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Instant-read Food Thermometer Accuracy in Measuring End-point Temperature in Ground Beef Patties Prepared by Three Methods

ABSTRACT

The accuracy of three dial and three digital consumer instant-read food thermometer models was assessed. Thermometer models were compared to a thermocouple in ground beef patties cooked to 71.1°C via three preparation methods. Patties were prepared to reflect methods used in scientific studies (flipped every 30 s) and two consumer methods (patties containing onion or topped with cheese and flipped once). Instant-read thermometer temperatures were recorded after the display had stabilized for 3 s. Dial thermometer models required 18–55 s to stabilize, while digital thermometers required 16–40 s. Both dial and digital thermometer models performed more accurately in ground beef patties flipped every 30 s than in those prepared by the other methods, measuring within 2.1°C of the thermocouple standard. Only one thermometer model accurately measured end-point temperature when consumer cooking methods were used; overestimation of patty temperature, a food safety risk, was observed. Flipping ground beef patties every 30 s produced a more uniform environment for temperature measurement, with a smaller temperature gradient throughout the patty. Both dial and digital food thermometers can be recommended for consumer use in ground beef patties if inserted through the side to measure the geometric center, if patty temperature gradient has time to equilibrate somewhat, and if the thermometer reading is allowed adequate time to stabilize.

INTRODUCTION

Ground beef patties must be cooked to a temperature sufficient to eliminate any foodborne pathogens that may be present, including *Escherichia coli* (*E. coli*) O157:H7, *Campylobacter jejuni*, or *Salmonella* spp. *(11)*. Thorough cooking is especially important in ground meats because, in addition to possible presence on meat surfaces, pathogens can be present throughout the meat *(5)*. Cooking ground beef patties so the entire patty reaches 71.1°C (160°F) will result in a safe product free from vegetative pathogens *(19)*.

In 1997, the United States Department of Agriculture (USDA) revised consumer food safety recommendations, from advising the public to cook ground beef patties until they are brown and the juices run clear *(1, 18)* to promoting

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the use of food thermometers to ensure than an internal temperature of 71.1°C (160°F) had been achieved *(11)*. The revision was instituted when research determined that approximately one in every four ground beef patties turns brown before reaching a safe internal temperature *(17)*. Therefore, the color of cooked ground beef represents an unreliable indicator to determine when a safe temperature has been achieved *(18)*.

The two most common instant-read thermometers used by consumers differ in temperature-sensing mechanisms, but both are recommended by USDA *(18)*. Dial thermometers contain a bimetallic coil temperature sensor that spans from the tip to 5–7.6 cm (2–3 inches) up the stem *(18)*. Hence, dial thermometers require that the entire length of the sensing area be inserted into the product to measure the temperature of a food accurately *(13)*. Digital thermometers contain a thermistor sensor in the tip of the probe. A thermistor is a semiconductor whose resistance changes with temperature, producing an electrical signal that responds proportionally to the change in temperature. Digital thermometers need to be inserted so that approximately 1 cm of the tip is in the center of the thickest part of the food *(18)*.

USDA's Food Safety and Inspection Service recommends to consumers that digital thermometers are preferred for use with thin foods; however, both dial and digital thermometers are acceptable *(18)*. Potential challenges have been acknowledged with achieving accurate temperature measurement in ground beef patties cooked in consumer homes. Some food safety specialists recommend that only thermistor or digital thermometers be used in thin cuts of meats like ground beef patties and that dial thermometers not be used, because of the difficulty of placing the 5–7.6 cm temperature sensing area in a patty *(15)*. Dial thermometers inserted into the top of a ground beef patty can result in a measurement that is off by 24°C, since temperature is measured across the entire length of the sensing area *(16)*. Increased accuracy for digital thermometers was also observed when inserted through the side of a ground beef patty to reach the center rather than through the top *(7)*. With thin cuts of meat such as ground beef patties, dial thermometers need to be inserted through the side of the patty to ensure that the entire sensing area registers the temperature of the food. However, not all educational materials emphasize the need to position a dial thermometer into the side of a thin cut of meat.

Research conducted on the accuracy of dial and digital consumer thermometers has tested thermometers both in water baths at various temperatures and in ground beef patties cooked to 71.1°C. In water bath testing, LeBlanc et al. *(7)* found six digital thermometer models, on average, overestimated water bath temperatures at 60°, 65° and 70°C, with the highest temperature difference being 1.9°C. Liu et al. *(8)* observed that two dial thermometer models registered within an average of 1°C of water bath temperatures of 71.1° and 76.6°C. However, when two digital thermometer models were tested using an insertion time of 10 s, which Liu et al. *(8)* noted was the recommended response time for digital thermometers, the water bath temperature was underestimated by 2° and 6°C. When a 30 s insertion time was used, the digital thermometers were within 2°C of the water bath temperatures *(8)*.

Results examining thermometer accuracy in water baths and ground beef patties are not always consistent. When LeBlanc et al. *(7)* tested six digital thermometer models in ground beef patties, the thermometers underestimated the temperature of the patties by 2° to 5°C. The ground beef patties were flipped once after 5 min of cooking on an outdoor grill and were removed from the grill after the reference thermocouple registered an internal temperature of 71.1°C. Liu et al. *(8)* assessed the accuracy of three models of dial and digital thermometers in ground beef patties cooked on an electric griddle or on an outdoor gas grill and flipped after 2 minutes of cooking, and then every minute to an end-point temperature of 71.1°C. Set insertion times of 20 s and 30 s were used for dial thermometers and 10 s and 30 s for digital thermo-meters. At both the 20 s and 30 s insertion times, dial thermometers underestimated the temperature of the ground beef patties by 3° to 6°C, compared with the thermocouple. At the 10 s insertion time, digital thermometers underestimated the patty temperature by 5° to 10°C; at a 30 s insertion time, digital thermometer accuracy was improved, although the patty temperature was still underestimated by 2° to 4°C. Thermometers that underestimate internal temperature could influence consumers to cook past the desired end-point temperature of 71.1°C, adding a margin of safety.

Dial and digital instant-read thermometers are widely available to consumers *(8, 9)*. Food thermometer ownership has increased in recent years, with 70% of consumers in the 2010 FDA/USDA Food Safety Survey reporting they have a food thermometer (of any type) *(6)*. Use of food thermometers for hamburgers, although increasing, is low, with 23% of consumers who owned thermometers in the same survey reporting they use them with hamburgers. Phang and Bruhn *(10)* observed 199 consumers preparing hamburgers at home and found that only 4% used a thermometer to check doneness. Dial thermometers are frequently less expensive than digital ones and consumers are unlikely to understand a value or usage difference between these food thermometer types. Extension educators in Idaho often distribute dial thermometers to Supplemental Nutrition Assistance Program Education (SNAP-Ed, formerly food stamp nutrition education) clients. Thus, there is a need to understand the capability of consumer-used dial and digital thermometers to obtain accurate end-point cooking temperatures of ground beef patties. Assessment of consumer thermometer accuracy in ground beef patties should use cooking methods that reflect common consumer practices.

A consumer survey indicated that 40% of consumers flip ground beef patties only once and frequently add ingredients such as onions or cheese *(2)*. It is critical to assess the accuracy of instant-read food thermometers when common consumer practices are used, to assure that the instruments will allow consumers to assess the safety of ground beef patties in the home. Therefore, assessment of dial and digital thermometer accuracy is needed, using both previously utilized methods and consumer cooking methods.

The current study evaluated the accuracy of six models (three models of dial and three models of digital) of instant-read food thermometers for assessing whether an end-point temperature of 71.1°C is achieved in cooked ground beef patties prepared utilizing three cooking methods (one utilized in scientific studies to ensure even cooking and two reflecting consumer practices). The selected thermometers represent the most widely available thermometers in three price categories to consumers in Washington and Idaho *(20)*. The objectives of the study were (1) to assess the accuracy of consumer dial and digital thermometers in a water bath and in ground beef patties cooked using scientific and consumer cooking methods, (2) to assess response time for different thermometer models, and (3) to assess temperature distribution within cooked ground beef patties prepared using scientific and consumer methods.

MATERIALS AND METHODS

Thermometer selection

Six instant-read food thermometer models, three dial and three digital, in low-, medium-, and high-cost price categories, were chosen for accuracy testing. Three thermometers of each model were purchased, each from a separate store, to evaluate precision within each thermometer model. The thermometer models were selected based on a survey conducted in 2008–2009 in which Extension volunteers visited 168 grocery, department, kitchen specialty, drug/variety, and hardware stores in Washington and Idaho to record information about commonly available thermometers for consumers. Price categories were established once the survey was complete; the dial-high cost thermometer price was over $10, dial medium-cost price was between $8 and $10, and dial-low cost price was less than $8, while the digital-high cost price was more than $15, digital-medium cost price was between $10 and $15, and digital-low cost price was less than $10. Within each cost category, the most widely available thermometer model was selected; the models selected were available in 6 to 29 stores.

Thermocouple and certified thermometer standards

Consumer thermometer accuracy was measured by comparing temperature readings to a thermocouple standard (type K, model TJ36-CASS-116U-6-SMPW-M, Omega Engineering, Inc., Stamford, CT) that had been calibrated to a certified mercury thermometer (temperature range 60°C to 80˚C, Cole-Parmer Instrument Co., Vernon Hills, IL). The thermocouple probe was 1.6 mm in diameter and 15.2 cm long. Thermocouple readings were logged every second using a Measurement Computing TC data logger (model #12567F9, Measurement Computing, Norton, MA) and Tracerdaq software (Measurement Computing, Norton, MA). When consumer preparation methods were used, a Thermapen® thermometer (thermocouple thermometer, model THS-211-376, Thermoworks Inc., Orem, UT) was used to assess the end-point temperature for removing cooked patties from the pan, because the sides of the pan prevented use of the type K thermocouple standard.

Accuracy in a water bath

The accuracy of the 18 consumer thermometers (six models, three of each model) and the thermocouple standard were initially assessed in a water bath (Model 2841, "Precision" Thermo Scientific, Thermo Fisher Scientific, Marietta, OH) adjusted to 71.1°C, using a certified mercury thermometer. The bulb of the mercury thermometer was suspended to a depth of two inches in the water bath alongside the thermocouple standard. Order of testing the consumer thermometers was randomized, and each of the 18 thermometers was measured six times. Thermometers were inserted to a depth that placed the center of the sensing area of both dial (bottom 6 cm) and digital thermometers (1 cm) in the same location as the bulb of the certified mercury thermometer. Temperature readings and response time (the time required to reach the final, stable end-point temperature) were recorded once the consumer thermometer display stabilized for 3 s. There is no official standard of accuracy for consumer thermometers. The Food and Drug Administration model *Food Code* specifies that food service thermometers shall be accurate to ± 1°C of the intended range of use *(3)*. This standard was applied to assess the accuracy of consumer thermometers studied in this work.

Accuracy in ground beef patties

After the water bath testing, the most accurate consumer thermometer from each of the six models (three dial thermometers, one from each price range, and three digital thermometers, one from each price range) was selected for further accuracy testing in cooked ground beef patties prepared by three methods. The selected thermometers were not calibrated prior to testing in ground beef patties; three of the six models (dial-low cost, dial-medium cost and digital-medium cost) were capable of being calibrated. To determine whether thermometer accuracy changed with use, the water bath test was repeated after completion of each cooking method examination in cooked patties.

Three patty preparation methods were utilized to assess thermometer accuracy. A scientific cooking method utilized in studies published in the literature *(4)* was examined, in which plain patties were flipped every 30 s (termed 'Frequent Flip'). Two procedures were selected to simulate common consumer preparation methods for ground beef patties *(2)*, one involving the addition of onion (Consumer Onion) and one involving the addition of a slice of cheese during cooking (Consumer Cheese); for both consumer methods, patties were flipped only once during cooking. The order of thermometer model testing was randomized within each statistical block, and 5 blocks were completed for each of the three preparation methods. To test the six thermometers, within each preparation method, six ground beef patties (representing one statistical block) were prepared from a single package of eighty percent lean ground beef purchased from a local grocery store 24 hours or less prior to cooking and refrigerated until use. For each block, ground beef was weighed and formed into the 6 patties using a 10.2 cm diameter plastic patty press to ensure consistent diameter patties.

For the Frequent Flip preparation method, ground beef (113 g) was formed into 1.3 cm thick patties. One patty was cooked at a time in the center of a Presto® electric griddle that had been preheated at 180.5°C (325°F) for 10 min; the patty was flipped every 30 s. The thermocouple was inserted through the side of the patty (3.8 cm) toward the end of cooking, based on prior experience, to determine when the end-point temperature of 71.1°C had been achieved.

For the Consumer Onion preparation method, chopped onion (141.5 g, approximately 0.6 cm pieces) was mixed into 794 g of ground beef (approximately 2 tbsp. onion per quarter lb. patty) and formed into patties that weighed 131.5 g and were 1.6 cm thick. One patty was cooked in the center of a fry pan (30.5 cm nonstick, item 06168, Bialetti, Ranchocucamonga, CA) that had been preheated on a 19.1 cm electric stove burner for 3 min at medium setting. The pan temperature averaged 99°C (210°F) after 3 min of preheating. Patties were flipped once after 7 min of cooking on one side. The Thermapen® thermometer was inserted 0.6 cm through the top of the patty into the center to determine that an end-point temperature of 71.1°C had been achieved before removing the patty from the pan.

For the Consumer Cheese preparation method, ground beef (113 g) was formed into a patty 1.3 cm thick. One patty at a time was cooked, following the same cooking and thermometer insertion procedures as for patties with onion. Once the center of the patty had reached 62.8°C as determined by the Thermapen®, a 28 g slice of cheddar cheese was added to the top of the patty. The patty continued to cook until the Thermapen® indicated that the end-point temperature of 71.1°C had been achieved.

For all preparation methods, patties were removed from the heat source when the internal temperature had reached 71.1°C as determined by the thermocouple (type K thermocouple standard for Frequent Flip and Thermapen® for Consumer Onion and Consumer Cheese preparation methods). Promptly after removal of the patty from the heat source, a consumer thermometer was inserted into it, either next to the thermocouple standard (Frequent Flip) or together with the thermocouple standard (Consumer Onion and Consumer Cheese), to place the sensing area in the geometric center. The stem of digital thermometers and thermocouple standard were inserted to a depth of 3.8 cm, whereas the dial thermometer stems were inserted to a depth of 6.4 cm (patties shrank to roughly 7.6 cm in diameter as they cooked). Consumer thermometer temperature readings and the length of time required to register the temperature were manually recorded once the thermometer reading had stabilized for 3 s. Consumer thermometer accuracy was calculated by subtracting the temperature recorded by the thermocouple standard from the temperature recorded simultaneously for the consumer thermometer.

Patty temperature distribution and cooking time

The effects of frequent flipping and of adding onion to patties on the temperature distribution within freshly cooked ground beef patties were measured. Patties were formed using the same protocol as used for Frequent Flip and Consumer Onion. Blocks of four patties were prepared for each experiment (one each for the One Flip [plain patty, flipped once], Frequent Flip, Consumer Onion, and Frequent Onion variables), the order of patty cooking was randomized, and the experiment block was replicated five times. Patties were cooked on an electric griddle as described for the Frequent Flip preparation method, except that the One Flip and Consumer Onion patties were flipped only once, after 7 min of cooking. Patties were removed from the heat source once the thermocouple standard indicated that the end-point temperature of 71.1°C had been achieved. Immediately after removal, a circular Teflon disc (10 cm diameter) with five type K beaded wire thermocouples (model 5SRTC-GG-K-30-36, Omega Engineering Inc., Stamford, CT) protruding 0.6 cm from the surface was placed on top of the patty to monitor internal temperature in five locations. The protruding thermocouples were located in each quadrant and in the center of the Teflon disc and adjusted to extend half the thickness of the cooked ground beef patties. The patty temperatures were recorded 10 s after placement of the Teflon disc. Cooking time to reach 71.1°C for these patties was also recorded.

Statistical analysis

Power computations were carried out using the PROC GLMPOWER procedure in SAS, assuming a randomized complete block design and assuming that means and errors were equivalent to those found in the empirical data. In all cases, sufficient statistical power (> 0.75) was observed to indicate that 5 blocks were adequate to detect significant differences. All analyses were conducted using SAS (Version

9.2) *(14)*. Statistical inferences were deemed significant, assuming a 95% confidence.

Analysis of variance was used to assess the consumer thermometer response time and the temperature difference between the consumer thermometers and the thermocouple standard as tested in ground beef patties prepared by the three methods. The factors of thermometer type (dial and digital) and cost level (low, medium, and high) were tested, assuming a randomized complete block design with 5 blocks. Following analysis, treatment means were compared using pair-wise *t*-tests.

For the patty temperature distribution (Objective 3) and cooking time data, the analysis of variance used the factors of frequency of flipping (once or every 30 s) and of patty composition (plain or with onion). Pair-wise comparisons of means (*t*-test) were used following analysis to assess specific treatment differences.

RESULTS

Thermometer availability

Of the 168 stores visited in 2008–2009 in Washington and Idaho, 126 (75%) carried at least one instant-read thermometer model; a total of 105 digital and 173 dial thermometer models were identified, as assessed by a unique model number, although many models appeared to be very similar. The prices ranged from \$3 to \$20 for dial models and from \$7 to \$30 for digital models. Consumer thermometers were most frequently found in kitchen specialty (88%), grocery (82%) and department (79%) stores, and less frequently in hardware (59%) and drug/variety (56%) stores.

Accuracy in a water bath

The 18 purchased thermometers (nine dial and nine digital) were tested for accuracy in a water bath directly after removal from their packaging (without calibration). All nine digital thermometers (3 replicate thermometers for each of 3 models) measured the temperature of the water bath (71.1°C) within 1.0°C of temperature measured by the certified mercury thermometer *(Table 1)*. However, the temperature indicated by seven of the nine dial thermometers (3 replicate thermometers from 3 models) differed from that indicated by the certified mercury thermometer by 1.3 to 7.0°C *(Table 1)*. The most accurate thermometer from each model was selected for further testing in ground beef patties. All were within 1.6°C of the certified thermometer.

To determine whether accuracy changed with use, the six selected thermometers were retested in the 71.1°C water bath after they were tested in cooked ground beef patties prepared by the three methods. The consumer thermometers consistently measured within 0.3°C of their initial measurement through three rounds of testing. Dial thermometers had a larger range of temperature difference from the certified mercury thermometer in each subsequent water bath assessment (0.1 to 1.6°C) than digital thermometers (0.1 to 0.7°C), and they read consistently lower (underestimated by 0.1 to 1.6°C) compared to the certified thermometer.

Accuracy in ground beef patties

The mean temperature differences between the consumer thermometers and the thermocouple standard when measured in ground beef patties are shown in *Table 2*. Two

TABLE 1. Mean temperature differences[a] (°C) for six consumer thermometer models, three thermometers per model, compared to a certified mercury thermometer in a 71.1°C water bath (n = 6)

	Dial Models			Digital models		
	Low Cost	Medium Cost	High Cost	Low Cost	Medium Cost	High Cost
Thermometer 1	7.0	-0.3	4.4	-0.4[b]	-0.7	-0.3
Thermometer 2	-1.3[b]	-2.5	-2.3	0.4	-1.0	-0.2
Thermometer 3	-1.6	-0.1[b]	-1.6[b]	0.5	0.6[b]	0.2[b]

[a]The mean temperature difference was calculated as the temperature recorded by the consumer thermometer minus the temperature recorded by the certified mercury thermometer.

[b]The most accurate thermometer within each model was selected for further accuracy testing in ground beef patties.

of the six consumer thermometers tested in the Frequent Flip patties, the dial-medium cost and the digital-low cost, measured within 1°C of the thermocouple standard. The remaining dial and digital consumer thermometer models measured the temperature within ± 2.1°C of the thermocouple standard.

In patties prepared by adding onion and flipping once (Consumer Onion), only the dial-medium cost thermometer measured the temperature of the patty within 1°C of the thermocouple standard *(Table 2)*. Four models, the dial-low and -high cost thermo-meters and the digital-low and -high cost thermometers, registered roughly 3°C (2.4 to 3.1°C) higher than the thermocouple standard, and one model, the digital-medium cost, registered 9.2°C higher than the thermocouple standard.

When tested in patties topped with cheese and flipped once (Consumer Cheese), none of the thermometer models registered within 1°C of the thermocouple standard. Two models, dial-high cost and digital-low cost, measured within 1.3 and 1.8˚C of the thermocouple standard, respectively. The other four consumer thermometer models showed greater discrepancy from the thermocouple standard, registering an average 3.9 to 6.5°C difference.

In addition, the standard deviations for temperature differences between the consumer thermometers and the thermocouple standard were larger for the consumer preparation methods (Consumer Onion, standard deviation range = 2.4 to 6.3 and Consumer Cheese, standard deviation range = 1.4 to 2.9) than the standard deviations for the patties flipped every 30 s (Frequent Flip, standard deviation range = 0.8 to 1.6) *(Table 2)*, suggesting that a less uniform patty temperature among the consumer methods may have affected thermometer response.

Patty temperature distribution and cooking time

Based on results and on the potential that consumer preparation methods produce increased temperature variability, the effects of flipping and the addition of vegetables were investigated. An investigation of the temperature uniformity of ground beef patties flipped once or flipped every 30 s, and with or without onion, was evaluated at five patty locations, and measurements were compared to the thermocouple standard measurement.

The temperature differences between the beaded wire thermocouples positioned via the Teflon disc midway through the thickness of ground beef patties at five locations and the thermocouple standard are shown in *Table 3*. Beaded wire thermocouples in the patties that were flipped once registered an average temperature that was 6.4 (One Flip) to 8.5°C (Consumer Onion) lower than the standard thermocouple. Conversely, beaded wire thermocouples in patties that were flipped every 30 s registered a higher temperature (2.7°C, Frequent Flip and 2.2°C, Frequent Onion) than the thermocouple standard. Of the five locations in patties flipped every 30 s, the center beaded wire thermocouple measured the closest to the thermocouple

TABLE 2. Mean temperature differences[a,b] (˚C) (± SD) for six consumer thermometers compared to a thermocouple standard in cooked ground beef patties prepared by three methods (n = 5)

Consumer Thermometer Model	Frequent Flip (Plain patties, flipped every 30 s)	Consumer Onion (Patties with added onion, flipped once)	Consumer Cheese (Patties topped with cheese, flipped once)
Dial-Low Cost	-2.0 ± 0.8[ab]	3.0 ± 4.1[abc]	4.7 ± 1.9[bcde]
Dial-Medium Cost	0.7 ± 1.6[bcd]	0.3 ± 4.8[ab]	3.9 ± 2.1[abcde]
Dial-High Cost	-2.1 ± 0.9[ab]	3.1 ± 5.7[abc]	1.3 ± 2.6[abc]
Digital-Low Cost	-0.8 ± 1.5[abc]	2.5 ± 2.4[abc]	1.8 ± 2.2[abcd]
Digital-Medium Cost	2.0 ± 1.3[cd]	9.2 ± 2.5[bc]	5.6 ± 2.9[cde]
Digital-High Cost	1.7 ± 1.3[cd]	2.4 ± 6.3[ab]	6.5 ± 1.4[cde]

[a]The mean temperature difference was calculated as the temperature recorded by the consumer thermometer minus the temperature recorded by the thermocouple standard.

[b]Means sharing a common superscript letter within a column are not significantly different at a significance level of $P < 0.05$.

TABLE 3. Mean temperature differences[a,b] (°C) of beaded wire thermocouples at five locations compared to the thermocouple standard in cooked ground beef patties prepared by four methods (n = 5)

Patty Preparation Method	Beaded Wire Thermocouple Location					
	Quadrant 1	Quadrant 2	Quadrant 3	Quadrant 4	Center	Mean of Five Locations
One Flip (Plain patties, flipped once)	-3.3	-6.5	-8.6	-7.1	-6.7	-6.4[b]
Consumer Onion (Patties with onion, flipped once)	-8.8	-10.2	-9.2	-5.9	-8.4	-8.5[a]
Frequent Flip (Plain patties, flipped every 30 s)	4.3	1.8	4.6	4.1	-1.0	2.7[c]
Frequent Onion (Patties with onion, flipped every 30 s)	4.4	2.3	3.5	2.7	-2.0	2.2[d]

[a]Mean temperature difference = beaded wire thermocouple–thermocouple standard.

[b]Overall means sharing a common superscript are not significantly different at a significance level of $P < 0.05$.

standard, while the beaded wire thermocouples located in the 4 quadrants read higher.

Average cooking times for patties containing onion were longer (13 min 48 s ± 75 s when flipped once and 10 min 10 s ± 43 s when flipped every 30 s) than average cooking times of plain patties (12 min 21 s ± 56 s when flipped once and 9 min 30 s ± 23 s when flipped every 30 s). Patties that were flipped every 30 s had a shorter cooking time, by 2–3 minutes, than the patties flipped only once during the cooking process.

Response time

Response times for the six consumer thermometers are shown in *Table 4*. When initially tested in a 71.1°C water bath, the dial-low cost thermometer model had a longer response time (55 s) than did the other dial models (22–29 s) and the digital-low cost thermometer had a longer response time (32 s) than did the other digital models (17 s). When response times were tested in ground beef patties cooked by the three methods, and then in a water bath, three thermometers (dial-medium cost, dial-high cost, and digital-medium cost) had response times that did not vary by more than 4 s. The other thermometer models varied by as much as 13 s *(Table 4)*. For dial thermometers tested in ground beef patties, response time followed a similar trend to that observed in the water bath tests; the dial-low cost thermometer model required significantly longer to stabilize than did the other dial thermometers. For digital thermometers, the digital-low cost thermometer required significantly longer to stabilize in Frequent Flip and Consumer Cheese patties.

DISCUSSION

Thermometer availability

Consumer thermometers were found in 75% of the stores visited in 2008–2009, while a previous survey found 70% of stores carried thermometers *(9)*. The 2008–2009 survey sampled more heavily from urban stores, which are more likely to carry thermometers. Interestingly, the price range observed for dial and digital thermometers was nearly identical to that observed in 2001–2002 *(9)*. While food thermometer ownership has increased recently *(6)*, thermometer availability and cost in the Pacific Northwest has remained stable.

Accuracy in a water bath

No official standard of accuracy exists for consumer thermometers; therefore, the FDA model *Food Code* guideline/standard, that food service thermometers shall be accurate to ± 1°C of the intended range of use *(3)*, was applied in this study.

TABLE 4. Mean response times^{a} (s) (± SD) for six consumer thermometers to reach 71.1˚C as tested in a 71.1˚C water bath before and after use (n = 6) and as tested in cooked ground beef patties prepared by three methods (n = 5)

Consumer Thermometer Model	**Initial Water Bath Test**	**Frequent Flip** (Plain patties, flipped every 30 s)	**Water Bath Test after First Use** (Frequent Flip)	**Consumer Onion** (Patties with added onion, flipped once)	**Water Bath Test after Second Use** (Consumer Onion)	**Consumer Cheese** (Patties topped with cheese, flipped once)	**Water Bath Test after Third Use** (Consumer Cheese)
Dial-Low Cost	55 ± 3	46 ± 4.1^{c}	49 ± 6	49 ± 6.5^{cd}	49 ± 6	45 ± 1.7^{e}	54 ± 3
Dial-Medium Cost	29 ± 3	27 ± 2.9^{a}	27 ± 3	26 ± 6.0^{abc}	23 ± 2	25 ± 3.3^{bc}	25 ± 2
Dial-High Cost	22 ± 4	22 ± 2.3^{a}	20 ± 1	20 ± 4.2^{ab}	20 ± 4	18 ± 2.9^{ab}	21 ± 2
Digital-Low Cost	32 ± 2	34 ± 1.3^{b}	34 ± 1	40 ± 5.0^{bcd}	34 ± 3	30 ± 3.1^{d}	35 ± 2
Digital-Medium Cost	17 ± 4	23 ± 3.0^{a}	21 ± 2	25 ± 10.3^{ab}	21 ± 2	22 ± 3.4^{abc}	19 ± 1
Digital-High Cost	17 ± 3	26 ± 8.6^{a}	17 ± 6	29 ± 20.4^{abc}	16 ± 2	22 ± 4.8^{abc}	16 ± 2

^{a}Means sharing a common superscript letter within a column are not significantly different at a significance level of $P < 0.05$.

The accuracy of dial and digital thermometers may depend on the specific model being examined and the medium utilized to evaluate accuracy. Based on assessment in a water bath (71.1°C), the dial-low cost and dial-high cost thermometer models evaluated in this work were less accurate than the digital thermometer models. Seven of the nine dial thermometers purchased initially (three thermometers from each of three models, as removed from packaging without calibration), would be considered inaccurate according to the 2009 FDA *Food Code*, because they differed by more than 1°C from the certified mercury thermometer. All nine digital thermometers purchased initially (three thermometers of each of three models) measured within 1°C of water bath temperature. Other studies have observed accuracy for both dial and digital thermometers. McCurdy et al. *(9)* reported that 8 models of dial and 13 models of digital thermometers accurately measured within 1.1°C of a 71.1°C water bath. Liuet al. *(8)* reported that two models of dial and one of two models of digital thermometers (10 thermometers per model) tested in a 71.1°C water bath met the *Food Code* requirement for accuracy.

The lack of accuracy observed in some thermometers in the current study is of concern. The results suggest that calibration before first use of dial thermometers would enhance accuracy. However, only two of the three dial thermometers tested in this study (dial-low cost and dial-medium cost) were equipped with a calibration nut, and only one (dial-low cost) came with calibration instructions and a calibration wrench built into the pocket case. McCurdy et al. *(9)* found that only 22% of the dial thermometer models contained visible instructions on the steps for calibration.

Accuracy in ground beef patties

When assessed in ground beef patties, the accuracy of consumer thermometers measured in the current study differed from that reported in previous research on the accuracy of dial and digital thermometers. LeBlanc et al. *(7)* and Liu et al. *(8)* reported that consumer thermometers underestimated the temperature of ground beef patties, whereas the current study found that all of the consumer thermometers overestimated the temperature of ground beef patties prepared via consumer methods. Both dial and digital consumer thermometer models overestimated the temperature compared to temperature indicated by the thermocouple standard by 0.3 to 9.2°C in ground beef patties flipped once during cooking (Consumer Onion and Consumer Cheese preparation methods). Only one thermometer (dial-medium cost) measured within 1°C of the thermocouple standard in patties with onion, and none of the thermometers measured within 1°C of the thermocouple standard in patties topped with cheese. The testing matrix influenced evaluation of thermometer accuracy; although thermometer performance in water bath testing appeared fairly precise, examination using several cooking methods with ground beef patties revealed that some thermometers were less accurate, and overestimation of temperature would present a food safety risk. The methods used in this study reflect common consumer cooking practices, and the results indicate a possibility that both dial and digital thermometers would provide inaccurate readings in ground beef patties cooked in consumers' homes. The potential for both thermometer types to overestimate patty temperature represents a food safety risk.

Individual thermometer precision

Retesting of the six consumer thermometers after use in ground beef patties revealed that the thermometers performed consistently after repeated use, registering within 0.3˚C of their temperature measurement prior to use.

Response time

In this study, thermometer readings were allowed to stabilize for 3 s prior to recording the response time; longer response times were observed than in other studies. Our results indicated that mean dial thermometers response times (as measured in a water bath and in ground beef patties, *Table 4*) ranged from 18 s to 55 s, greater than the range observed in an earlier study from our laboratory, 16 to 25 s, where response time was recorded when the thermometer reached within 0.25°C of the final temperature *(9)*. In a study by Liu et al. *(8)*, dial thermometers required 13 to 23 s to reach the end-point temperature, as determined by a thermocouple.

Similarly, in this study digital thermometers required 16 s to 40 s to produce a stable end-point temperature. In our previous study *(9)*, the time range for digital thermometers was 10 to 31 s, and Liu et al. *(8)* reported that digital thermometers registered the temperature in 9 to 22 s. The dial-low cost and the digital-low cost thermometers consistently required longer insertion times to register a stable temperature, compared with the other thermometer models. The only performance factor related to thermometer cost was that the response times of consumer dial and digital thermometers in measuring end-point temperature of ground beef patties significantly decreased as the cost increased. Consumers should be aware that instant-read food thermometers do not register the correct temperature instantly and should be allowed to stabilize in order to measure end-point temperature accurately.

Patty temperature distribution and cooking time

Flipping ground beef patties every 30 s produced a more suitable environment for accurate temperature measurement as well as a smaller temperature gradient throughout the patty. Ground beef patties flipped every 30 s measured within 4°C of the thermocouple standard when measured by five beaded wire thermocouples in 5 locations (in each quadrant and in the center) of the patty *(Table 3)*. Consumer thermometers registered temperatures more accurately in ground beef patties flipped every 30 s (all readings within 2.1°C of the thermocouple standard) compared with patties flipped once (readings differed by as much as 9.2°C for Consumer Onion and 6.5°C for Consumer Cheese) *(Table 2)*.

In this study, ground beef patty cooking time was decreased significantly by flipping the patty every 30 s during cooking, compared with flipping once; cooking time was increased by the addition of onion (about 2 tablespoons per quarter pound patty). Rhee et al. *(12)* also reported that frequent flipping, rather than flipping once, decreased cooking time of ground beef patties from 10.9 min to 6.6 min. In a 2009 survey, almost half of consumer participants (47%) reported using cooking time as a way to determine if ground beef patties are ready to eat *(2)*. In the same survey, over half (52%) of consumers report adding vegetables to hamburgers. Since this practice significantly increases cooking time to achieve a safely cooked patty, the importance of using a thermometer to determine whether a safe end point has been reached is further emphasized.

Recommendations for consumer education

Four of the six tested instant-read consumer thermometer models proved accurate and consistent in water bath testing. However, unlike as in previous research reports, when the six thermometer models were tested for accuracy in hamburger patties cooked via commonly used consumer procedures, they did not meet the FDA standard for thermometer accuracy. Patty temperature was overestimated by 2 to 9°C, a potential safety concern, because of uneven temperature distribution within the patty. Dial and digital thermometers can be recommended to consumers for use in ground beef patties if inserted through the side of the patty to measure the geometric center and if the patty is removed from the heat source to allow the temperature gradient to decrease.

Response time to achieve an accurate measurement varies considerably among thermometers, so consumers should be encouraged to wait for readings to stabilize rather than use a pre-determined length of time. Out of the package, dial thermometers posed an increased risk compared with digital thermometers, based on the inaccuracy of their readings as examined in water bath testing. Since the majority of dial thermometers can be calibrated *(9)*, thermometer packaging should include clear and concise calibration instruction to allow consumers to check their accuracy periodically after purchase. Food safety specialists, educators, and those devising future educational campaigns promoting thermometer use would increase their effectiveness by emphasizing the importance of correct placement of thermometers into the side of ground beef patties and by emphasizing that increasing the number of flips during the cooking of ground beef patties or allowing time for patty temperature to equilibrate somewhat after cooking produces a patty that is more uniform in temperature and more likely to give an accurate temperature reading.

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