Radiometric Detection of Some Food-Borne Bacteria

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Studies on detection of bacteria by radiometric techniques have been concerned primarily with aerobic species in clinical specimens. The data presented here are related primarily to detection of aerobic and anaerobic species that are of significance in foods, by measurement of $^{14}$CO$_2$ evolved from the metabolism of $^{14}$C-glucose. *Salmonella typhimurium* and *Staphylococcus aureus* were inoculated into tryptic soy broth containing 0.0139 $\mu$Ci of $^{14}$C glucose/ml of medium. Detection times ranged from 10 to 3 hr for inocula of $10^5$ to $10^6$ cells/ml of broth. Heat-shocked spores of *Clostridium sporogenes* or *C. botulinum* were incubated in tryptic soy broth supplemented with Thiotone and NaHCO$_3$. The medium was rendered anaerobic with N$_2$. Spores were detected when 0.0833 $\mu$Ci of labeled glucose was available/ml of medium but not when 0.0139 $\mu$Ci of glucose was present/ml. The spores required 3 to 4 hr longer for detection than did comparable numbers of aerobic vegetative cells. The results demonstrate the importance of availability of sufficient label in the media and the potential of the application of this technique for sterility testing of foods.

Methodology classically used for bacterial detection requires a period of about 1 day up to weeks to certify the presence or absence of bacteria in canned foods (9). Recent publications have demonstrated detection of bacteria in blood or urine samples within a matter of a few hours. The method depends on evolution of $^{14}$CO$_2$ from metabolism of $^{14}$C-glucose by bacteria (2-4, 11). Data have been accumulated primarily on aerobic organisms encountered in blood or urine samples. Little evidence is available concerning detection of anaerobes by this technique or on its application to the detection of bacteria in foods. This paper presents the results of preliminary work to establish methods for determining the potential application of radiometric techniques to the detection of bacteria in some foods.

MATERIALS AND METHODS

Cultures. A lyophilized culture of *Staphylococcus aureus* strain Giorgio was rehydrated, inoculated into tryptic soy broth (BBL), and incubated for 20 to 24 hr at 37 C. Serial dilutions were made in sterile distilled water, and the number of viable cells was determined from colony counts of streak plates made on tryptic soy agar.

*Salmonella typhimurium* strain RIA was grown and counted as above.

Putrefactive anaerobe 3679 (*Clostridium sporogenes*) was chosen as a representative food spoilage anaerobic sporeformer. It is encountered at times as a survivor in thermally underprocessed foods. Spores were prepared in a biphasic culture (1). They were stored at $-25$ C in 2-ml portions.

A tube was thawed and heated for 10 min at 80 C to kill the vegetative cells prior to each experiment. Serial dilutions were made in 1-ml amounts in sterile distilled water. They were added to tubes (12 by 208 mm) containing 0.2 ml of 5% filter-sterilized NaHCO$_3$. A 10-ml amount of molten Thiotone yeast extract agar (TYETA) held at 45 to 50 C was added to each tube, and the tube contents were allowed to cool and solidify. This medium contained 0.5% Trypticase, 0.5% yeast extract, 5% Thiotone, 0.05% sodium thioglycolate, and 0.75% purified agar. It was adjusted to pH 7.2 with 5 n KOH prior to autoclaving. Average colony counts of triplicate tubes incubated at 37 C for 24 hr or more were used to establish that the initial population contained $10^8$ viable spores/ml.

*C. botulinum* strain 62A spores were prepared in a biphasic culture system as described earlier (8) and were stored at $-25$ C. They were thawed just prior to use, heat-shocked (80 C for 10 min), diluted in tryptic soy broth supplemented as described below (TSS), and counted as described above. The number of viable spores available for use in each experiment was $10^6$/ml.

Detection medium. Tryptic soy broth was pur-
chased with \( ^{14} \text{C-glucose} \) in a 30-ml volume (culture vial 6A, Johnston Laboratories, Cockeysville, Md.). The vials were inoculated with 6 ml of dilutions of bacterial cultures. They contained 1.42% Trypticase, 0.25% Phytone, 0.42% NaCl, 0.21% K\(_2\)HPO\(_4\), and 0.0139 \( \mu \text{Ci of} \) \( ^{14} \text{C-glucose/ml} \) in a final volume of 36 ml. Hereafter, this medium will be referred to as TSB. The \( ^{14} \text{C-glucose} \) was uniformly labeled with an activity of 3 to 3.5 mCi/0.18 g. For studies with anaerobic organisms, TSB was flushed with sterile \( \text{N}_2 \). It would not support detection of low levels of spores of putrefactive anaerobe 3679. Therefore, it was modified as described below to approximate media that enhance germination and outgrowth of anaerobic spores (1, 7, 8).

TSB was supplemented to contain, after addition of bacterial cultures, 3.91% Thiotone, 0.42% yeast extract, and 0.042% sodium thioglycolate in a final volume of 12 or 36 ml. Prior to its addition, the supplement was adjusted to pH 7.2 with 5 n NaOH, and the mixture was autoclaved. Hereafter, this medium will be referred to as TSS (TSB with supplements). It was used with a low or high level of \( ^{14} \text{C-glucose} \) (0.0139 or 0.0833 \( \mu \text{Ci/ml} \), respectively). Just prior to its use for the detection of anaerobic spores, 0.023 ml of filter-sterilized 5% NaHCO\(_3\) was added per ml of TSS. After addition of a spore inoculum, each vial was rendered anaerobic by sparging the broth with sterile \( \text{N}_2 \), or for 2 min through a sterile cotton-plugged syringe and 3-inch (7.6-cm) 22-gauge needle at a pressure of 10 psi. The excess gas was vented through a second syringe. In early studies, the cultures were mixed with a magnetic stirrer. In later studies, they were mixed on a rotating shaker at 275 rev/min (New Brunswick Scientific Co., New Brunswick, N.J.). There was no apparent difference in detection times.

**Beef loaf.** Commercial flexible packets of sterile beef loaf were used as the source of food (Oscar Mayer and Co., Chicago, Ill.). They had been stored at 40 to 50 C for 6 years. Each packet contained 391 to 405 g of cooked beef, egg whites, cracker meal made of wheat flour, salt, spice, and monosodium glutamate. A heavy layer of fatty material coated the surface of each loaf. The contents of a packet were placed in a vaccine-capped Waring Blender and autoclaved at 121 C for 15 min. They were then cooled, stored overnight at 5 C, and mixed with 2 ml of culture which had been grown as described above and diluted in TSS. The cultures were introduced into each Blendor jar by means of a 10-ml syringe with a 13-gauge needle inserted through the vaccine cap on top of the jar. The contents were blended for 1 min and shaken well. Samples (3 ml) were withdrawn from each inverted jar with a sterile syringe and injected into vials which contained 1.0 \( \mu \text{Ci of} \) \( ^{14} \text{C-glucose/10 ml of TSS} \). Triplicate samples were tested separately in this way. The inocula for four different microorganisms ranged from \( 10^4 \) to \( 10^6 \) viable cells per ml of TSS.

**Detection system.** Bacterial metabolism was detected in a Bactec model 301 (Johnston Laboratories) by evolution of \( ^{14} \text{CO}_2 \) evolved from the metabolism of \( ^{14} \text{C-glucose} \) by a culture growing in a vaccine-capped bottle. The effluent \( ^{14} \text{CO}_2 \) was trapped in a series of five vaccine-capped Erlenmeyer flasks. The middle three contained 125 ml of 5 \( \mu \text{m NaOH} \), and the first and last flasks in the series were empty. The empty flasks minimized possible backflow of fluid into the instrument and loss of fluid droplets containing labeled carbon into the atmosphere. A reading of 20% of full scale was considered as positive evidence of metabolism in the culture vial. This reading is recommended by the manufacturer as sufficiently higher than background to avoid false positives. Background readings above 4% of scale were not observed in this laboratory.

**RESULTS**

Detection of *S. aureus* and *S. typhimurium*. Cells of *S. aureus* (10\(^6\) to 10\(^8\)/ml) or *S. typhimurium* (2 \times 10\(^5\) to 1 \times 10\(^9\)/ml) were inoculated into a final volume of 36 ml of TSB containing 0.5 \( \mu \text{Ci of} \) \( ^{14} \text{C-glucose} \) or TSS containing 3.0 \( \mu \text{Ci of} \) \( ^{14} \text{C-glucose} \) (0.0139 and 0.0833 \( \mu \text{Ci/ml} \), respectively). Detection times ranged from 4 to 10 hr and from 3 to 9 hr for the high and low levels of inocula of the two respective organisms (Fig. 1). Each 10-fold increment of cells reduced detection time by 1 to 2 hr. Detection time was generally 1 hr shorter in TSS, which contained a higher \( ^{14} \text{C-glucose} \) level than did TSB. Only with inocula of less than 10\(^6\) salmonellae were detection times about equal in both types of media.

**Detection of spores of putrefactive ana-**

![Fig. 1. Detection of Salmonella and Staphylococcus with 0.5 \( \mu \text{Ci of} \) \( ^{14} \text{C-glucose/36 ml of TSB} \) or 3.0 \( \mu \text{Ci of} \) \( ^{14} \text{C-glucose/36 ml of TSS} \).](attachment:image.png)
aerobe 3679 and C. botulinum. Heat-shocked spores of putrefactive anaerobe 3679 (10⁶/ml) were inoculated into 36 ml of TSB containing 0.5 μCi of ¹⁴C-glucose (0.0139 μCi/ml). The vials were rendered anaerobic by flushing with N₂. The activity of ¹⁴CO₂ evolved over an 8-hr period did not exceed background levels. Similar results were obtained over a 28-hr period of incubation when TSB was supplemented with 0.5% yeast extract and 0.7 ml of 5% NaHCO₃, and was inoculated with 3 × 10⁴ to 1 × 10⁶ spores/ml of medium.

Interesting results were obtained when TSS, containing a comparable level of labeled glucose, was used as a detection medium. ¹⁴CO₂ was produced in amounts that raised activity above background, but below the level set as positive evidence of growth (20% of scale). The readings reached a peak of 0.150 to 0.160 (15 to 16% of scale) at 7 to 8 hr. Results obtained when 3 × 10⁴ spores were inoculated/ml of TSS are shown in Fig. 2. Readings attained a maximum of 0.140 (14% of scale) within 7 hr. Between 7 and 10 hr, the level of activity decreased. Methylene blue smears were made from samples taken from vials at each sampling interval and were examined under phase-contrast microscopy. A number of spores showed loss of refractility, indicating germination. Although no attempt was made to quantitate results, many spores showed outgrowth, but few dividing vegetative cells were observed. Among samples taken thereafter, stainable dividing vegetative cells were rarely observed.

In view of these results, it seemed that a higher level of ¹⁴C-glucose in TSS might allow positive detection of anaerobic spores as defined in this system. Dilutions of heat-shocked spores of putrefactive anaerobe 3679 and C. botulinum were made in TSS and inoculated into a final volume of 12 ml of TSS containing 1.0 μCi of ¹⁴C-glucose (0.0833 μCi/ml). This represented a sixfold increase in the level of available labeled glucose compared to previous experiments. Detection times ranged from 4 to 11 hr for inocula of 9 × 10⁴ to 9 × 10⁷ putrefactive anaerobe 3679 spores per ml of broth (Fig. 3). For C. botulinum, they ranged from 1 to 8 hr with inocula of 2 × 10⁷ to 2 × 10⁸ spores/ml. The detection times of comparable numbers of spores of the two species were essentially the same.

Cell number at time of detection. The number of cells present at the time of detection in 12 ml of TSS containing 1.0 μCi of ¹⁴C-glucose (0.0833 μCi/ml) showed variations among the species tested (Table I). Generally, fewer cells of S. typhimurium and putrefactive anaerobe 3679 were present at detection (10⁴ to 10⁶/ml), whereas there were more cells of Staphylococcus (10⁴ to 10⁷/ml) and C. botulinum (10⁸ to 5 × 10⁷). The time required to detect comparable inocula of vegetative cells of either aerobic species was 3 to 4 hr less than
that required for heat-shocked spores of either anaerobic species (Fig. 1 and 3).

Detection in beef loaf. In these experiments, 10⁴ to 10⁶ cells of each organism were blended with nonlabeled TSS in sterile beef loaf. Triplicate 3-ml samples were inoculated into separate vials containing 10 ml of TSS and 1.0 μCi of ¹⁴C-glucose. Detection times were 2 hr for 5 × 10⁵ salmonellae inoculated per ml of TSS, 4 hr for 3 × 10⁴ staphylococci, 5 hr for 4 × 10⁴ putrefactive anaerobe 3679 spores, and 5 to 6 hr for 10⁴ C. botulinum spores (Table 2).

**DISCUSSION**

Variations in detection time of aerobes in TSS and TSB are probably due to the higher level of ¹⁴C-glucose in TSS (Fig. 1). Experiments in which the ¹⁴C-glucose level in TSB was increased to 0.0833 μCi/ml (as it was in TSS) also allowed detection times to be decreased. TSB as supplied did not have unlabeled glucose added, but did contain Phytone, which has 37% carbohydrate (BBL; unpublished data). A peptone source with less carbohydrate (such as Thiotone) might afford labeled glucose greater opportunity to be metabolized. A medium different in composition from TSB could shorten detection time. It is clear that 0.0139 μCi of ¹⁴C-glucose/ml of TSB or TSS does not seem to provide sufficient label for detection of some species of microorganisms (Fig. 2). Since background activity did not exceed 4% of scale in this laboratory, the maximal readings attained under the conditions illustrated in Fig. 2 (14% of scale) are indicative of active bacterial metabolism. This was confirmed by the observation of germinating spores and dividing vegetative cells under phase microscopy. However, the amount of glucose in the media seemed to be limiting, and the process of germination, emergence, and outgrowth did not lead to active vegetative cell division and detection. A significant amount of the label may have been incorporated into cell constituents and may not have been metabolized to ¹⁴CO₂. A sixfold increase in the level of labeled glucose (to 0.0833 μCi/ml of media) allowed detection of anaerobic spores (Fig. 3). It indicates again that the amount of glucose may be a limiting factor in detecting certain bacterial species.

Others have reported that C. botulinum vegetative cells or spores can release ¹⁴CO₂ without evidence of growth in thioglycolate media (4). Unfortunately, details concerning these results were not provided. In the present experiments, 10⁴ heat-shocked C. botulinum spores could be detected within 1 hr (Fig. 3). It has been demonstrated that near maximal germination can be obtained within this time under optimal conditions (8). When sufficient labeled glucose is available, it may be used as an energy source during aerobic germination (5). However, the detection time of 10⁴ to 10⁵ anaerobic spores/ml of TSS was about 3 to 4 hr greater than that of comparable numbers of aerobic vegetative cells (Fig. 1 and 3). This corresponds to the amount of time required for the majority of spores to germinate, emerge, elongate, and initiate cell division (7).

Some investigators failed to detect some bacterial species using a radiometric technique (10). They indicated that their use of a rotary shaker rather than a magnetic stirrer to agitate cultures during incubation probably was not responsible for differences between their results and those of De Land and Wagner (3, 4). In the present experiments, either system of agitation provided equivalent results with the species tested. However, the failure of these investigators to detect growth of Bacteroides, as they admit, was probably due to lack of anaerobiosis. Also, they used thioglycolate in their medium, an agent that may inhibit some anaerobes (Difco Manual, 9th ed., p. 195, 1964). Furthermore, their failure to detect incula of fewer than 10 cells of Pseudomonas or group D streptococci in simulated blood samples could be due to sampling errors inherent in handling so few bacteria or to provision of less than optimal conditions for radiometric detection, or to a combination of these factors.

**Table 1. Number of cells per milliliter at detection with 1.0 μCi of ¹⁴C-glucose per 12 ml of TSS**

| Organism                  | Range in no. of cells/ml of TSS |
|---------------------------|---------------------------------|
| Salmonella typhimurium     | 1.2 × 10⁴ to 3.0 × 10⁵           |
| Staphylococcus aureus      | 2.3 × 10⁴ to 1.2 × 10⁷           |
| Ps. putrefactive anaerobe  | 4.5 × 10⁴ to 9.6 × 10³           |
| Clostridium botulinum      | 1.6 × 10⁴ to 5.2 × 10⁷           |

**Table 2. Detection of bacteria mixed with beef loaf**

| Organism                  | Inoculum per ml of TSS | Detection time (hr) |
|---------------------------|------------------------|---------------------|
| Salmonella typhimurium     | 5.3 × 10⁴              | 2                   |
| Staphylococcus aureus      | 2.9 × 10⁴              | 4                   |
| Ps. putrefactive anaerobe  | 4.2 × 10⁴              | 5                   |
| Clostridium botulinum      | 1.5 × 10⁴              | 5–6                 |
The data reported here indicate that 8 to 10 hr was required for detection of inocula of fewer than 10 staphylococci or salmonellae/ml of TSS or TSB (Fig. 1). Furthermore, if individual readings of $^{14}$CO$_2$ evolved from one culture over several hours were added, the total activity exceeded that necessary for detection. Therefore, delay in sampling until 6 hr would probably provide positive readings sooner than when earlier and more frequent samplings are used. Cultures often showed turbidity at the time of detection with cell numbers present ranging from $10^4$ to $5.2 \times 10^7$/ml (Table 1). However, fresh samples of blood, urine, food, or other natural substances can alter broth chemically or physically, or both, rendering turbidity a poor indicator of bacterial growth.

Washington and Yu (10) used inocula of 1 ml of simulated blood culture for the radiometric analyses and 10 ml for their conventional detection technique. The sampling procedure certainly biased their results in favor of the latter technique. Furthermore, their simulated blood cultures were diluted with Mueller-Hinton broth prior to inoculation. This medium contains a significant amount of carbohydrate. Data with putrefactive anaerobe 3679 show unequivocally that the ratio of labeled to nonlabeled glucose can be critical for detection of some species (Fig. 2 and 3). Media containing nonlabeled carbohydrate can increase time for detection because of competition between labeled and nonlabeled substrates. It may well be that for some bacterial species the optimal amount of label per milliliter is higher than that which has been used in some radiometric studies. One might also consider incorporation of other labeled substrates in addition to $^{14}$C-glucose in the event that the test organism does not utilize glucose preferentially as an energy source or that it uses pyruvate anaerobically as a terminal electron acceptor, thereby not generating CO$_2$ from glucose.

The detection of aerobic vegetative cells of *Salmonella* and *Staphylococcus* and anaerobic spores of putrefactive anaerobe 3679 and *C. botulinum* mixed in broth or blended in beef loaf was achieved readily in TSS containing a high level of $^{14}$C-glucose (Fig. 3 and Table 2). Further exploratory studies should be made to apply these findings to detection of a variety of aerobes and anaerobes from different sources and to optimize the media used for their detection.

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LITERATURE CITED

1. Anellis, A., and D. B. Rowley. 1970. Production of *Clostridium botulinum* spores types A and B, p. 317-324. In M. Herzberg (ed.), Proceedings of the First U.S.-Japan Conference on Toxic Microorganisms. Mycotoxins. Botulism. U.S. Department of Interior, Washington, D.C.
2. DeBlanc, H. J., F. DeLand, and H. N. Wagner, Jr. 1971. Automated radiometric detection of bacteria in 2,967 blood cultures. Appl. Microbiol. 22:846-849.
3. DeLand, F. H., and H. N. Wagner, Jr. 1969. Early detection of bacterial growth with carbon-14-labelled glucose. Radiology 92:154-155.
4. DeLand, F. H., and H. N. Wagner, Jr. 1970. Automated radiometric detection of bacterial growth in blood cultures. J. Lab. Clin. Med. 75:529-534.
5. Hyatt, M. T., and H. Levinson. 1961. Interaction of heat, glucose, L-alanine, and potassium nitrate in spore germination of *Bacillus megaterium*. J. Bacteriol. 81:204-211.
6. Malin, R., and R. K. Finn. 1951. The use of a synthetic resin in anaerobic media. J. Bacteriol. 62:349-350.
7. Rowley, D. B., H. M. El-Bai, A. Anellis, and O. P. Snyder. 1970. Resistance of Clostridium botulinum spores to ionizing radiation as related to radapppertization of foods, p. 459-467. In M. Herzberg (ed.), Proceedings of the First U.S.-Japan Conference on Toxic Microorganisms. Mycotoxins. Botulism. U.S. Department of Interior, Washington, D.C.
8. Rowley, D. B., and F. Feeherry. 1970. Conditions affecting germination of *Clostridium botulinum* 62A spores in a chemically defined medium. J. Bacteriol. 104:1151-1157.
9. Sharf, J. M. (ed.). 1966. Recommended methods for the microbiological examination of foods, 2nd ed., p. 35-48. American Public Health Association, Inc., New York.
10. Washington, J. A., II, and P. K. W. Yu. 1971. Radiometric method for detection of bacteremia. Appl. Microbiol. 22:100-101.
11. Waters, J. R. 1972. Sensitivity of the $^{14}$CO$_2$ radiometric method for bacterial detection. Appl. Microbiol. 23:198-199.