninoculated product. Numbers of Listeria transferred from surface-inoculated turkey to uninoculated salami (10⁵ CFU/cm²), inoculated salami to uninoculated turkey (10⁵ CFU/cm²), and inoculated turkey (10⁵ CFU/cm²) to uninoculated turkey were quantifiable by direct plating out to 11, 16, and 30 slices, respectively (Fig. 6). Mean recovery was significantly greater (P < 0.05) for inoculated turkey sliced before uninoculated turkey than when inoculated salami was followed by uninoculated turkey or when inoculated turkey was followed by uninoculated salami. A 2-log reduction was seen within the first 15 slices for all transfer scenarios, along with greater transfer when uninoculated turkey followed inoculated turkey. Enrichments were typically negative after 28 slices when inoculated turkey was sliced before uninoculated salami or when inoculated salami was sliced before uninoculated turkey. Inoculated turkey before uninoculated turkey yielded positive enrichments to 30 slices.

Quantification of injured Listeria on grade 304 and 316 stainless steel knife blades. The nonselective plating medium (mTPA) afforded greater recovery of healthy and injured Listeria cells from stainless steel blades than did selective media (mTPAN and MOX). With mTPAN and

![Image](http://meridian.allenpress.com/jfp/article-pdf/69/12/2939/2002242/0362-028x-69_12_2939.pdf)
MOX, 46 and 72% of the Listeria population was injured, respectively, after 1 h of drying in a laminar flow cabinet. These results partially account for the recovery differences seen when selective media were used for the direct plating and enrichment of slices.

DISCUSSION

Deli meats were chosen for this study on the basis of fat and moisture content, with turkey having the lowest fat (<1%) and highest moisture (78%). Salami had the highest fat (36%) and lowest moisture (43%) content. All knife blades were manufactured to exact specifications to minimize the variability seen in commercially available knife blades. Use of the Instron eliminated operator variability in cutting speed, force, and cutting action (sawing versus chopping). Cutting force and knife sharpness were not significantly different within stainless steel grades and product ($P > 0.05$). The force required to slice the product was significantly higher ($P < 0.05$) for salami than for turkey and bologna.

Product compositional differences did not affect Listeria transfer during slicing, except when inoculated turkey was followed by uninoculated turkey. Although Lin et al. (19) reported that a visible fat layer developed on their delicatessen slicer during the slicing of salami, this fat layer was not pronounced in our study after the knife blade slicing of salami. In our study, Listeria transfer was similar when turkey, salami, and bologna were sliced with an inoculated knife blade. However, when inoculated turkey was sliced and followed by uninoculated turkey, greater transfer was seen to more slices than when inoculated salami or turkey was followed by uninoculated salami.

Our findings are similar to those reported by Vorst et al. (42) and Lin et al. (19), who demonstrated repeated transfer of Listeria from mechanical slicer blades to deli meats. While repeated transfer can occur when products are sliced with kitchen knives, the dynamics of Listeria transfer from kitchen knife blades to products and vice versa are vastly different from mechanical delicatessen slicers because of the sawing and chopping versus the rotating action of the blade. The centrifugal force of the rotating blade and subsequent transfer to other parts of the slicer (e.g., guard, back plate, table, collection area) and the surrounding work surfaces is not observed when evaluating the downward sawing and chopping action of a knife. When mechanically slicing salami, the excessive smearing of fat and the development of a fat layer on the blade, as reported by Vorst et al. (42) and Lin et al. (19), were not as prevalent on kitchen knife blades, resulting in a different transfer scenario than in commercial delicatessen slicers. Unlike previous studies with mechanical slicers, the reduced fat layer on knife blades resulted in greater transfer rates (>1 log CFU per slice) from inoculated turkey to uninoculated turkey during sequential slicing.

Different types of stainless steel exhibit pronounced differences in ductility, toughness, strength, workability, and resistance to corrosion that dictate their specific use. In the food industry, AISI (American Iron and Steel Institute) grades 304, 304L, 316, and 316L stainless steel are the most popular alloys (3, 5, 6, 8, 32, 33), with the 400 series also commonly used for knife and slicer blades. A seemingly endless variety of knives are being marketed for industrial and home use. In addition to obvious differences based on intended use, knife blades differ in surface finish and polish type, stainless steel grade (e.g., carbon, nickel, molybdenum content), cutting edge styles (serrated and straight), and overall surface area. Knife blade sharpness did not affect Listeria transfer but did result in a lower cutting force for sharp blades. Although cutting force and speed would be expected to affect bacterial transfer, variability between or within the products sliced was too high to identify any discernible differences. Furthermore, large changes in surface topography most likely masked any subtle difference seen in knife force or sharpness.

Current methods for quantifying Listeria on heavily soiled food contact surfaces are too imprecise to allow the use of more realistic contamination levels ($10^1$ to $10^2$ CFU/cm²) (10). Recent studies have also indicated Listeria transfer near the end of mechanical slicing after negative slices or slices in which Listeria was not previously detected, thus suggesting that slicer design, blade rotation speed, and accumulation of debris are factors affecting the presence or absence of Listeria (19, 42). Our study supports these findings, with sporadic recovery of Listeria at the low ($10^3$ CFU per blade) inoculation level. Once improved recovery methods have been developed, further research needs to be conducted at very low-level inoculation levels to fully understand the impact of knife sharpness on bacterial transfer during the slicing of RTE meats.

Stainless steel grade did not significantly affect ($P > 0.05$) the total number of Listeria cells transferred during slicing. However, the two stainless steel grades were significantly different with respect to slice ($P < 0.05$) for the first 10 slices, with a pronounced “tailing effect” seen for grade 304 stainless. In contrast, greater transfer of Listeria to fewer slices was evident with grade 316 stainless, which may be related to the smoother finish, greater durability, and easier cleanability (8, 18). Our surface topography results support these findings, with overall $R_{a}$ values being significantly lower and less variable for grade 316 stainless steel knives. Surface scoring was also less pronounced on grade 316 than on grade 304 stainless steel blades, with the latter showing obvious score marks after 6 months of repeated use and cleaning. According to Percival (28), the molybdenum concentration in grade 316 stainless may be partially responsible for decreased viability of bacteria and reduced biofilm formation. While our findings cannot confirm or deny these biocidal claims for molybdenum, greater injury of Listeria was seen with grade 316 (72% molybdenum) than with grade 304 stainless (46% molybdenum).

On the basis of U.S. Food and Drug Administration guidelines published in the 2005 Food Code (38), all food contact surfaces on equipment must be cleaned every 24 h if held at <5°C, every 10 h when held at 10 to 12.8°C, and every 4 h if held at ambient temperature, with cleanliness being defined as “clean to sight and touch.” These cleaning schedules clearly allow sufficient time for bacterial attachment, growth in the presence of food residues, and subse-
quent transfer to previously uninfected products or other food contact surfaces. Food preparation equipment such as knives will score over time, with these scratches and crevices becoming potential harborage for bacteria even after cleaning and sanitizing. On the basis of our findings, ample opportunity exists for transfer of _Listeria_ with kitchen knives in both commercial and home settings, with the highest risk of consumer exposure coming from the first 5 to 15 slices, depending on the grade of stainless steel used, the type of product being sliced, and other factors. While the numbers of listeriae transferred in such settings would be admittedly very low, even a few _L. monocytogenes_ cells may pose a public health risk to consumers if the product formulation permits the growth of _Listeria_ in home refrigerators during extended storage.

**ACKNOWLEDGMENTS**

This study was funded by the U.S. Food and Drug Administration under contract FD-U-0021-05-02. The authors are grateful for the surface profile analyses conducted by the Center for Microanalysis of Materials, University of Illinois at Urbana, which is partially supported by the Department of Energy under grant DEFG02-91-ER45439.

**REFERENCES**


study of stainless-steel finishes used in food processing equipment. 

34. Tompkin, R. B. 2001. Control of *Listeria monocytogenes* in the food-


