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Comparing Infrared and Probe Thermometers to Measure the Hot Holding Temperature of Food in a Retail Setting

ABSTRACT

In Ontario, potentially hazardous food that is kept hot must be held at an internal temperature of ≥ 60°C. This limits the use of infrared thermometers for food safety compliance, as they show only the surface temperature of foods. This research examined the relationship between the internal temperature of hot-held foods measured via a probe thermometer and the surface temperature measured via an infrared thermometer in a retail setting. Seven different food items in hot holding stations at seven different retail stores were examined on six occasions for probe and infrared temperatures. The data were analyzed descriptively, and a multivariable linear mixed-effects model (controlling for store location as a random effect) was developed to determine the predictive relationship of infrared to probe thermometer measurements. A strong correlation was identified between the two measurements (r = 0.706; n = 212). The regression model indicated that the infrared temperature significantly predicted the probe temperature, and this relationship differed by food type. The minimum infrared thermometer temperature needed to predict a probe temperature of ≥ 60°C, with 95% confidence, ranged from 53°C for whole chicken to 62°C for chicken strips. These results can be used to inform temperature compliance monitoring for hot-held foods.

INTRODUCTION

With changing consumer habits, grocery stores and supermarkets have experienced the largest share of growth compared to other types of traditional food stores in the past few years *(3, 29)*. Another trend seen recently is the increasing availability of ready-to-eat hot foods in supermarkets and grocery stores. A national study in 2015 that observed 4361 retail stores in the United States (U.S.) found that 90% of supermarkets, 36% of grocery stores, and 64% of convenience stores were selling ready-to-eat food such as sandwiches, pizza, hot dogs, and hamburgers *(34)*. A food safety risk is associated with such food service establishments that sell pre-cooked foods that are prepared on site *(15)*. Currently, there is little evidence available showing the overall burden of foodborne illness from hot-held foods in grocery stores or supermarkets. However, a

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recent study in the U.S. found that 2.1% (n = 6/297) of single-setting foodborne disease outbreaks associated with food premises between 2009 and 2013 were linked to food from these settings *(6)*.

Temperature abuse of cooked food is one of the major contributing factors for microbial growth and foodborne disease outbreaks *(7, 9)*. From a food safety standpoint, temperature control of food products is considered an important measure to reduce the risk of microorganism growth and to ensure that the food is safe for consumption *(9, 32)*. The greatest risk of pathogenic organism growth occurs at food temperatures between 4°C and 60°C – the temperature danger zone *(23)*. Most retail and food service establishments use some type of hot holding unit to maintain hot food at temperatures above 60°C *(4, 5)*. The safety of food in such units depends on their proper operation and use *(27)*. If the hot holding unit is set for very high temperatures, above 60°C, it prevents microbial growth. However, such high temperatures may also negatively affect the quality, taste and visual appearance of food *(2)*, which could affect consumer purchases, as these are influenced by meat juiciness, flavor and color *(33)*. This highlights the importance of using food thermometers to monitor optimal food temperatures of foods in hot holding units.

Various types of food thermometers are available *(22, 30)*. The most widely used food thermometers are the thermocouple type, also called probe thermometers, as they usually have a probe that penetrates the food item to measure the internal temperature of the food. A disadvantage of probe thermometers is that they need to be appropriately cleaned and sanitized between uses to reduce the risk of cross-contamination *(12)*. Infrared thermometers use infrared technology to measure the surface temperature of foods *(16)*. Infrared thermometers are also known as non-contact thermometers because they allow measurement at a short distance from the food, without any direct contact. Infrared thermometers have some limitations, in that they need to be perpendicular to the surface, the lens should be cleaned regularly, and they are prone to show rapid change in ambient temperatures *(21)*. Despite these limitations, infrared thermometers are becoming more widely used in the food service industry and retail setting, as they offer certain advantages over probe thermometers in practical applications. Apart from prevention of cross-contamination, infrared thermometers are more convenient as they have a simple design that allows them to be hand held, and they offer accuracy of measurement in a non-invasive manner without any detrimental effect to food, compared with probe thermometers *(20)*. The fundamental difference between the probe and infrared thermometers is that the infrared thermometer provides only surface temperatures of foods while the probe thermometer provides internal temperatures.

In Ontario, food safety compliance at retail and food service premises is regulated under the Health Promotion and Protection Act, 1990 *(10)*. Under the Food Premises Regulation of this act, it is mandatory for every food premise to maintain the internal temperature of potentially hazardous foods above ≥ 60°C if they are held hot on the premise *(17)*. This creates a challenge to fully utilize the benefit of infrared thermometers at the retail and food service level. Previous research has shown a predictive relationship between surface temperatures and internal temperatures of food in other settings *(8, 28)*. The purpose of this study is to examine the relationship between the temperatures determined with probe and infrared thermometers of hot-held food in a retail setting to inform future food safety compliance monitoring.

MATERIALS AND METHODS

Data collection

Seven stores (coded A to G) from the same retail chain were selected for this study in the Greater Toronto Area, Ontario. The stores were selected, in collaboration with the retailer, on the basis of which ones within the study region had a hot holding unit on site. The study was conducted from 22 February 2018 to 17 March 2018. Seven different food items were selected for the study: whole chicken, chicken strips, chicken pieces, breaded chicken wings, honey garlic chicken wings, potato wedges, and ribs. All of the food items were cooked in the store kitchen with standardized cooking processes and kept hot in a hot holding unit at the store for customer purchase. The hot holding units in each store were from the same manufacturer and all had heat bulbs as a heating element. Five stores had a similar type of hot holding station with access to holding food from both sides — the customer side and kitchen side — whereas two stores had hot holding units with no customer access on the top half of the unit. Except for the whole chicken, every food item was prepared and packed in 450 gram boxes. The whole chickens were packed with one chicken per box.

One researcher visited each of the locations six times during the research period. During each visit, food temperature measurements were taken with a probe and infrared thermometer. We used a multi-function thermometer for the temperature measurements. This is the same instrument used by the retailer for routine food safety compliance and quality assurance. The thermometer had the availability of probe (thermocouple), infrared (IR), and RFID temperature measurements. For study purposes, the RFID function was not used. When multiple samples of each food item were available, one representative sample of each food item was selected randomly for temperature measurement.

At each location and sample visit, each selected food item was measured with the probe thermometer twice, followed by two infrared measurements. The researcher chose the thickest part of the sample to insert the probe thermometer into the food, while keeping the two insertion points as far apart from each other as possible. The probe thermometer was inserted at a 90° angle to the food surface. The infrared thermometer measurements were taken using the probe insertion points as a reference, with the thermometer facing downward toward the food. The two measurement values for each thermometer type were averaged together for analysis and reporting purposes. All temperatures were recorded manually in degrees Celsius.

During each visit, additional variables were also collected. The operating temperature (°C) of the unit was recorded through the inbuilt thermometer of the unit. The total number of food boxes available in the hot holding unit was also recorded. The store cooking log and cooking time stamps on the food boxes were recorded as 'preparation time.' A variable called 'time elapsed' was calculated from the time of sampling minus the preparation time, indicating the amount of time a food item had been sitting in the hot holding unit. For each store, the distance of the hot holding unit from the outside door (entrance) of the store was measured in meters, and during each visit, the outside weather temperature at the nearest weather station was also recorded through the Weather Network mobile application.

Data analysis

All recorded data were entered into a Microsoft Excel spreadsheet (Excel 2013, Microsoft Corporation, Redmond, WA). Descriptive analysis of the data was conducted using Microsoft Excel. A Pearson correlation coefficient was calculated to compare the temperature measurements of the probe vs. infrared thermometers, and to examine the relationship between different continuous variables (hot holding unit temperature, number of food boxes, outside temperature, and time elapsed) and both thermometer measurements. In addition, an analysis of variance (ANOVA) was conducted to examine the relationship of store location and type of food with the probe and infrared thermometer measurement outcomes. These analyses were conducted using SPSS software (v24, IBM, Armonk, NY).

A multivariable linear mixed-effects model was developed to evaluate the predictive relationship between infrared and probe thermometer measurements, while accounting for other important covariates *(14, 24)*. The dependent variable was the probe thermometer temperature, while the main independent variable of interest was the infrared thermometer temperature. The model included store location as a random effect, as measurements were clustered by store, while all other independent variables were modelled as fixed effects. Other covariates considered in the model-building process were: food sample type (categorical); time elapsed since the food was prepared (continuous); hot-holding unit operating temperature (continuous); outside air temperature (continuous); quantity of food boxes in the hot-holding unit (continuous); and distance of the hot-holding unit from the store entrance (> 20 meters vs. ≤ 20 meters). For the food type variable, the single sample of ribs was excluded, while chicken wing and pieces measurements were grouped together as a single category.

The model was estimated using maximum likelihood methods *(24)*. All covariates were first evaluated for significance in series of univariable mixed-effects models, and those with a liberal $P < 0.20$ were further considered in a multivariable model. The final model was selected by use of a manual backwards-selection process. This included adding all significant covariates, along with the independent variable of interest (infrared temperature), to a multivariable model and removing variables one at a time until all remaining variables were statistically significant at $P < 0.05$. Interactions between all independent variables in the final model were evaluated. The final model was evaluated for normality of residuals and homogeneity of variance (homoscedasticity) via normality plots and residual vs. fitted value plots, respectively.

Predicted (fitted) values of probe thermometer temperatures were calculated from the final model, and these were plotted against the infrared thermometer temperature measurements. Predictive margins were then calculated to determine the minimum infrared thermometer temperature required to have 95% confidence that the average predicted probe thermometer temperature would be ≥ 60°C, thereby conforming to provincial regulations for hot holding temperatures of potentially hazardous foods. The mixed-effects modelling was conducted using Stata IC 14 (StataCorp LLC, College Station, TX).

RESULTS

Descriptive results

A total of 212 food samples were assessed with paired probe and infrared temperature measurements during the study, across a total of 42 unique sampling visits. *Table 1* shows the mean values of all continuous study variables. The average probe thermometer temperature was 66.07°C (SD = 6.39°C, n = 212), and the average infrared thermometer temperature was 64.98°C (SD = 9.21°C, n = 212). The average temperature of the hot holding units was 74.64°C (SD = 10.69°C, n = 33). It was not possible to obtain this measurement for all sample visits, as one store (Store A) had no inbuilt thermometer in the hot holding unit, and Store C had a reading available for only half of the visits. The mean quantity of food products for all of the visits was 21.53 (SD = 9.74, n = 43). The sample size was 43 for this variable because on one occasion additional food samples were added to the hot holding unit partway through data collection on one of the visits. The average 'time elapsed' from when the food was prepared until the time of sampling was 1 hour and 59 minutes (SD = 1:32 hours, n = 182). It was not possible to calculate this variable for all samples, as some foods did not have a recorded preparation time. The average outside weather temperature was 1.76°C (SD = 3.30°C, n = 42). Four stores had a layout where the hot holding unit was < 20 meters from the store entrance, and three stores had the hot holding unit > 20 meters from the entrance. The number

TABLE 1. Summary of probe and infrared thermometer measurements, and other study variables, for foods sampled at a hot holding station in a retail setting

Variable	Mean	SD	N
Hot holding unit temperature (°C)	74.64	10.69	33
Hot holding unit food quantity	21.53	9.75	43
Time elapsed (h:min)	1:59	1:32	182
Probe temperature (°C)	66.07	6.39	212
Infrared temperature (°C)	64.98	9.21	212
Difference between probe and infrared temperature (°C)	1.10	6.54	212
Outside temperature (°C)	1.76	3.30	42

SD = Standard deviation

TABLE 2. Mean probe and infrared thermometer temperature stratified by food type and store location

Variable	Quantity (n)	Percentage of Total	Probe (°C)		Infrared (°C)	
			Mean	SD	Mean	SD
Food						
Whole chicken	42	19.81	69.28	5.63	63.26	6.19
Chicken strips	32	15.09	64.77	6.31	67.06	9.94
Chicken pieces	36	16.98	69.27	6.94	69.76	8.22
Breaded chicken wings	35	16.51	65.25	6.63	67.69	9.78
Honey garlic chicken wings	27	12.74	62.83	3.45	60.08	5.64
Potato wedges	39	18.40	63.32	4.62	61.27	9.97
Ribs	1	0.47	77.40	0.00	75.15	0.00
Store						
Store A	35	16.51	63.38	4.11	67.14	6.77
Store B	26	12.26	67.89	5.90	65.40	7.49
Store C	35	16.51	64.92	7.01	63.40	6.04
Store D	28	13.21	64.61	4.39	58.23	5.61
Store E	26	12.26	65.00	4.94	61.31	5.14
Store F	31	14.62	65.90	6.05	61.26	7.44
Store G	31	14.62	71.32	8.06	76.91	11.14

SD = Standard deviation

of sample measurements stratified by food type and store location is shown in *Table 2*. The sample sizes were different for different food items because of varying availability of food types during the sample visits.

The ANOVA test indicated that the average internal temperature of food items differed significantly by food type ($F = 7.705$; $P < 0.001$), with the whole chicken having the highest internal temperature of 69.27°C (SD = 5.63°C, n = 42) and honey garlic chicken wings having the lowest internal temperature of 62.83°C (SD = 3.45°C, n = 27) *(Table 2)*. The average probe temperature also differed significantly by store location ($F = 6.247$; $P < 0.001$) *(Table 2)*. Among

TABLE 3. Pearson correlations between continuous variables and the probe and infrared thermometer temperatures

Variable	Probe			Infrared		
	r	*P*	N	*r*	*P*	N
Hot holding unit temperature	-0.109	0.171	159	-0.293	< 0.001	159
Hot holding unit food quantity	0.021	0.766	212	-0.131	0.580	212
Time elapsed	-0.261	< 0.001	182	-0.379	< 0.001	182
Outside temperature	0.053	0.439	212	0.059	0.396	212

TABLE 4. Pearson correlation between the probe and infrared thermometer temperatures, stratified by food type and store location

Variable	*r*	*P*	N
Food type			
Whole chicken	0.741	< 0.001	42
Chicken strips	0.837	< 0.001	32
Chicken pieces	0.756	< 0.001	36
Chicken wings (breaded)	0.867	< 0.001	35
Chicken wings (honey)	0.677	< 0.001	27
Potato wedges	0.592	< 0.001	39
Ribs	-	-	1
Store			
Store A	0.569	< 0.001	35
Store B	0.744	< 0.001	26
Store C	0.866	< 0.001	35
Store D	0.531	< 0.001	28
Store E	0.603	< 0.001	26
Store F	0.907	< 0.001	29
Store G	0.719	< 0.001	31
Overall	0.706	< 0.001	212

continuous variables *(Table 3)*, only the time elapsed variable was significantly correlated with the probe thermometer temperature (r = -0.261, n = 182).

The infrared temperature also differed significantly by food type (F = 5.877; P < 0.001), with the highest temperature noted for chicken pieces, at 69.76°C (SD = 8.22°C, n = 36) and the lowest temperature noted for honey garlic chicken wings, at 60.08°C (SD = 5.64°C, n = 27) *(Table 2)*. The infrared temperature also differed significantly by store location (F = 5.877; P < 0.001) *(Table 2)*. Among continuous variables *(Table 3)*, the time elapsed variable (r = -0.379, n = 182) and the hot holding unit temperature (r = -0.293, n = 159) were both significantly correlated with the infrared thermometer temperature.

The average difference between the probe and the infrared temperature measurements was 1.10°C (SD = 6.54°C, N = 212). The Pearson correlation coefficient *(r)* between the two types of thermometer measurements was 0.706 (P < 0.001, n = 212). This relationship is shown in *Fig. 1*. *Table 4* shows the values of the Pearson correlation coefficient between the probe temperature and infrared temperature, stratified by food type and store location. Among the different food types,

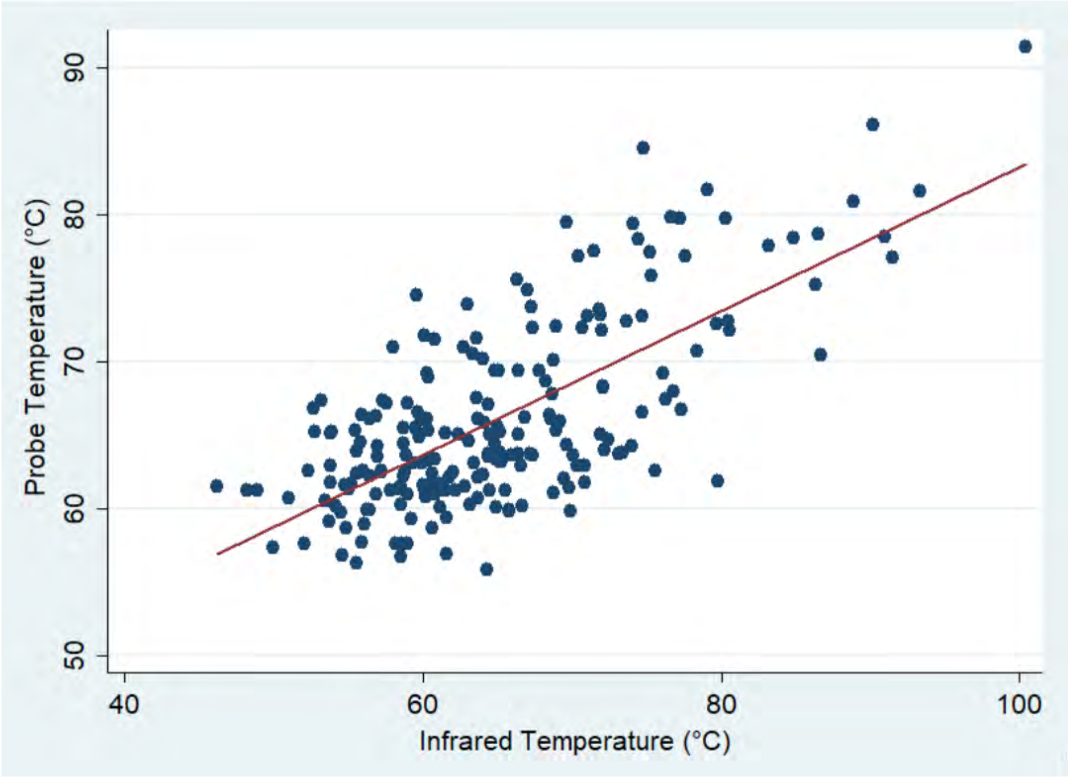

Figure 1. Correlation between the infrared and probe thermometer measurements of foods sampled at a hot holding station in a retail setting.

the highest correlation was observed for the breaded chicken wings ($r = 0.876$, n = 35) and the lowest for potato wedges ($r = 0.592$, n = 39). Among the store locations, Store F had the highest correlation ($r = 0.907$, n = 29) and Store D had the lowest correlation ($r = 0.531$, n = 28).

Regression model results

The results of the final multivariable mixed-effects model are shown in *Table 5*. The independent variable of interest, infrared thermometer temperature, was a significant predictor of the probe thermometer temperature in the final model, along with food sample type. In addition, there was a significant interaction between the infrared temperature and food type variables, as shown in *Fig. 2*. The interaction indicates that the relationship between the infrared and probe thermometer measurements differs by food type. The relationship between these two thermometer measurements was stronger in the samples of chicken products than in the samples of potato wedges *(Fig. 2)*. The intraclass correlation due to the random effect at the store level was 0.25, indicating that roughly 25% of the variation in the probe thermometer measurements was due to differences between stores rather than residual variation.

The results of the predictive margins of the probe thermometer temperature at different levels of infrared thermometer temperatures (from 51 to 65°C) for each food sample type are shown in *Table 6*. These results indicate the minimum infrared thermometer temperature needed to predict an average probe thermometer temperature of ≥ 60°C, with 95% confidence, is 53°C for whole chicken, 62°C for chicken strips, 60°C for chicken wings and pieces, and 58°C for potato wedges *(Table 6)*.

DISCUSSION

This study included an analysis of probe vs. infrared thermometer measurements from a variety of food samples across seven stores of one major retailer. The stores were similar to each other in their layout and food safety policies, because of consistent guidelines and internal quality control practices implemented by the retailer. The stores are representative of current trends of big box stores and supermarkets that share a similarity in operations and display of hot-held foods *(3, 29)*. However, even though the stores in this study were part of the same retail chain, a large proportion of the variance in the probe thermometer measurements (25%) was due to difference by store, with the relationship between the thermometer measurements stronger in some stores than in

TABLE 5. Multivariable linear mixed-effects model of the effects of covariates on the probe thermometer temperature of foods sampled at a hot holding station in a retail setting

Variable	Coefficient	95% CI	*P*-value
Food type			< 0.001
Whole chicken (referent)	-	-	
Chicken strips	-5.83	-19.24, 7.59	0.394
Chicken pieces and wings	-6.36	-18.16, 5.44	0.291
Potato wedges	10.83	-1.82, 23.47	0.093
Infrared temperature	0.65	0.48, 0.81	< 0.001
Food type × infrared temperature interaction			0.001
Whole chicken (referent)	-	-	
Chicken strips	-0.01	-0.22, 0.20	0.917
Chicken pieces and wings	0.02	-0.16, 0.20	0.836
Potato wedges	-0.25	-0.45, -0.05	0.014

Number of observations included in the model = 211; number of random-effect groups (i.e., stores) = 7; Wald test chi^2 $P < 0.0001$; model constant value = 28.32 (95% CI = 17.76, 38.89)

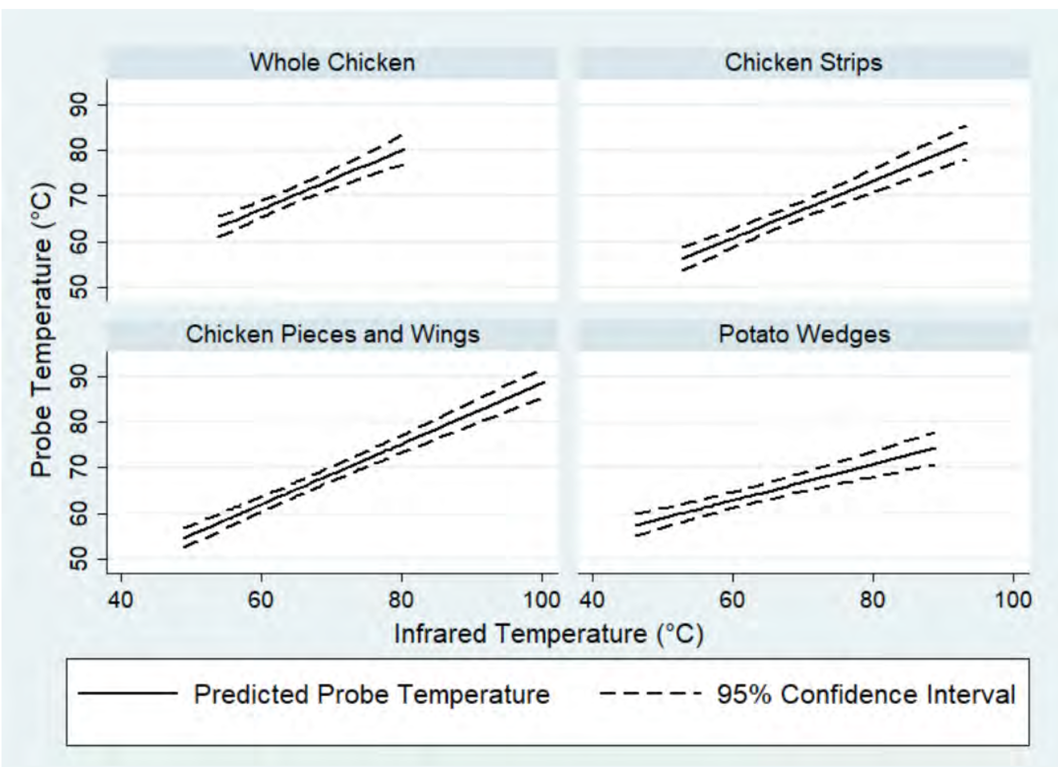

Figure 2. Relationship between the predictive probe thermometer temperature and measured infrared temperature of foods sampled at a hot holding station in a retail setting, stratified by food type. Predictive temperatures are estimated from a multivariable linear mixed-effects model.

TABLE 6. Predictive margins of the probe thermometer temperature for different infrared thermometer measurement values (51 to 65°C), stratified by food type

Infrared thermometer temperature	Whole chicken		Chicken strips		Chicken pieces and wings		Potato wedges	
	Margin (°C)	95% CI (°C)	Margin (°C)	95% CI (°C)	Margin (°C)	95% CI (°C)	Margin (°C)	95% CI (°C)
51°C	61.4	58.7, 64.0	55.0	52.3, 57.6	56.0	53.9, 58.0	59.3	57.2, 61.4
52°C	62.0	59.5, 64.5	55.6	53.0, 58.2	56.6	54.7, 58.6	59.7	57.6, 61.8
53°C	**62.6**	**60.2, 65.1**	56.2	53.7, 58.7	57.3	55.4, 59.2	60.1	58.1, 62.1
54°C	63.3	61.0, 65.6	56.9	54.4, 59.3	58.0	56.1, 59.9	60.5	58.5, 62.4
55°C	63.9	61.7, 66.2	57.5	55.2, 59.9	58.6	56.8, 60.5	60.9	59.0, 62.8
56°C	64.6	62.5, 66.7	58.1	55.9, 60.4	59.3	57.5, 61.1	61.3	59.4, 63.2
57°C	65.2	63.2, 67.3	58.8	56.6, 61.0	60.0	58.2, 61.7	61.7	59.9, 63.5
58°C	65.9	63.9, 67.8	59.4	57.3, 61.6	60.6	58.9, 62.4	**62.1**	**60.3, 63.9**
59°C	66.5	64.7, 68.4	60.1	58.0, 62.1	61.3	59.6, 63.0	62.5	60.7, 64.3
60°C	67.2	65.4, 69.0	60.7	58.7, 62.7	**62.0**	**60.3, 63.6**	62.9	61.1, 64.6
61°C	67.8	66.0, 69.6	61.3	59.4, 63.3	62.6	61.0, 64.3	63.3	61.5, 65.0
62°C	68.5	66.7, 70.2	**62.0**	**60.0, 63.9**	63.3	61.7, 64.9	63.7	61.9, 65.4
63°C	69.1	67.4, 70.9	62.6	60.7, 64.5	64.0	62.4, 65.6	64.1	62.3, 65.8
64°C	69.8	68.0, 71.5	63.2	61.4, 65.1	64.6	63.1, 66.2	64.4	62.7, 66.2
65°C	70.4	68.7, 72.2	63.9	62.0, 65.7	65.3	63.7, 66.9	64.8	63.0, 66.7

others. This finding could be due to several factors, such as differences in the location of the hot holding stations within each store, different times of day when the sampling was conducted, and despite the internal quality control process in place, variations in food preparation, handling, or operation practices among stores. These results suggest that larger differences may be observed for different types of grocery stores as well as other food service establishments. Future studies with larger sample sizes and a greater variety of food premise types should be conducted to further evaluate the results and compare the outcomes of this study to results across different retail settings.

The study included seven different food items that were kept hot. Poultry and other meats are usually considered potentially hazardous foods because of their physical and microbiological properties, and they need to be kept out of the temperature danger zone to prevent microbial growth and possible foodborne illness *(31)*. The mean temperature of the hot holding units that stored and displayed these foods was 74.64°C *(Table 1)*, which is higher than the regulatory requirement for safe food handling. When compared with the internal temperature of the food products, the hot holding unit temperature was not statistically correlated. This signifies the importance of conducting specific measurements of individual, representative food products to assess food safety compliance. This research suggests that the hot holding unit temperature should not be considered as a surrogate for determining the temperature of individual food products it contains. In contrast, we found a statistically significant correlation between the infrared measurements of foods and the hot holding unit temperature, which suggests that the hot holding unit temperature may be a better indicator of the surface temperature of the held foods than of their internal temperature.

Previous studies have found an association between the shopping habits of consumers and weather conditions, specifically, that the sale of hot foods is higher during colder weather conditions *(1, 18)*. This study included outside weather temperature as one of the study variables to assess the relationship with the temperature foods in hot holding units. We did not find a significant relationship, although there was little variability in these measurements, as the research was conducted throughout only winter months (average temperature of 1.76°C across all store visits). Further research comparing these results to temperature measurements in summer months would be useful.

We found a negative and statistically significant bivariate correlation between the duration of time a food product was sitting in the hot holding unit and both the probe temperature and the infrared temperature. This indicates that the longer the food sat in the hot holding unit, the more likely it was to have a lower temperature. This finding is important with respect to microbial growth prevention. A time limit requirement should be considered as a part of food safety compliance at the retail and food service level for hot-held foods, to reduce the possibility of a food reaching danger zone temperatures while being kept hot. The U.S. Department of Agriculture developed a guidance document that suggests checking the food temperature of hot-held food at least once every two hours *(11)*. The findings of this research also suggest a similar approach to food safety compliance for hot-held food in supermarkets. However, it should also be noted that the 'time elapsed' variable was not significant in the final multivariable regression model, which may be due to the large number of missing observations for this variable because some foods did not have a recorded preparation time.

We found that the infrared and probe thermometer temperatures were strongly correlated *(Table 4)*, and this relationship was confirmed in the multivariable regression model. The results of our study are comparable to results obtained with the predictive model developed by Tao et al. (2000), where infrared imaging was used to predict the internal temperature of cooked chicken *(28)*. The study by Fujikawa and Kano (2008) also found a predictive relationship between the surface temperature and internal temperature of food *(8)*. The predictive model in this study found that the relationship between infrared and probe measurements differed by food type, which is likely explained by different characteristics of the food measured (e.g., thickness, composition, preparation method). For example, a much lower infrared temperature was needed (53°C) to predict an acceptable hot holding temperature of 60°C (with 95% confidence) for whole chicken than for the other food types, which likely relates to the ability of the whole chicken to stay hot longer because of its larger size compared to the smaller pieces of other food types *(25)*. The model results have practical utility, as the ability to predict or confidently estimate the internal temperature of potentially hazardous food items via surface temperature measurements can improve the viability of infrared thermometers for food safety compliance in retail and food service settings.

We found that the difference between the probe and infrared thermometer temperatures was widest at the extreme of measured temperatures and narrowest near temperatures closer to 60°C *(Figures 1 and 2)*. The results also suggest that the surface temperature of the foods changed more rapidly compared to the internal temperature. Another study, by Schaffner (2013), found that the temperature change of food directly related to the temperature difference between food and its environment *(26)*. The change in the relationship between the probe and infrared measurement can be explained by the fact that the temperature change on the surface of food is faster than the change of the internal temperature of food *(13)*.

There are several limitations of this research. Because this study was conducted in partnership with a local retailer, we were limited by the types of food samples and hot holding units available. Therefore, this study included only a limited number of food types (mostly poultry-based foods), because of restrictions on the types of foods offered in the participating stores at the time of sampling. The sampled foods were all discrete food items, and none of the stores sold any hot-held composite foods with different consistencies, such as soup, chili, or casseroles. Furthermore, all stores used the same type of hot holding unit. The temperature relationships observed in this study likely differ for different types of food products and hot holding units (e.g., steam tables), and this could be an area for future research. Another limitation of this study is that only two sample points were taken for each food using each thermometer type, and collection of additional sample points could have improved the accuracy of the temperature measurements. However, we believe that the impact of this would likely be small, given the very strong correlation between the two averaged sample points for both probe ($r = 0.80$) and infrared ($r = 0.83$) thermometer measurements.

The method of measuring the food samples could have influenced the results of this study. While a standardized sampling plan was used, the variable structure (e.g., size) of the food items and slight variations in the angle, location, and depth of the probe thermometer measurements, as well as angle of infrared measurements, could have led to variability in the results. Other intrinsic and extrinsic factors may have also contributed to differences in the infrared and probe thermometer measurements, such as physical characteristics of the foods (e.g., weight, size), intrinsic food attributes (e.g., pH, a_w), and environmental factors such as store size, internal ambient temperature, and food handling procedures. Therefore, we recommend that those interested in using infrared thermometers as a surrogate for probe (internal) temperature measurements conduct their own validation study or assessment for different food products to determine acceptable measurement indicators.

CONCLUSIONS

We found a strong correlation between infrared and probe thermometer temperature measurements of hot-held food items in a retail setting, and a multivariable regression model confirmed this predictive relationship. Therefore, infrared thermometers can provide a surrogate measure of the internal temperature of hot-held foods. In contrast, the results of this study suggest that temperature reading of the hot holding unit should not be used as a surrogate for the internal temperature of the held foods. The nature of the predictive relationship between the thermometer types differed by store location and type of food measured. Thus, food retailers who plan to use infrared thermometers in this context should conduct their own product assessments to evaluate how these temperature relationships might change for different types of foods and hot holding units in different settings. Food safety regulatory authorities should consider allowing the use of infrared thermometers to measure the temperature of hot-held foods in retail settings. Because of the possible influence of time elapsed since preparation on the foods' internal temperature, frequent temperature measurements should be conducted throughout the day (e.g., every 2 hours) for hot-held foods.

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