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ABSTRACT

The microbiology of plastic and wooden cutting boards was studied, regarding cross-contamination of foods in home kitchens. New and used plastic (four polymers plus hard rubber) and wood (nine hardwoods) cutting boards were cut into 5-cm squares ("blocks"). Escherichia coli (two nonpathogenic strains plus type OI57:H7), Listeria innocua, L. monocytogenes, or Salmonella typhimurium was applied to the 25-cm2 block surface in nutrient broth or chicken juice and recovered by soaking the surface in nutrient broth or pressing the block onto nutrient agar, within 3-10 min or up to ca. 12 h later. Bacteria inoculated onto plastic blocks were readily recovered for minutes to hours and would multiply if held overnight. Recoveries from wooden blocks were generally less than those from plastic blocks, regardless of new or used status; differences increased with holding time. Clean wood blocks usually absorbed the inoculum completely within 3-10 min. If these fluids contained J(Y-104 CFU of bacteria likely to come from raw meat or poultry, the bacteria generally could not be recovered after entering the wood. If ~106 CFU were applied, bacteria might be recovered from wood after 12 h at room temperature and high humidity, but numbers were reduced by at least 98%, and often more than 99.9%. Mineral oil treatment of the wood surface had little effect on the microbiological findings. These results do not support the often-heard assertion that plastic cutting boards are more sanitary than wood.

For millennia, surfaces on which meat was cut and other foods were prepared have traditionally been wooden. Various polymers became available in the early 1970s and seem to have become the work surfaces of choice despite a dearth of published microbiological research to support the change.

The hypothetical concern, at least in home kitchens, was and is cross-contamination. Residues of fluid ("juice") from raw meat or poultry might remain on the work surface and transfer disease agents to raw vegetables or other foods that would not be cooked further before being eaten. And some of the bacteria-though not viruses or other disease agents-might multiply on the surface between being de-posited from the first food and contaminating another.

Wooden cutting boards have probably been suspected in this context for as long as bacteria have been recognized as causes of disease. Although use of wooden work surfaces has generally been advised against for at least 20 years, it is important to note that circumstances in home kitchens are special and may differ from those in restaurants, butcher shops, and meat processing establishments, where ready-to-eat foods are ideally prepared on surfaces other than those on which raw animal products are handled or cut.

The bacteria of greatest concern as cross-contaminants on kitchen cutting boards are principally of animal origin but are significant causes of human infectious disease (zoonoses) transmitted via

foods and able to multiply at room temperature or below. Escherichia coli 0157:H7, Listeria monocytogenes, and Salmonella typhimurium meet these criteria. Campylobacter jejuni may also be a cross-contaminant but does not multiply at room temperature, and Yersinia enterocolitica seems to be less prevalent than the other named zoonotic bacterial species. C. jejuni and Salmonella spp. have been isolated, by swabbing, from cutting boards on which raw chicken had been cut (3). Neither the material of which the boards were made, nor any attempt to clean them after contamination, was mentioned.

Conclusions regarding the microbiology of cutting boards may depend greatly on how contamination and sampling are done, yet there are not standard methods for carrying out such experiments. Mossel et al. (10) contaminated a used beech butcher block by pressing ground meat onto it and tested for indigenous Enterobacteriaceae and Gilbert (5) enumerated indigenous flora on food-contact surfaces in a self-service retail store. Both studies found the alginate swab method to be more sensitive, but contact testing (e.g., the "agar sausage" method) (13) appeared to be the more useful routine control procedure. Ruosch (12) compared cotton swabs and cold water jets for recovery of inoculated Serratia marcescens or indigenous microflora: various results were obtained with plastic surfaces; S. marcescens that was not recovered from balsa wood surfaces by the swab or water jet methods could evidently be recovered from the interior by homogenization of the wood.

Gilbert and Watson (6) inoculated wood and proprietary plastic cutting boards by pressing ground beef onto their surfaces and found the wood harder to clean under their conditions. Kampelmacher et al. (8) contaminated a butcher's chopping block with Salmonella typhimurium and Staphylococcus aureus, applied by mixing them with gamma-ray sterilized ground beef which was rubbed onto the surface; sampling was by alginate swab, "agar sausage" contact, gouging out the wood surface, or pounding a gamma-ray sterilized veal cutlet. With this method of contamination, S. typhimurium was detectable (by agar sausage) on wood surfaces contaminated with ground beef containing 6 x 108 and 4 x 107 CFU/g but not 1.4 x 105 CFU/g. After decontamination of surfaces that had received the higher levels of inoculum, the gouge and veal cutlet methods were most likely to recover S. typhimurium.

Given the dearth of published experimental results, it is noteworthy that the U.S. Department of Agriculture (USDA) Meat and Poultry Inspection Manual (14) recommends that boards used on boning and cutting tables be of approved plastics, though, "Close grained hardwood boards are acceptable, provided they are smooth and in good repair." These stipulations, with the further requirement that boards be thoroughly cleaned, sanitized, and air dried after each day's operation, were specifically directed to meat and poultry processing facilities under USDA inspection. Still, the USDA's Food News for Consumers (9) extrapolated and recommended that plastic, not wooden, cutting boards be used in consumers' kitchens.

The objective of the present study was to compare the potential of plastic and wooden cutting boards to promote cross-contamination under conditions pertinent to home kitchens. We report here experimental contamination of plastic and wooden cutting boards with model and zoonotic bacteria and recovery of the contaminants as functions of the type of board and its history. Development of the necessary contamination and recovery methods is detailed. An accompanying paper (1) describes experimental clean-ing and disinfection of the plastic and wooden cutting boards, as well as attempts to characterize the interaction of bacteria with wood.

MATERIALS AND METHODS

Boards

New plastic and wooden cutting boards were donated by manufacturers and distributors. Used plastic and wooden boards came from home kitchens, a retail meat cutting establishment, and pilot meat and poultry processing facilities of the University of Wisconsin-Madison. Woods tested included ash, basswood, beech, birch, butternut, cherry, hard maple, oak, and American black

walnut. Polymers were polyacrylic, polyethylene, foamed polypropylene, polystyrene, and hard rubber. Not all were available in both new and used conditions. When a board was received, its surface was sampled by the modified "agar sausage" (see below) method, and the board was cut into 5-cm square blocks (area 25 cm2). Laminated wooden boards were usually cut diagonal to the wood grain and included two or more glue joints. Pieces of board were selected randomly for each experiment. Some of the new wooden boards had been treated with mineral oil; these were re-treated before each experiment with the mineral oil supplied by their manufacturers.

The ability of wood blocks to withstand the following cleaning or decontamination procedures was tested: pouring hot (55°C) or cold (17°C) chlorine bleach solution (25%, vol/vol; available chlorine ca. 12,500 mg/L) or boiling water over the blocks, washing the blocks in a dishwasher with commercial detergent (65°C; wash and rinse time: 40 min; drying time: 20 min), or autoclaving them (liquid cycle; 121°C for 15 min). In each of these treatments, blocks were placed on a solid support so that they did not soak in the water. Surface roughness (raised grain) resulting from these cleaning procedures was corrected as necessary with fine sandpaper. In the case of autoclaving there was also glue joint failure in some blocks; therefore, autoclaving was not used in further experiments. An attempt at disinfecting the blocks in a microwave oven caused them to char. Therefore, at the end of each experiment, the blocks were washed with a hot water solution of laboratory grade detergent (Micro, International Products Corp., Trenton, NJ) or immersed (contaminated-side-down, left for 1 h) in a pan of hot solution of chlorine bleach if the contaminant was a pathogen. Blocks were air dried and stored at room temperature; some blocks were used in >30 experiments.

Bacteria

Initial studies were done with E. coli Kl2 Hfr (ATCC 23631), an environmental strain (ECC 132) of E. coli that had been isolated from the Chesapeake Bay (C. W. Kaspar, unpublished) and Listeria innocua (provided by K. A. Glass, Food Research Institute). Definitive experiments were done with Escherichia coli OI57:H7, Listeria monocytogenes (Scott A), and Salmonella typhimurium (clinical isolate), all provided by K. A. Glass. Indigenous bacteria in juice from commercial chicken packages were used in two experiments.

Media were nutrient agar and nutrient broth (Difco Laboratories, Detroit, MI). Cultures used to contaminate blocks had been grown overnight at 37°C in nutrient broth.

Contamination of blocks

Before each experiment, each test surface was sterilized with ultraviolet light for 1 h in a laminar flow hood. Tests of uninoculated control blocks showed that this treatment eliminated background contamination. Two methods were used to contaminate test surfaces.

Method 1. The surface to be contaminated was pressed against the bottom of a petri dish containing 0.33 ml of inoculum Gust enough to cover the block's surface), which required weigh-ing each block before and after contamination to determine the amount of inoculum taken by the block, and also testing both the block surface and the remaining inoculum in the petri dish (it was not assumed that the bacteria were distributed exactly as the fluid was) in the case of recovery studies. These results had to be expressed as percentage of the inoculum taken up by each block and were relatively variable.

Method 2. The inoculum (0.5 ml) was deposited directly on the upper block surface and spread with the side of the pipet. The increased volume of inoculum permitted uniform spreading.

In early experiments, contaminant levels were low (ca. 103 CFU/25 cm2), to simulate practical situations (4,7). In some later experiments, levels were 106_108 CFU/25 cm2, to determine the effect of extreme contamination.

Recovery of contaminants

In our version of the "agar sausage" surface sampling technique, nutrient agar medium was sterilized in plastic cylinders made from autoclavable 60-ml syringes, 2.54 cm diameter, by cutting the end from the barrel. The agar surface (ca. 5 cm2 area) was raised past the end of the barrel by pushing the plunger, pressed against the test surface, sliced off with a sterile knife, and transferred into a petri dish. Bacteria were also recovered by pressing a block directly onto the surface of nutrient agar in a petri plate (applied so as to avoid trapped air and pressed gently for 2 min) or by soaking the contaminated surface for 2 min in 5 ml nutrient broth in a petri plate. Bacteria in the broth were enumerated by spread plating serial lO-fold dilutions onto nutrient agar or by a 5-tube (nutrient broth) most probable number (MPN) scheme that was interpreted by a standard MPN table (11). Colonies were counted and MPN tubes read after ca. 20 h at 37°C.

The more frequently used recovery technique consisted of soaking the block surface in 5 ml of nutrient broth for 2 min. Several modifications of this method, such as sonication during soaking for 30 s, doubling the soaking time, repeating the soaking once more with a fresh medium, and replacing the nutrient broth with phosphate-buffered saline (pH = 7.2) were tested. Sampling intervals after contamination were typically 0 and 3 or 10 min and ca. 12-18 h. To avoid the confounding antibacterial effect of drying, blocks held for overnight were kept in a saturated-humidity chamber.

Results were analyzed with the analysis of variance, t- and t" -test procedures using Statgraphics software (STSC, Inc., Rockville, MD; 2).

RESULTS

Cutting boards as received

New plastic and wooden boards were sampled by the agar sausage method when their shrink wrapping was removed; most were found to be virtually sterile as received. Among the used boards, noteworthy observations were that one used polyethylene board from a retail meat cutting establishment had very few bacteria, whereas a used maple board from a home kitchen had many (data not shown).

Recovery method

Because there are no standard methods for recovering bacteria from such surfaces, the basic method used here (soaking the block surface 2 min in 5 ml nutrient broth) was validated. Oil-treated birch blocks were contaminated with E. coli K12 Hfr in nutrient broth (Method 1) and immediately soaked: (i) 2 min in 5 ml nutrient broth; (ii) 2 min in 5 ml nutrient broth, then 2 min in another 5 ml of nutrient broth; or (iii) 4 min in 5 ml of nutrient broth. With four replicates per treatment, the mean percentages of the inoculated bacteria recovered, ± standard error, were 90 ± 6, 94 ± 6, and 83 ± 6, respectively, which did not differ significantly ($p > 0.05$). At least under these conditions, there was no mandate to extend or complicate the soaking process for recovery of bacteria.

In that fewer of the inoculated bacteria could be recovered from wood as early as 3 min after inoculation, a sonic cleaning bath (Branson, B-52 Ultrasonic Cleaner, Branson Cleaning Equipment Company, Shelton, CT) was evaluated as a means of dislodging the missing microbes. A petri dish containing the rinse medium and block was placed on a rack in the bath so that all of the bottom surface of the dish was in the water. The distance between the transducer and bottom surface of the petri dish was ca. 7.3 cm; sonication was applied for 30 s. Various wood species, without and with oil treatment, were contaminated with E. coli K12 Hfr in nutrient broth (Method 1), held 3 min, and soaked 2 min in 5 ml nutrient broth without and (in a separate trial) with sonication; foamed polypropylene blocks served as controls (Table 1). Results did not differ significantly ($p > 0.05$) with sonication, as determined by two-way analysis of variance, showing that sonication did not

enhance recovery of the inoculated bacteria from wood (with or without oil treatment) or plastic boards.

TABLE 1. *Recovery of* E. coli *K12 Hfr from various surfaces 3 min after contamination, as a function of sonication.*[a]

Material	Oil treatment	Sonication[b] No	Sonication[b] Yes
Basswood	-	5 ± 2	11 ± 2
	+	8 ± 2	2 ± 1
Birch	+	2 ± 1	2 ± 1
Birch (sanded)	+	1 ± 0	3 ± 2
Maple + walnut[c]	-	3 ± 1	9 ± 7
	+	0 ± 0	3 ± 1
Polypropylene	-	60 ± 15	59 ± 16

[a] Three minutes after contamination (Method 1, 1.1×10^4 CFU/inoculum), the surface was immersed, inverted, in 5 ml of nutrient broth for 2 min, without or with sonication.

[b] Data are the mean percentage of the inoculated bacteria recovered ± the standard error; there were four replicates for each treatment except those of polypropylene, which had two.

[c] Laminated of alternate strips of hard maple and American black walnut.

Monoculture contamination was used through most of the study, to obviate the need for selective media that might bias the tests against detection of injured organisms. Given that injured organisms may be less able to multiply on agar than in fluid medium, the MPN assay procedure was compared with spread plating (Table 2). On the basis of the t' -test, which does not assume homogeneity of variances, the results of the two methods did not differ significantly ($p > 0.05$). This shows that MPN and CFU titers from these wooden and plastic blocks were equivalent--within the considerable experimental error that inheres (especially) in the MPN assay.

TABLE 2. *Comparison of MPN vs CFU assays for* E. coli *K12 Hfr recovered from mineral oil coated-birch, oiled-hard maple, and foamed polypropylene boards.*

Material	Trial[a]	MPN[b]	CFU[c]
Birch	1	7.3 ± 4.2	0.4 ± 0.1
	2	0.4 ± 0.3	2.7 ± 1.0
Maple	1	6.8 ± 1.4	4.9 ± 1.8
	2	1.7 ± 0.9	1.6 ± 1.5
Polypropylene	1	89.2 ± 25.2	66.8 ± 5.2
	2	40.8 ± 15.3	72.5 ± 33.5

[a] Method 1 contamination with 4.3×10^3 CFU/25-cm^2 block in Trial 1 and 6.6×10^3 CFU/25-cm^2 block in Trial 2, 4 blocks per determination; blocks were held 3 min at room temperature before recovery was attempted.

[b] Data are the mean MPN/block ± the standard error.

[c] Data are the mean CFU/block ± the standard error.

Another attempt to determine whether organisms were injured, rather than killed, compared recoveries from blocks soaked with phosphate-buffered saline (PBS) and with nutrient broth (Table 3). By two-way analysis of variance, differences were notsignificant between the two recovery diluents nor between the two bacterial species. This shows that PBS was not a more efficient eluent than nutrient broth.

TABLE 3. *Comparison of two rinsing media (nutrient broth vs phosphate-buffered saline) for recovery of* E. coli *ECC 132 and* L. innocua *from mineral oil-coated birch board surfaces (two replicates each) after overnight holding at high humidity.*[a]

Bacterium	Recovery	
	Nutrient broth	PBS
E. coli	$1.8\ (\pm 1) \times 10^{-3}$	$2.4\ (\pm 0.2) \times 10^{-3}$
L. innocua	$4.3\ (\pm 2) \times 10^{-2}$	$1.4\ (\pm 1) \times 10^{-2}$

[a] Method 2 contamination: *E. coli* = 1.3×10^7 CFU/25-cm^2 block; *L. innocua* = 2.6×10^7 CFU/25-cm^2 block; data are percentage recovery ± standard error.

Block type and history

Given an extensive body of diverse experiments regarding recovery of bacteria from various cutting boards, results have been summarized according to the following general hierarchy: (i) plastic versus wood surfaces, (ii) blocks from new versus used boards, and (iii)--for wood only--plain or oil-treated surfaces. Recoveries of E. coli KI2 Hfr from new wood (without and with oil treatment) and plastic boards were compared as a function of wood species or polymer type at various intervals after contamination by Method I (Table 4). Analysis of variance showed that recoveries: (i) at 0 min from basswood (without oil treatment) and polypropylene differed significantly ($p < 0.05$) from one another and the others; (ii) at 3 min did not differ significantly among wood species ($p > 0.05$) nor among polymers, but did differ significantly ($p < 0.05$) between wood and plastic boards; and (iii) at ca. 12 h differed ($p < 0.05$) only for polypropylene (the only polymer tested at this interval) versus all others. This showed that, with Method I contamination, more bacteria were recovered from new plastic blocks than from new wood blocks, beginning as early as 3 min.

TABLE 4. *Recovery of* E. coli *K12 Hfr from new wood and plastic surfaces at various intervals after contamination.*[a]

Material	Oil treatment	Sampling time[b] 0[c]	3 min[d]	12 h[e]
Basswood	-	23 ± 4	4 ± 1	0 ± 0
	+	54 ± 6	6 ± 1	1 ± 1
Birch	+	68 ± 5	1 ± 1	1 ± 1
Birch (sanded)	+	66 ± 7	7 ± 6	0 ± 0
Maple	+		3 ± 1	
Maple + walnut[f]	-	62 ± 6	1 ± 1	0 ± 0
	+	57 ± 8	4 ± 1	2 ± 1
Polyacrylic	-		71 ± 7	
Polyethylene	-		70 ± 4	
Polypropylene	-	92 ± 8	74 ± 10	2518 ± 745
Polystyrene	-		79 ± 15	

[a] At the indicated time after contamination (Method 1, 10^3-10^4 CFU/inoculum), the surface was immersed in 5 ml of nutrient broth.

[b] Data are the mean percentage of the inoculated bacteria recovered ± the standard error.

[c] There were 12 replicates of each of the wood determinations done and 32 of the polypropylene.

[d] There were 8 replicates of all determinations, except 14 for polypropylene and 7 for polystyrene.

[e] Approximate sampling time. There were 6 replicates of every determination.

[f] Laminated of alternate strips of hard maple and American black walnut.

Important events clearly occurred during the first 3 min, especially on the wooden surfaces. Therefore, this holding period was chosen for preliminary determination of the effect of new or used status on the recovery of E. coli ECC 132 from plastic and wooden surfaces (Table 5). Because the boards were donated, it was not possible to match new and used boards of the same species. Recoveries from the butternut (used) and polyethylene (both new and used) differed significantly ($p < 0.05$) from each other and from all of the others by analysis of variance. Hence, the difference between recoveries of bacteria from wood and plastic within 3 min after contamination did not depend on whether the boards were new or used.

TABLE 5. *Recovery of* E. coli *ECC 132 from new and used board surfaces, 3 min after contamination.*[a]

Material	Used	Oil treatment	Replicates	Recovery[b]
Butternut	+	-	4	20 ± 2
Maple	-	+	8	3 ± 1
	+	-	4	4 ± 4
	+[c]	-	3	8 ± 8
Polyethylene	-	-	8	70 ± 4
	+	-	8	64 ± 6

[a] At 3 min after contamination (Method 1, 10^3-10^4 CFU/inoculum), the surface was immersed, inverted, in 5 ml of nutrient broth for 2 min.

[b] Data are the mean percentage of the inoculated bacteria recovered ± the standard error.

[c] These pieces were cut from a used maple cutting board other than those in the row above.

A further trial, with ca. 12-h holding time, was in-tended to verify that wood was not greatly affected by having been used (Table 6). There was no significant difference ($p :> 0.05$) among the recoveries from the wooden boards, though the recoveries from the polypropylene differed significantly ($p < 0.05$) from all others by analysis of variance. Even with very high levels of contamination, bacteria applied to either new or used wood were greatly reduced or undetectable after overnight hold-ing. Bacteria on the new polypropylene appeared to have undergone at least four doublings during the holding period.

TABLE 6. *Recovery of* E. coli *ECC 132 from new and used board surfaces, ca. 12 h after contamination.*

Material	Used	Oil treatment	Recovery[b]
Basswood	-	-	<50
		+	<50
Birch	-	+	$8.3\ (\pm 1.6) \times 10^3$
Birch (sanded)	-	+	<50
Butternut	+	-	<50
Cherry	+	-	<50
Maple	+	-	<50
	+[c]	-	<50
Maple + walnut[d]	-	-	$2.9\ (\pm 0.76) \times 10^4$
	-	+	<50
Polypropylene	-	-	$5.4\ (\pm 1.6) \times 10^8$

[a] At 12 h after contamination (Method 2, 2.1×10^7 CFU/25-cm^2 block), the surface was immersed, inverted, in 5 ml of nutrient broth for 2 min.

[b] Data are the mean CFU of the inoculated bacteria recovered ± the standard error.

[c] These pieces were cut from a used maple cutting board other than those in the row above.

[d] Laminated of alternate strips of hard maple and American black walnut.

When additional types of wood boards became avail-able, these were tested with both 3-min and 12-h holding periods (Table 7). The end-grain maple, which absorbed the inoculum most rapidly, showed particularly rapid disappearance of the bacterium. With high levels of contamination by Method 2, some bacteria were still detectable after 3 min but generally not after 12 h.

TABLE 7. *Persistence of* E. coli *O157:H7 on new wooden cutting boards as functions of type of wood and holding time.*[a]

Material	Holding period	
	3 min	12 h
Ash	$2.5\ (\pm 0.17) \times 10^7$	<50
Maple (end grain)	$5.0\ (\pm 0.56) \times 10^5$	<50
Oak	$2.6\ (\pm 0.02) \times 10^7$	$4.3\ (\pm 2.2) \times 10^2$

[a] Method 2 contamination, 2.8×10^7 CFU/25-cm^2 block; room temperature holding; two replicates per determination; data are the mean CFU/block ± the standard error.

Results presented above showed little influence of oil treatment on the microbiology of wooden cutting surfaces. The purpose of treating the wood with oil is to limit water penetration, possibly in part to protect glue joints. A proprietary oil product that contained a wetting agent was com-pared to pure mineral oil, from the standpoint of water uptake by laminated maple-and-walnut blocks. Four blocks treated with each oil were placed in contact with 0.33 ml sterile distilled water, as in Method 1 contamination. The mean uptake by each group was 27% (wt/wt) of the added water (no difference).

Oil treatment was tested further regarding its influence on water penetration and thus on bacterial contaminants. Laminated maple and walnut blocks, with and without oil treatment, were soaked for 10 min in 5 ml of sterile distilled water in a petri dish; uptake was estimated as ca. 10% of the weight of the block or 2.5 to 2.8 ml per block. These and two matching blocks that had not been soaked were contaminated (Method 2, 2.8 x 107 CFU per block) with E. coli ECC 132 and held ca. 12 h at room temperature before testing. All recoveries were SO.Ol%, and differences in recoveries between treatments (oil or none, soaking or none) were not significant ($p > 0.05$) by t-tests. These findings indicated that oil treatment had minimal effect on both water uptake by and apparent disappearance of bacteria from wooden surfaces.

Bacterial contaminants

Many experiments were done with nonpathogenic strains of E. coli and with L. innocua to minimize hazards as much as possible. Still, it was important to determine whether results obtained with a particular strain or species were probably applicable to others. Recoveries of the two nonpathogenic E. coli strains (Method 2 contamination at levels> 107 CFU125-cm2 block) from four wood species were compared after overnight holding; these ranged downward from 0.0021 %. Recoveries, paired by type of wood and whether oil had been applied, were compared by the t' -test (which does not assume homogeneity of variances) and found not to differ significantly ($p > 0.05$), indicating that these two strains of E. coli, at least, interacted similarly with wood.

Two experiments were done with the intrinsic flora of the chicken juice collected from retail packages. In both instances, estimates of levels of bacteria present in several samples were inaccurate, so that some results had to be reported as "greater than" or "less than." In the first trial, there appeared to be some multiplication of the chicken juice flora on the wooden blocks, whereas very substantial multiplication occurred on the plastic blocks (Table 8).

TABLE 8. *Overnight (ca. 12 h) persistence, at room temperature, of intrinsic bacteria in chicken juice applied to cutting boards.*[a]

Material	Oil treatment	Replicate	CFU recovered
Basswood	-	1	$>5 \times 10^3$
		2	$>5 \times 10^3$
	+	1	$>5 \times 10^3$
		2	$>5 \times 10^3$
Birch	+	1	6.8×10^3
		2	$>1.4 \times 10^4$
Maple	+	1	$>5 \times 10^3$
		2	7×10^3
Maple + walnut[b]	-	1	1.5×10^4
		2	8.5×10^3
	+	1	1.3×10^3
		2	2.4×10^4
Plastics[c]	-	(8)	$>5 \times 10^6$

[a] Method 1 contamination, 3.2×10^3 CFU/25-cm^2 block.

[b] Laminated of alternate strips of hard maple and American black walnut.

[c] Polyacrylic, new polyethylene, used polyethylene, and polypropylene (two blocks each) all yielded $>5 \times 10^6$ CFU.

In the second experiment, blocks were contaminated by Method 2 with chicken juice containing 3 x 103 CFU of intrinsic flora. After overnight (ca. 12 h) holding at room temperature with the usual humidification, 10 wooden blocks (two each of used butternut, used cherry, and from each of three different used maple boards) yielded <150 CFU, whereas a sole block of used polyethylene yielded 2.5 x 109 CFU. In this instance, recoveries of the bacteria from wood were below the levels inoculated, whereas extensive multi-plication occurred on the polyethylene.

Recoveries of three selected species of bacteria were then compared after application in filter-sterilized raw chicken juice and holding the blocks overnight at room temperature. New blocks were selected randomly from each class (plastic or wood) for this experiment (Table 9). It seems clear that, even when chicken juice was substituted for the nutrient broth in which the contaminants were usually suspended, substantial increases in numbers of bacteria recovered from plastic and decreases in recoveries from wood were seen with all three bacterial species.

TABLE 9. *Overnight (ca. 12 h) persistence at room temperature of bacteria applied in filter-sterilized chicken juice.*

Material[a]	Replicate	Recovered (%)		
		E. coli [b]	*L. innocua* [c]	*S. typhimurium* [d]
Plastic	1	9.8×10^3	1.4×10^3	2.3×10^3
	2	7.0×10^3	1.7×10^3	2.1×10^3
Wood	1	5.5×10^{-2}	1.9	6.4×10^{-1}
	2	1.0×10^{-2}	9.0×10^{-2}	3.4×10^{-2}

[a] Picked randomly from among new plastic (regardless of polymer) and wooden (regardless of species) boards.
[b] Serotype O157:H7, Method 2 contamination, 4.4×10^6 CFU/25-cm^2 block.
[c] Method 2 contamination, 5.2×10^6 CFU/25-cm^2 block.
[d] Method 2 contamination, 1.4×10^7 CFU/25-cm^2 block.

In a similar experiment with nutrient broth as the suspending medium, E. coli ECC 132, L. innocua, and S. typhimurium were each applied (Method 2, all at levels 107 CFU/25-cm2 block) to 12 randomly selected blocks from new boards of several wood species and held over-night. Mean recoveries ranged downward from 0.024% of the levels of bacteria applied; there was no significant difference among recoveries from different boards ($p > 0.05$). In the comparisons among microorganisms, there was a significant ($p < 0.05$) difference in recoveries among species: E. coli ECC 132 differed significantly from L. innocua, but neither of these differed significantly from S. typhimurium.

Method 2 contamination was also used with moderate numbers «104 CFU) of bacteria in nutrient broth, applied to various board surfaces (Table 10). In this instance, the sampling interval was only 10 min, and some of the inoculated bacteria were recovered from all but one of the surfaces. When the results were tested with multi-factor analysis of variance, no significant difference was found among pathogen species, but recoveries were significantly ($p < 0.0002$) greater from plastic than from wood.

TABLE 10. *Recoveries of three bacterial species from various board surfaces 10 min after contamination at moderate levels by Method 2.*

Bacterium[a]	Material[b]	Used	Oil	Recovery (%)
E. coli O157:H7	Beech	+	-	1.7
	Birch	-	+	22.2
	Maple	-	+	29.9
		+	-	33.3
	Polyacrylic	+	-	61.5
	Polypropylene	-	-	72.6
L. monocytogenes	Basswood	-	-	0
	Maple	-	+	8.6
	Maple #1[c]	+	-	46.4
	Maple #2	+	-	27.5
	Polyacrylic	+	-	51.4
	Polyethylene	-	-	56.4
S. typhimurium	Birch	-	+	21.8
	Butternut	+	-	60.9
	Maple	+	-	29.6
	Maple + walnut[d]	-	+	14.6
	Polyethylene	-	-	82.3
		+	-	61.6

[a] Levels inoculated were: *E. coli* O157:H7 = 1.9×10^3 CFU/25-cm^2 block; *L. monocytogenes* = 6×10^3 CFU/25-cm^2 block; *S. typhimurium* = 4.0×10^3 CFU/25-cm^2 block.

[b] Because different varieties of wood and plastic were used with each bacterium and no significant differences had been seen among woods or among plastics, woods were pooled as a group and plastics as another group to compare recoveries of the different pathogen species.

[c] These numbers represent blocks produced from different boards from different sources.

[d] Laminated of alternate strips of hard maple and American black walnut.

DISCUSSION

This study was intended to help minimize cross-contamination by bacteria from raw animal products, via cut-ting boards, to other foods in home kitchens. Although we originally hoped only to

find some practical means for home cooks to clean or sanitize a wooden cutting board so as to be almost as safe as a plastic board, our early experiments showed that wood generally yielded fewer bacteria than did plastic after contamination. Experimental conditions of contamination and holding temperatures were predicated on home kitchens, except that the bacterial contaminants were generally monocultures, to avoid the need for selective media that might bias tests if injured cells were present. Although the strategy of cutting the blocks into 5-cm squares has not been used by others, it affords significant flexibility in replication, randomization, combinations of treatments, etc. This approach should be considered seriously if standard methods for these kinds of experiments are ever to be developed.

In these preliminary studies, we encountered unexpected difficulty in recovering inoculated bacteria from wood surfaces, regardless of wood species and whether the boards were new or used and untreated or oiled. This may be similar to the findings of Kampelmacher et al. (8) and Ruosch (12), who contaminated wood surfaces and needed destructive procedures to recover bacteria that had gone beneath the surfaces to which they had been applied. Inoculated bacteria were readily recovered from plastic surfaces, regardless of the polymer and whether the boards were new or used. Attempts to relate these findings to contamination and cleaning situations that occur in kitchens, and to determine what happens to bacteria applied to wood, are described in a further report (1).

////////////////////// TABLE 1 ////////////////////////////
TABLE 1. Recovery of E. coli K12 Hfr from various surfaces 3 min after contamination, as a function of sonication." a. Three minutes after contamination (Method 1, 1.1 X 104 CFU/ inoculum), the surface was immersed, inverted, in 5 ml of nutrient broth for 2 min, without or with sonication. b. Data are the mean percentage of the inoculated bacteria recovered ± the standard error; there were four replicates for each treatment except those of polypropylene, which had two. c. Laminated of alternate strips of hard maple and American black walnut.
////////////////////// TABLE 2 ////////////////////////////
TABLE 2. Comparison of MPN vs CFU assays for E. coli K12 Hfr recovered from mineral oil coated-birch, oiled-hard maple, and foamed polypropylene boards. a. Method 1 contamination with 4.3 x 103 CFUI25-cm2 block in Trial 1 and 6.6 x 103 CFUI25-cm2 block in Trial 2, 4 blocks per determination; blocks were held 3 min at room temperature before recovery was attempted. b. Data are the mean MPN/block ± the standard error. c. Data are the mean CFU/block ± the standard error.
////////////////////// TABLE 3 ////////////////////////////
TABLE 3. Comparison of two rinsing media (nutrient broth vs phosphate-buffered saline)for recovery ofE. coli ECC 132 and L. innocua from mineral oil-coated birch board surfaces (two replicates each) after overnight holding at high humidity." Method 2 contamination: E. coli = 1.3 x 107 CFU/25-cm2 block; L innocua = 2.6 x 107 CFU125-cm2 block; data are percentage recovery ± standard error.
////////////////////// TABLE 4 ////////////////////////////
TABLE 4. Recovery of E. coli KJ2 Hfr from new wood and plastic surfaces at various intervals after contamination." a. At the indicated time after contamination (Method I, 103_104 CFU/inoculum), the surface was immersed in 5 ml of nutrient broth. b. Data are the mean percentage of the inoculated bacteria recovered ± the standard error. c. There were 12 replicates of each of the wood determinations done and 32 of the polypropylene. d. There were 8 replicates of all determinations, except 14 for polypropylene and 7 for polystyrene. e. Approximate sampling time. There were 6 replicates of every determination. f. Laminated of alternate strips of hard maple and American black walnut.
////////////////////// TABLE 5 ////////////////////////////
TABLE 5. Recovery of E. coli ECC 132 from new and used board surfaces, 3 min after contamination." a. At 3 min after contamination (Method I, 103-104 CFU/inoculum), the surface was immersed, inverted, in 5 ml of nutrient broth for 2 min. b. Data are the mean percentage of the inoculated bacteria recovered ± the standard error. c. These pieces were cut from a used maple cutting board other than those in the row above.
////////////////////// TABLE 6 ////////////////////////////
TABLE 6. Recovery of E. coli ECC 132 from new and used board surfaces, ca. 12 h after

contamination. a. At 12 h after contamination (Method 2, 2.1 x 107 CFU/25-cm2 block), the surface was immersed, inverted, in 5 ml of nutrient broth for 2 min. b. Data are the mean CFU of the inoculated bacteria recovered ± the standard error. c. These pieces were cut from a used maple cutting board other than those in the row above. d. Laminated of alternate strips of hard maple and American black.

//////////////////////// TABLE 7 ////////////////////////////

TABLE 7. Persistence of E. coli 0157:H7 on new wooden cutting boards as functions of type of wood and holding time. a a Method 2 contamination, 2.8 x 107 CFU/25-cm2 block; room temperature holding; two replicates per determination; data are the mean CFU/block ± the standard error.

//////////////////////// TABLE 8 ////////////////////////////

TABLE 8. Overnight (ca. 12 h) persistence, at room temperature, of intrinsic bacteria in chicken juice applied to cutting boards. a a. Method 1 contamination, 3.2 x 103 CFU/25-cm2 block. b. Laminated of alternate strips of hard maple and American black walnut. c. Polyacrylic, new polyethylene, used polyethylene, and polypropylene (two blocks each) all yielded >5 x 106 CFU.

//////////////////////// TABLE 9 ////////////////////////////

TABLE 9. Overnight (ca. 12 h) persistence at room temperature of bacteria applied in filter-sterilized chicken juice. a. Picked randomly from among new plastic (regardless of polymer) and wooden (regardless of species) boards. b. Serotype OI57:H7, Method 2 contamination, 4.4 x 1()6CFU/25-cm2 block. c. Method 2 contamination, 5.2 x 106 CFU/25-cm2 block. d. Method 2 contamination, 1.4 x 107 CFU/25-cm2 block.

//////////////////////// TABLE 10 ////////////////////////////

TABLE 10. Recoveries of three bacterial species from various board surfaces 10 min after contamination at moderate levels by Method 2. a. Levels inoculated were: E. coli 0l57:H7 = 1.9 x 103CFU/25-cm2 block; L monocytogenes = 6 x 103 CFU/25-cm2 block; S.typhimurium = 4.0 x 103 CFU/25-cm2 block. b. Because different varieties of wood and plastic were used with each bacterium and no significant differences had been seen among woods or among plastics, woods were pooled as a group and plastics as another group to compare recoveries of the different pathogen species. c. These numbers represent blocks produced from different boards from different sources. d. Laminated of alternate strips of hard maple and American black walnut.

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