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The effect of two methods of cooking and cooling on *Clostridium welchii* and other bacteria in meat

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SUMMARY

A comparison was made of beef cooked in conventional and moist air (Rapidaire) ovens. In both large (*ca.* 4·5 kg.) and small (*ca.* 2·7 kg.) joints, spores of *Clostridium welchii* survived after cooking but vegetative cells, *Escherichia coli*, and *Staphylococcus aureus*, did not, regardless of the type of oven used.

Cooling at room temperature after cooking permitted growth of *Cl. welchii*. Although some multiplication also occurred in the centre of large roasts cooled under refrigeration, the viable counts were considered too low to constitute a potential health risk.

INTRODUCTION

The ability of bacteria to survive cooking and to multiply within a particular food during cooling and subsequent storage is an important factor in the epidemiology of food poisoning outbreaks. Adequate cooking and rapid cooling of foods, particularly meats and poultry, is frequently advocated as a means of reducing the incidence of food poisoning within the population. Unfortunately, there is only a limited amount of published quantitative information available on the temperature changes that occur within meat during cooking and cooling, and the effect of these temperature changes on the survival and multiplication of food-poisoning bacteria. Sylvester & Green (1961) recorded a temperature of 79° C. in the centre of a 4–5 lb. roast after cooking for 2¼ hr. in an oven heated to approximately 215° C. Woodburn & Kim (1966) studied the survival of *Clostridium welchii* in turkey stuffing during roasting at 94, 163 and 232° C. They found that *Cl. welchii* spores could survive these cooking temperatures, although vegetative cells were generally killed. These workers found that after cooking in an oven at 94° C for 10 hr. the temperature of the stuffing was 62° C. in lightweight turkeys (12–16 lb.) and 41° C. in heavyweight birds (20–24 lb.). Final cooking temperatures were not given for turkeys cooked at 163° and 232° C.

The following work was carried out to compare temperature changes in portions of beef of different sizes cooked in a traditional hot air oven (213° C.) and in a Rapidaire moist air oven (82° C.).

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The rate of cooling of meat samples was investigated at room temperature (15° C.), in a refrigerator (4–5° C.) and in a blast freezer (−30° C.). The effect of different cooking and cooling procedures on the survival and multiplication of food poisoning organisms inoculated into the meats before cooking was also investigated. The work was carried out in the kitchen of a large mental hospital.

MATERIALS AND METHODS

Equipment for cooking and cooling meat

Electronic thermometer. This was type 166C, manufactured by Comark Electronics Limited, Littlehampton, Sussex, used with chrome alumel thermocouples 4–7 ft. long. The accuracy of the system was ± 1° C.

Moist air oven. The Rapidaire oven was manufactured by Eureka Engineering Company, Pratts Bottom, Kent. Meat was cooked in this oven at a temperature of 82° C. and at an RH of 95 %. The cooking process therefore differs greatly from that of steam cookers

Hot air oven. The large coke-fired hot air oven was used routinely in the hospital kitchen; it was fitted with an external recording thermometer. Meat was cooked at 213° C.

Blast freezer. The commercial 'Prestcold' blast freezer was operated at −30° C. with an air flow rate of 12,000 ft.^{3}/min.

Cold room. The room was commercially designed and operated at 4–5° C.

Meat

Lean beef from which surface fat had been removed was used as follows:

(*a*) Bulky cuts of irregularly cubical shape, weighing approximately 4·5–5 kg.

(*b*) Long slim cuts, approximately 5–6·5 cm × 9 cm. in section, weighing about 2·7–3·2 kg. When cooked in the Rapidaire oven these smaller cuts were placed in polythene Visicase bags, which was the routine practice of the chef. Thermocouple leads were inserted through the neck of the bag before sealing.

Media

Veal cooked-meat medium. A modification of Robertson's meat medium (Cruickshank, 1965) was used, made with boneless veal instead of bullocks' hearts. A similar meat medium with the addition of 10 % NaCl was used for *Staphylococcus aureus* enrichment.

Neomycin blood agar (Sutton & Hobbs, 1968). A modified 5 % horse blood agar was used.

MacConkey broth and MacConkey agar. These media were prepared from basic materials.

Phenolphthalein phosphate agar (Barber & Kuper, 1951) was modified according to Hobbs, Kendall & Gilbert (1968) and Gilbert, Kendall & Hobbs (1969).

Organisms

Clostridium welchii

Spores of F2063/67 (Type 17, heat-resistant) and F3795/67 (type xii, heat-sensitive), together with vegetative cells of F9191/66 (type iv, heat-sensitive) and F6849/67 (type 18, heat-resistant) were used. The term 'heat-sensitive' when applied to spores of *Cl. welchii* has led to confusion. Although these spores (F3795/67) are less resistant at high temperatures (90–100° C.) than the so-called heat-resistant food poisoning strains, they are, nevertheless, able to survive temperatures as high as 80° C. for relatively long periods of time, particularly if heated in a meat medium (Sutton, 1969). They are, therefore, much more resistant to heat than vegetative cells of *Cl. welchii* or other food-poisoning organisms.

Specific antisera were available for each of the strains. A selection of colonies isolated from the meat samples after cooling was tested against the specific antisera using a slide agglutination technique.

Preparation of spore suspensions. Spores of *Cl. welchii* present on meat are usually derived, either directly or indirectly, from the faeces of animal or man. For this reason, and because of the difficulty in obtaining large numbers of spores of *Cl. welchii* in laboratory media, and of the probable reduction in heat resistance of laboratory prepared spores, the spores used in this work were obtained from the faeces of food-poisoning patients.

Faecal samples known to contain large numbers of *Cl. welchii* spores (F. 2063/67 and F. 3795/67) were emulsified in water to give approximately 1/10 suspensions, and filtered through gauze. The filtrates were centrifuged at 3500 rev./min. for 30 min. and the centrifuged deposits washed twice with water before making 1/100 suspensions in water. The final suspensions contained approximately 10^5 spores/ml. and were relatively free of faecal matter.

Staphylococcus aureus

NCTC 4163; phage type 6+/42E/47/54/42D.

Escherichia coli

NCTC 7152; O 25, H 12, K 19.

Inoculum

The same inoculum was used for each sample, consisting of:

Cl. welchii	Spores	$1{\cdot}5 \times 10^5$ type 17
		$1{\cdot}6 \times 10^5$ type xii
	Vegetative cells	$1{\cdot}0 \times 10^9$ type 18
		$9{\cdot}0 \times 10^9$ type iv
Staph. aureus		$8{\cdot}0 \times 10^9$
E. coli		$7{\cdot}5 \times 10^8$

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Method of inoculation

Five samples of beef were inoculated with the above suspension in a longitudinal and vertical plane through the centre of the meat by means of a syringe fitted with with a 6 in. cannula.

Cooking and cooling procedures

Thermocouples were inserted into the centre and outer edge (approximately 6 mm. into the meat) of 15 samples of raw meat. In the moist air oven the meats were cooked for 30 min. per 4·5 kg. weight; meats cooked in the conventional oven were turned, basted and removed from the oven at the chef's discretion in order to simulate a normal cooking procedure.

After cooking, samples of beef were left to cool at room temperature (15° C.), in a cold room (4° C.) and in a blast freezer (−30° C.). Samples cooled in the refrigerator and blast freezer were allowed to stand at room temperature for 15 min. after removal from the oven to avoid condensation.

Throughout the cooking and cooling period, temperatures were recorded with the electronic thermometer; the wires of the thermocouples were long enough to allow the oven and refrigerator doors to remain closed during the experiment.

Sampling and recovery of survivors

After cooking and overnight storage at 15° C. or at 4° C., the five inoculated meat samples were examined bacteriologically. The entire portion of meat could not be cultured, but it was assumed that the majority of surviving organisms would be present around the line of the inoculum and particularly in the centre of the meat. The results obtained, therefore, represent the numbers found in this portion, usually 250–500 g., and not in the entire sample of meat. The portion was chopped into small pieces, mixed with an equal volume of ¼-strengh Ringer's solution and homogenized in a blender for 30 sec. The homogenized suspension was passed through sterile gauze to remove coarse material and used for direct viable counts by the surface spread technique, and for enrichment cultures.

RESULTS

Effect of shape and weight of meat sample on heat penetration

The results indicated that during cooking the temperature at any point within the meat was dependent on the distance of that point from the outer surface of the meat. The centres of large bulky cuts of meat will therefore heat more slowly than those of long slim portions of like weight, so that longer cooking times are required to reach the same final temperature. When meats of similar shape and weight were cooked the results were reproducible.

Tables 1 and 2 summarize the data obtained for 15 samples of meat cooked in the conventional hot air and Rapidaire ovens. Figs. 1*a* and 1*b* show in graphic form the relationship of the distance of the thermocouple from the outer surface of the meat to the time taken to reach 60° C. for both cooking methods. A temperature of 60° C. was chosen because vegetative cells of food poisoning bacteria are

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Table 1. *Mean heat penetration data at the centre and outer edge of seven samples of beef cooked in a conventional hot air oven at* 213° C.

	4·5 kg. meat cooked for 205 min.				2·7 kg. meat cooked for 165 min.		
Depth of thermocouple (mm.)	76	51	6	3	38	19	6
Time to reach 60° C. (min.)	220	145	40	37	126	115	65
Temperature at end of cooking (°C.)	55	64	90	96	79	79	88
Maximum temperature (°C.)	65	71	90	96	81	80	89

Table 2. *Mean heat penetration data at the centre and outer edge of eight samples of beef cooked in a moist air oven at* 82° C.

	4·5 kg. meat cooked for 315 min.				3 kg. meat cooked for 322 min.			
Depth of thermocouple (mm.)	76	63	19	3	44	32	19	3
Time to reach 60° C. (min.)	230	200	80	43	160	95	65	43
Temperature at end of cooking (°C.)	68	76	77	81	63	78	74	81
Maximum temperature (°C.)	70	77	77	81	66	78	74	81

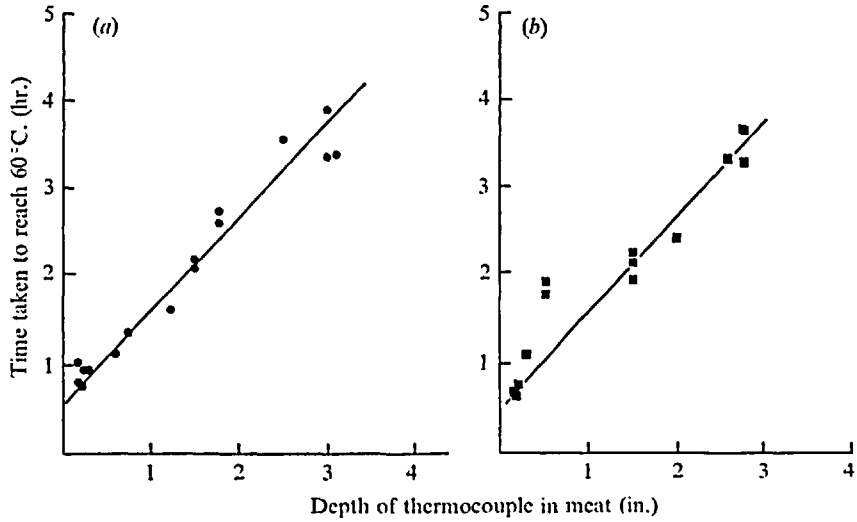

Fig. 1. Relationship of the depth of the thermocouple to the time taken to reach 60° C for (*a*) the moist air oven, and (*b*) the conventional hot air oven.

usually killed and growth no longer occurs at this temperature; it is not implied that a maximum temperature of 60° C. renders the meat bacteriologically safe.

Comparison of the conventional hot air and the moist air ovens

Although both ovens cooked effectively, the results showed that there were differences in the rates of heat penetration in the two ovens. The centres of large portions of meat cooked in the hot air oven were slow to heat up, and a 'lag period' of approximately 1 hr. occurred in which little or no increase in temperature occurred. The lag period did not occur when similar portions of meat were cooked in the moist air oven. This is shown in Fig. 2.

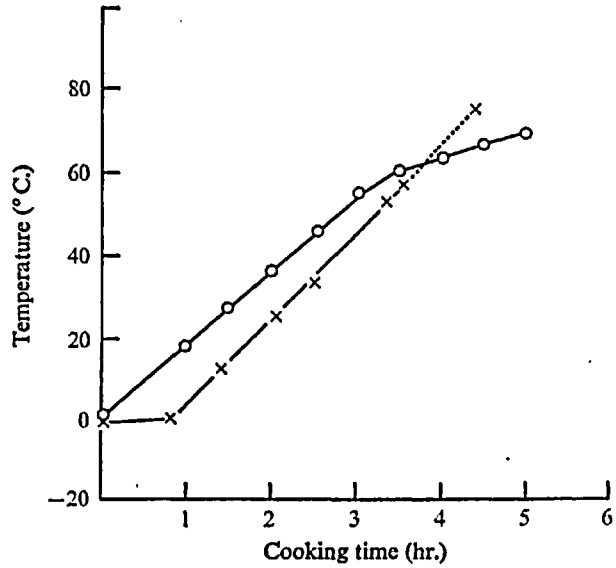

Fig. 2. Heat penetration at the centre of two large samples of meat (*ca.* 4·5 kg.) cooked in the moist air oven (○) and the conventional hot air oven (×). Thermocouples approximately 7·5 cm. from surface of meat. (× - - - - ×) shows the continued rise in temperature recorded after the completion of the cooking time.

All of the samples tested reached a maximum temperature above 60° C. although not always by the end of the cooking time. In the moist air oven the maximum temperature was reached by the end, or within 15 min. of the completion of cooking. With the conventional oven, however, the temperature recorded in the centre of large roasts at the end of the cooking time was considerably lower than the recorded maximum. Temperatures of 55°, 56° and 64° C. were recorded at the end of the cooking time, but there was a continuous rise in temperature for an hour afterwards to reach maximum temperatures of 65°, 68° and 70° C. respectively. This effect was less marked with the smaller roasts.

Cooling of meat

Table 3 summarizes the main features of the results from temperature records of cooling meat. Fig. 3 shows the cooling at the centre of three samples of meat of similar size and weight which were cooked in the hot air oven and then allowed to cool at 15°, 4° and −30° C.

Cooling at 15° *C.* This was effective only in lowering the temperature to approximately 25° C. Loss of heat was very slow, and even after 7 hr. the samples had not reached 15° C., the ambient temperature in the kitchen.

Cooling at 4–5° *C.* This was a more effective method of cooling, although there was little difference in the initial cooling rate for samples cooled at 4° C. or at 15° C. The important difference with refrigeration was that the temperature at the centre of the meat fell to 15° C. or below during the 7 hr. course of the experiment, and would do so irrespective of the room temperature. Fifteen degrees centigrade is taken as the lowest temperature at which *Cl. welchii* will multiply.

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Table 3. *Effect of storage at room temperature* (15° *C.*), *in a refrigerator* (5° *C.*) *and in a blast freezer* (−30° *C.*) *on the cooling of freshly cooked meat*

Weight of sample (kg.)	Temp. of cooling (°C.)	Depth of thermocouple (mm.)	Temp. °C at end of cooling (420 min.)	Time to reach 15 °C. (min.)
	Samples cooked in moist air oven			
4·5–5	4	76	15	420
	−30	76	−15	215
2·7–3·2	15	38	21	> 420
	4	44	15	415
	−30	38	−28	120
	Samples cooked in hot air oven			
4·5–5	15	51	22	> 420
	4	76	14	395
	−30	76	−5	220
2·7–3·2	15	38	17·5	> 420
	4	38	9	235
	−30	38	−20	110

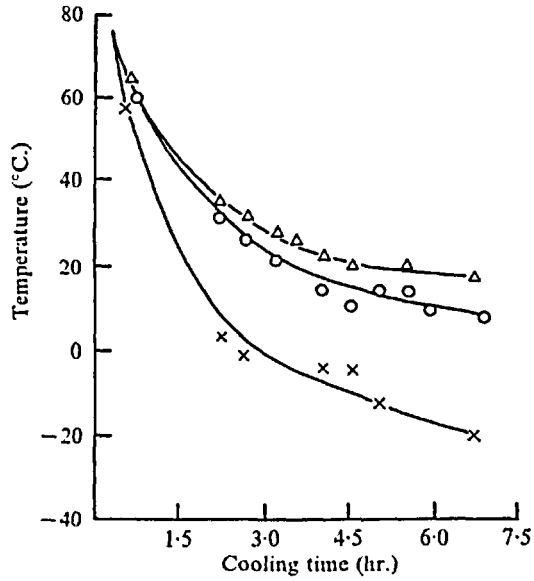

Fig. 3. Cooling at the centre of three smaller samples of meat (*ca.* 2·7 kg.) previously cooked in the hot air oven. (△) at room temperature, 15 °C.; (○) at 4 °C.; (×) at −30 °C. Thermocouples approximately 3·8 cm. below surface of meat.

Cooling at −30° *C.* This was naturally the quickest method of cooling. The centre of large (4·5 kg.) samples of beef cooled to below 15° C. in 3 hr. 40 min. – half the time required to reach the same temperature by refrigeration at 4° C.

Effect of shape and weight of meat sample on rate of cooling

There was a relationship between the recorded rate of cooling and the position of the thermocouple. The centre of small roasts reached 15° C. in about half the time required for the larger bulky roasts. When samples were cooked in the moist

Table 4. *Cooking and cooling data for five samples of beef inoculated with viable bacteria before cooking*

Sample	Weight of sample (kg.)	How cooked (oven)	Time for centre to reach 60° C. (min.)	Max. centre temp. (°C)	Temp. of cooling (°C)	Time for centre to reach 15° C. (min.)	Min.* centre temp. (°C)
1	2·7	Rapidaire	130	71	13–15	> 420	21
2	4·5	Hot Air	145	71	13–15	> 420	22
3	2·7	Hot Air	135	71	13–15	> 420	17
4	4·5	Hot Air	220	65	4	420	15
5	5·0	Rapidaire	200	77	4	420	15

* Minimum temperature recorded during the first 7 hr. of cooling, when temperature readings were taken regularly.

air oven the relationship of size to cooling rate was not so marked. The smaller samples (but *not* the larger samples) were cooked and cooled in polythene 'Visicase' bags, which are known to reduce the efficiency of cooling; hot air from the meat condenses on the Visicase and the meat shrinks during cooling so that a layer of air becomes trapped between the meat and the casing.

Survival and multiplication of Cl. welchii *in meat during cooking and cooling*

Table 4 summarizes the results of cooking and cooling for the five inoculated samples of beef.

The results given in Table 5 show that spores of *Cl. welchii* (type 17 and xii) survived cooking and that the outgrowths from the spores could multiply during subsequent cooling. Samples 1–3 were initially cooled at room temperature (15° C.) followed by overnight storage in a room where the minimum recorded temperature was 13° C. These three samples included both small and large roasts and samples cooked by both moist air and conventional roasting methods. The lower count from sample 3 probably reflects the more rapid cooling of this sample.

The two larger samples cooled at 4–5° C. showed only a small increase in the number of cells present, but this was expected. Although both samples were cooled at 4–5° C. the centre temperatures were above 15° C. for 7 hr.; the long cooling would allow germination and some multiplication to occur. However, the number of *Cl. welchii* in the refrigerated samples would be unlikely to give rise to food poisoning, assuming that a dose of 10^8 organisms may be required to initiate infection (Dische & Elek, 1957). The results indicated that the method of cooling and not the method of cooking was the relevant factor with regard to numbers of *Cl. welchii*.

In view of the failure to isolate *Cl. welchii* type iv and 18, it is assumed that all vegetative cells were killed by the cooking. Neither *E. coli* nor *Staph. aureus* were recovered after cooking.

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Table 5. *Cell counts obtained after overnight cooling with five samples of beef inoculated before cooking with food poisoning organisms*

Sample no.	Cooled at	Serotype of *Cl. welchii* isolated	Number of orgs/g in* inoculated portion
1	Room temperature	17	$4{\cdot}5 \times 10^6$
		xii	$5{\cdot}3 \times 10^3$
2		17	$8{\cdot}0 \times 10^6$
		xii	$1{\cdot}9 \times 10^3$
3		17	$6{\cdot}2 \times 10^5$
		xii	$3{\cdot}4 \times 10^2$
4	Refrigerator	17	$2{\cdot}2 \times 10^4$
		xii	enrich†
5		17	$3{\cdot}3 \times 10^3$
		xii	enrich

* No *S. aureus*, *E. coli* or cells of *Cl. welchii* type 18 or iv, which together with types 17 and xii made up the inoculum, were isolated.

† Enrich: sample positive by enrichment culture only.

DISCUSSION

One of the objectives of this work was to assess, from a bacteriological standpoint, the safety of the 'Rapidaire' oven for cooking large quantities of meat needed for both traditional methods of feeding a hospital population, and for a frozen meals system which was under investigation for the hospital and for commercial production. The results indicated that the Rapidaire oven was satisfactory, but, like the conventional hot air oven, it could not be relied upon to kill bacterial spores.

The final temperatures reached by cooking in the conventional hot air oven, particularly in the centre of large bulky roasts, were not as high as expected, but this may have been due to the relatively short cooking time. A comparison of this work with that of Sylvester & Green (1961) shows that the two sets of results are similar. These workers recorded a temperature of 79° C. in the centre of a 4–5 lb. roast after cooking for 2¼ hr. in an oven heated to approximately 215° C. Although the dimensions of the roasts were not given, it seems likely that the distance of the thermocouple from the surface of the meat was about 1–1½ in. in a roast of this weight.

The need for refrigeration, if meat is not to be eaten immediately after cooking, has been stressed frequently (Knox & Macdonald, 1943; Hobbs *et al.* 1953). Even with ordinary domestic refrigeration at 4° C., large bulky portions of meat are slow to cool, which re-emphasizes the necessity for using small cuts of meat for efficiency of both cooking and cooling.

The survival of spores from both heat-sensitive and heat-resistant strains of *Cl. welchii* confirms the results of Woodburn & Kim (1966), who found that heat-sensitive spores of *Cl. welchii* in turkey stuffing survived cooking. Several incidents of food poisoning due to heat-sensitive *Cl. welchii* have been reported (Hall, Angelotti, Lewis & Foter, 1963; Taylor & Coetzee, 1966; Sutton & Hobbs, 1968)

and because of the ubiquitous presence of these spores, prevention of this form of food poisoning lies primarily in preventing multiplication of the surviving organisms to the large numbers needed to cause food poisoning. Bryan & Kilpatrick (1971) again draw attention to the necessity for care after cooking meat and poultry in the prevention of *Cl. welchii* food poisoning. The organism was isolated from many meat and environmental samples taken in the kitchen. Useful recommendations are presented at the end of their paper.

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