Advisory Committee on the Microbiological Safety of Food

Ad Hoc Group on Safe Cooking of Burgers

Report on the Safe Cooking of Burgers

Advises the Food Standards Agency on the
Microbiological Safety of Food

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Contents

Acknowledgements

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The ACMSF accepts full responsibility for the final content of the report.

Summary

1. In this report, we have reviewed the advice issued by the Chief Medical Officer (CMO) in 1998 on the safe cooking of burgers. In particular, we have considered whether this advice is still appropriate for consumers, manufacturers, retailers, caterers and suppliers to caterers in light of differences between the recommended cooking conditions in the UK and the USA.

2. The report considers the epidemiology of *Escherichia coli* O157, contamination of carcasses, meat and meat products, guidance on safe cooking of burgers in the US and in other countries and industry controls to ensure safety of cooked burgers. A modelling approach to setting confidence limits to provide the basis for risk management decisions is outlined. Published scientific evidence on safe cooking of burgers is also reviewed.

3. Key conclusions arising from the work of the *Ad Hoc* Group are that:

- The advice of the CMO for the safe cooking of burgers should not change and, in line with current advice, should remain at 70°C for 2 minutes or equivalent.
- A *z*-value of 6°C should be used for time/temperature equivalents for burgers, e.g. 65°C for 13.6 minutes or 75°C for 18 seconds.
- Also in line with current advice, use of other time/temperature combinations should not be ruled out where producers are in a position to consistently demonstrate that they can ensure that the final product is safe, and that the process is under effective control.
- FSA consider using a modelling approach to set recommended time/temperatures based on required inactivation levels and required limits of confidence.
- Advice to consumers and caterers on cooking of burgers should be reiterated.

Introduction

4. In September 2004 the ACMSF set up an *Ad Hoc* Group to review current advice on the safe cooking of burgers and similar minced beef products in light of differences between the recommended cooking conditions in the UK and the USA. This followed a suggestion from an American fast food restaurant chain to the Food Standards Agency (FSA) that the UK recommended temperature/time conditions (70°C for 2 minutes or equivalent) were more stringent than was necessary and that these conditions led to overcooking and associated deterioration in the quality of some products.

5. Requirements for the cooking of ground beef issued by the US Food and Drug administration (US FDA) specify that these products are cooked to heat all parts of the food to a minimum temperature of 63°C for 3 min, 66°C for 1 min, 68°C for 15 sec or 70°C for <1sec (instantaneous) (FDA, 1999). The US Department of Agriculture Food Safety and Inspection Service (USDA FSIS) recommend that consumers use a thermometer to ensure that ground beef is cooked to 71°C (USDA 2003).

6. Following this approach by the fast food restaurant chain, the FSA sought the ACMSF's view on whether the advice issued by the CMO in 1998 on UK time and temperature conditions for the safe cooking of burgers was still appropriate.

7. This report reviews the current advice issued by the CMO in 1998 and reports on the work carried out by the Group. The terms of reference and membership of the Group are provided at Annex I. A list of contributors to the deliberations of the *Ad Hoc* Group is at Annex II and the Group wishes to express its gratitude to those individuals for their time and effort.

8. The Group considered documentary and verbal evidence relating to the epidemiology of *E. coli* O157 and other key pathogens such as *Listeria monocytogenes* and *Salmonella* spp., data modelling approaches and risk assessment, and guidance and cooking conditions for burgers used in the USA, UK and other countries. The Group also reviewed published scientific evidence and information submitted by the UK meat processing industry. On examination of evidence presented, *E. coli* O157 was identified as a particular hazard of concern.

9. The *Ad Hoc* Group also received a presentation from a major fast food restaurant chain on the controls employed to ensure the safety of burgers from raw materials through to cooking. The company had commissioned work at a UK research association on the heat resistance of *E. coli* O157:H7 in their thickest burger. This generated *D*-values (time required to reduce the initial

population 10-fold) at a number of temperatures, e.g. at 70°C, the *D*-value was 1.4 seconds. Applying all the data to the ACMSF recommended cook of 70°C for 2 minutes, the minimum equivalent process was reported to equate to a 60 log reduction in *E. coli* O157. Data was also provided to illustrate the fact that *E. coli* O157 outbreaks associated with large fast-food restaurants had not occurred in the USA over the preceding 13 years. An insight was also given into the rationale for the US FDA recommended heat process requirements for burgers.

Background

10. The current UK recommendations on the safe cooking of burgers are based on ACMSF recommendations issued in 1997, which also formed the basis of the CMO's revised guidance published in 1998 (Annex III) (Department of Health, 1998).

11. This advice is directed to consumers, manufacturers, retailers, caterers and suppliers to caterers. In commercial settings the advice is that minced meat products including burgers should be cooked to an internal minimum temperature of 70°C for two minutes or equivalent throughout. No specific time/temperature requirement is given to consumers other than following the manufacturer's instructions and observing that these products are thoroughly cooked and piping hot throughout. Research had shown that colour change in burgers during cooking was unreliable as an indicator of safe cooking (Hague *et al,* 1994; Hunt *et al,* 1995). The advice also stressed that eating undercooked burgers which were rare in the middle was dangerous.

12. The USDA FSIS recommends that consumers use a thermometer or temperature probe to ensure that ground beef is cooked to a minimum of 71.1 °C. In the UK, it is not common practice for consumers to use temperature probes during cooking.

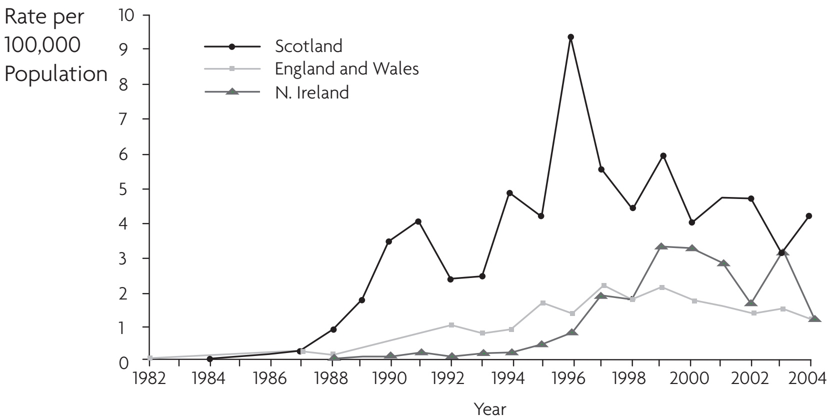
13. The ACMSF has not reviewed its recommendations on the safe cooking of burgers since the CMO's advice was issued in 1998. The Food Safety Authority of Ireland issued similar advice in 1999 (FSAI, 1999). In September 2005 the FSA issued advice on the safe cooking of burgers as part of its 'Safe Food Better Business' tool kit to help food law enforcement officers implement food safety management with local businesses. This advice also reflects the key points of the CMO's guidance.

14. Cooking ground beef using different cooking methods (e.g. single sided or double-sided (clamshell)) has been found to influence the survival of *E. coli* O157. Therefore recommendations on safe cooking need to have an appropriate safety margin to account for the wide range of conditions in which burgers and other minced meat products will be prepared and cooked.

The epidemiology of Shiga toxin-producing *Escherichia coli O157*

15. An important consideration in the safe cooking of burgers is the emergence of Shiga toxin-producing *E. coli* (STEC) as an important human pathogen. In 1982 the investigation of outbreaks of STEC O157 in different parts of the US demonstrated an association with the consumption of burgers (Riley *et al*, 1983), whilst in Canada the connection between STEC infection and the development of haemolytic uraemic syndrome (HUS), one of the most severe clinical consequences, was recognised (Karmali *et al*, 1983). Raw and improperly handled or cooked sausages and burgers can harbour *E. coli* O157, *Salmonella* and *Campylobacter.* In particular, *E. coli* O157 infections can result in bloody diarrhoea and, occasionally, kidney failure. Infants and young children are at particular risk of the debilitating effects of an *E. coli* O157 infection.

16. STEC infection rates in Scotland are generally higher than those reported in the rest of the United Kingdom (Figure 1). Regional variations in infection rates are also apparent. For example in Scotland rates are remarkably higher in the North East and in Dumfries and Galloway. In England and Wales rates tend to be higher in the North and in the West. The predominant pathogen in the UK is STEC O157.



Data sources: HPA CfI, CDSC Northern Ireland, Health Protection Scotland

Figure 1: Laboratory confirmed cases of STEC O157 in the UK – 1982 to 2004

17. The epidemiology of STEC infection has evolved over time. It emerged as a foodborne pathogen and the early association with eating undercooked burgers earned it the label the "burger bug". Twenty years later, however, it is evident that transmission from the animal reservoir (usually cattle) occurs via food-, water-, environmental- and animal-to-person spread. Person-to-person transmission has also been demonstrated in outbreaks in households, nurseries, hospitals and nursing homes (O'Brien & Adak, 2002).

18. Although a variety of foods have been implicated in foodborne outbreaks of STEC, foods of bovine origin continue to dominate the picture. In the UK unpasteurised milk is commonly implicated in foodborne outbreaks of STEC (Gillespie *et al,* 2005). Where red meat has been implicated the problem has tended to relate to cross-contamination of cooked meats from raw meats in butchers' shops (Cowden *et al,* 2001; Gillespie *et al,* 2005). Indeed, there are very few outbreaks in which burgers are identified as the contaminated food vehicle in England and Wales (Table 1) and no recent outbreaks in which burgers from fast food restaurants have been implicated.

Table 1: Foodborne outbreaks of STEC O157 reported to the Health Protection Agency Centre for Infections, England and Wales, 2000-5

Year	Place reporting the outbreak	Setting	No. ill	No. confirmed	Suspected food vehicle
2000	West Pennine	Farm	4	4	Unpasteurised milk (M)
2000	Somerset	School	2	2	Unpasteurised milk (M)
2000	East Norfolk	Mobile retailer	14	5	Brawn, Jot (M)
2000	Stockport	Retailer	11	8	Cold cooked meats (D)
2000	Calderdale & Kirklees	Community	18	18	None
2000	NW Lancashire	Hotel	30	8	None
2000	South Derbyshire	Retailer	8	4	Meat products (D)
2000	South Staffs	Retailer	9	9	Cold cooked meats (D)
2000	Dorset	Prison	56	32	Grilled pork chops, lamb steaks, spaghetti rings (S)
2001	Northampton	Family	5	4	Beefburger (M)
2001	Birmingham	Restaurant	5	5	None
2001	Chorley	Supermarket	27	10	Inadequate Heat treatment
2002	Wigan & Bolton	Community	6	6	Milk (D)
2004	County Durham & Tees	Retailer	14	11	Sandwiches, cooked meats (S)
2005	Cumbria	School	4	3	None
2005	Wales	Community	157	97	Cooked meats (D)

Note: (M) = microbiological; (S) = statistical; (D) = descriptive
Source: Health Protection Agency Communicable Disease Report Weekly (CDR Weekly)

19. In a recently published review of outbreaks in the US, 52% of outbreaks over a 20-year period were foodborne, amongst which ground beef was implicated as a food vehicle in 41% of outbreaks (Rangel *et al,* 2005). In a draft risk assessment of the public health impact of *E. coli* O157 in ground beef, Ebel and colleagues (2004) estimated that on average 0.018% of servings consumed between June and September and 0.007% of servings consumed during the rest of the year are contaminated with one or more *E. coli* O157:H7 cells, equating to a U.S. population risk of illness of nearly one illness in each 1 million servings of ground beef consumed.

20. The majority of cases of STEC O157 are sporadic. Table 2 shows the risk factors for sporadic STEC O157 infection identified in analytical studies published since 2000 world-wide. In North and South America eating undercooked ground beef continues to pose a risk to the population, but this has not been implicated as a food vehicle in the UK since a study by Parry *et al* (1998).

Table 2: Risk factors for sporadic STEC infection in case-control studies

Country	Study Population	Size of study	Independent risk factors	Reference
US	Community (5 FoodNet sites)	196 cases, 372 controls	Farm exposure, cattle exposure, eating a pink hamburger (both at home and outside the home), eating at a table-service restaurant, using immunosuppressive medication, obtaining beef through a private slaughter arrangement	Kassenborg *et al*, 2004
Australia	Community	11 cases, 22 controls	Eating berries, including strawberries, blueberries, and blackberries	Hundy & Cameron, 2004 (Note: this was a pilot study)
Argentina	Community (Buenos Aires and Mendoza)	92 cases, 181 matched controls	Contact with another child with diarrhoea, eating undercooked steak, drinking from a bottle left at ambient temperature for › 2 hours	Rivas *et al,* 2003 (Note: Preliminary analysis only)
US	Community (7 FoodNet sites)	326 cases, 591 matched controls	Eating undercooked ground beef in the home, exposure to surface water and to farms	Kennedy *et al,* 2002 (Note: Preliminary analysis only)
UK (England)	Community	369 cases, 511 unmatched controls	Exposure to farming environment, travel away from home, recreational exposure to water	O'Brien *et al*, 2001
UK (Scotland)	Community	183 cases, 545 matched controls	Contact, or likely contact, with animal faeces	Locking *et al,* 2001.

Contamination of carcasses, hides, meat and meat products

Carcasses and hides

21. Raw meat and meat products can become contaminated with a diverse range of *E. coli* strains from food animals carrying these organisms prior to slaughter. In the ACMSF's report on verocytotoxin-producing *Escherichia coli* (ACMSF 1995) relatively little published data was found on the occurrence of *E. coli* O157:H7 on cattle carcasses or in meat products.

22. Richards *et al* (1998) reported *E. coli* O157 from 0.47% of 4067 neck muscle samples from abattoirs in the UK and Chapman *et al* (2001), reported *E. coli* O157 from 1.4% of 1500 beef carcasses and 0.7% of 1500 lamb carcasses at an abattoir in the Sheffield area. More recently, McEvoy *et al* (2003) reported *E. coli* O157 from 3.2% of bovine carcasses at a commercial Irish abattoir.

23. Data on contamination of hides has tended to show a higher prevalence of *E. coli* O157 contamination than on carcasses. Small *et al* (2002) reported 29% of 90 cattle hides and 5.5% of 90 sheep pelts as positive and Avery *et al* (2002) found 33% of 73 cattle hides to be positive. In the Republic of Ireland 7.3% of 1500 cattle hides tested positive (O'Brien *et al* 2005).

Meat and meat products

24. Meat may become contaminated with bacteria during slaughter and processing. For meat products such as steaks, cutlets and joints, any contamination is generally on the outside of the product. Proper cooking destroys this type of contamination, with the meat cooked to preference. However for minced products such as hamburgers and sausages, bacteria can be found throughout the product due to the way in which they are made.

25. In the UK *E. coli* O157 was first isolated from food (raw milk, raw beef burger) in 1993 (ACMSF 1995). Little & de Louvois (1998) found 0.3% (3/1015) of beef burgers to be contaminated with *E. coli* O157 and in another survey (Little *et al* 1999) *E. coli* O157 was found in 1/183 samples (0.4%) of raw prepared meats from halal butchers premises. In south-east Scotland, Coia *et al* (2001) reported 2/1190 raw meat samples (0.17%), both beef burger, to be positive for *E. coli* O157. A MAFF survey of minced meat in 1997 found *E. coli* O157 in 1/195 lamb (0.5%), 1/132 pork (0.76%) and 0/980 beef samples (Anon 2000).

26. Chapman *et al* (2000) reported *E. coli* O157 from 1.1% (36/3216) of raw beef products, 2.9% (29/1020) of raw lamb products and 0.8% (7/857) of raw meat products from retail outlets in the Sheffield area. A further study by the same research group found 0.4% (12/3112) of raw beef products to be contaminated with *E. coli* O157 (Chapman *et al* 2001). Cagney *et al* (2004) found *E. coli* O157 in 2.8% (43/1533) of minced beef and beef burger samples in the Republic of Ireland.

27. There is very little published data on the numbers of *E. coli* O157 bacteria present but on the basis of the limited information available the number of organisms present in most contaminated samples is likely to be low. Chapman *et al* (2001) conducted a 1-year study of *E. coli* O157 in raw beef and lamb products from 81 small butchers shops in the Sheffield area between April 1996 and March 1997. *E. coli* O157 was most frequently isolated during the summer months. Counts of *E. coli* O157 were low in comparison to total *E. coli* counts. Most samples had <3/g *E. coli* O157 with the highest level found (90/g) being from a lamb burger. More recently Crowley *et al* (2005) also reported low levels of contamination in positive samples of beef from retail outlets in the Republic of Ireland, although in 4/43 samples (9%) counts exceeded 10^3/g.

28. The methodology for the detection of *E. coli* O157 and other STEC has advanced over the last 10-15 years and the application of various methods in different studies can make comparisons difficult. However, the overall picture suggests that contamination rates are low, although there has been little recent work in the UK.

Guidance in the United States of America and other countries

29. Official guidance on the minimum heat process requirements for the safe cooking of burgers in other countries was sought in order to provide a useful basis for comparison with the UK position. Advice on the minimum temperature and time combinations to cook burgers in other countries is limited and, in that available, supporting information on any risk assessment used to underpin the advice is rare.

30. The most comprehensive advice on cooking burgers, outside of the UK, was found in the USA. Several temperature/time regimes are advocated for safe cooking of meat products, which vary depending on the meat type and sometimes on the establishment in which the product is cooked, e.g. commercial versus consumer.

31. The USDA FSIS publishes consumer advice regarding the minimum temperature requirements for cooking a variety of raw products (Anon 2006a). It recommends that all burgers (comminuted, reformed beef patties) are cooked to achieve a minimum temperature of 160°F (71.1°C) and, whilst this same temperature is also advocated for pork and egg dishes, higher temperatures are recommended for chicken breasts and whole chicken (165°F/75.3.°C). In addition, advice to consumers is to use a thermometer to check the temperature rather than rely on visual appearance due to concerns over the potential for the burger to appear cooked even though lethal temperatures may not have been reached.

32. Meat and poultry products cooked in official establishments in the USA are subject to specified legislative requirements. Fully cooked beef patties (burgers) must meet the following temperature/time requirements; 66.1°C (151°F) for 41 seconds, 66.7°C (152°F) for 32 seconds, 67.2°C (153°F) for 26 seconds, 67.8°C (154°F) for 20 seconds, 68.3°C (155°F) for 16 seconds, 68.9°C (156°F) for 13 seconds and 69.4°C (157°F) for 10 seconds (Anon 2006b). In contrast no temperature/time requirements are specified for cooked beef, roast beef and cooked corned beef products, where the requirements specify that a process must be applied to ensure that a 6.5-$\log_{10}$ reduction of *Salmonella* is achieved (or a process that achieves an equivalent probability that no viable *Salmonella* organisms remain in the finished product) (Anon 2006c). Similar requirements exist for fully cooked poultry products except that they must achieve a 7-log reduction in *Salmonella* spp. (Anon 2006d). Risk assessments were conducted when establishing these minimum process requirements which took into account an estimate of the "worst case" raw product, i.e. highest levels of *Salmonella* contamination and the probability distribution of survival in the finished product given different lethal processes (Anon 1998).

33. The US FDA recommend that comminuted fish, meat and certain game animals are cooked to a minimum of 68°C (155°F) for 15 seconds or in accordance with the following temperatures and times: 63°C (145°F) for 3 minutes; 66°C (150°F) for 1 minute; 70°C (158°F) for <1 second (instantaneous) (FDA, 1999). However, they require poultry, certain wild game animals and stuffed meat and fish products to be cooked at 74°C for 15 seconds, presumably due to the presence of higher levels of contamination distributed throughout the product. In contrast, whole meat roasts (beef, lamb, pork and ham) can be cooked to lower equivalent internal temperatures, e.g. 54.4°C (130°F) for 112 minutes, 60.0°C (140°F) for 12 minutes, 65°C (149°F) for 85 seconds, 68.3°C (155°F) for 22 seconds and 70.0°C (158°F) instantaneously.

34. Consumer advice for cooking burgers in Canada matches that given in the USA where the public is advised to use a thermometer to check that the middle of the burger reaches 71°C (160°F) (Anon 2006e). This is further reiterated in advice given by the Canadian Food Inspection Agency (Anon 2006f); 71°C is the recommended cooking temperature for ground beef, ground pork, ground veal, pork chops, ribs and roasts with 74°C being recommended for stuffing, casseroles, hot dogs, leftovers, egg dishes, ground chicken and ground turkey. The recommendation for cooking chicken and turkey portions and whole birds is to achieve a temperature of 85°C.

35. The Food Safety Authority Ireland confirmed that whilst no official temperature/time recommendations exist in law, guidelines for cook-chill systems in the food catering sector recommend that cook-chill foods receive a heat process of 70°C for 2 minutes. This is based on a requirement to ensure the process will reduce contamination of *Listeria monocytogenes* by 6 log units. In addition, they publish specific advisory leaflets in relation to the prevention of *E. coli* O157 infection to factories, caterers/retailers and consumers. Factories are advised to cook foods to ensure a temperature/time combination of 70°C for 2 minutes or equivalent (Anon 2005a); caterers/retailers are advised to cook food so that the thickest part is heated to at least 75°C or equivalent, e.g. 70°C for 2 minutes (Anon 2005b), and consumers are advised to cook beef burgers, minced, diced or rolled meat well, until the juices run clear or until the thickest part of the meat has reached 75°C (Anon 2005c).

Research – literature review

36. The first major review of the literature made after the CMO's advice was by Stringer *et al* (2000), who compiled thermal inactivation data for *E. coli* O157:H7 in various food preparations from 32 refereed papers published between 1984 and 2000.

37. In most of these studies thermal inactivation was assumed to occur by first-order reaction kinetics, from which *D*-values (the time taken to reduce the population by 90% - i.e. 1 log - at a particular heating temperature) were calculated. Stringer *et al* (2000) stated that although this assumption is not really justified on a theoretical basis (i.e. the death of cells in a bacterial population is likely to be a more complex process) it can provide an adequate description of thermal death.

38. From the line of best fit for all the published data in which meat was used as the test matrix, the $D_{60°C}$ was 1.8 minutes and the temperature increase required to reduce the *D*-value by a factor of 10 (known as the *z*-value) was 5.5°C. None of the published data suggested that *E. coli* O157:H7 is unusually heat resistant compared with other non-sporing food-borne pathogens such as *Listeria monocytogenes.*

39. However, the range of reported $D_{60°C}$ values was 0.3 to 10.0 minutes and *z*-values ranged from 3.5 to 7.25°C. Only one study of all those surveyed used a temperature higher than 66°C. Moreover, heat resistance was:

- strain dependent (3-fold differences in *D*-values between strains were reported),
- dependent on growth phase (stationary phase cells are more heat resistant) and growth conditions (cells in anaerobic conditions are more heat resistant),
- dependent on storage conditions (bacteria that have been stored frozen are more heat resistant than those stored at refrigerator or cold room temperatures),
- greater following heat shock (this has implications for the speed at which cooking temperatures are reached),
- dependent on salt content, pH, fat content and other parameters of the matrix in which heating was performed.

40. Stringer *et al* (2000) concluded, on the basis of their extensive survey, that there was "no strong evidence that a heat treatment of 70°C for 2 min or the equivalent fails to deliver a 6*D* reduction in cells of *E. coli* O157:H7".

41. The *Ad Hoc* Group was also provided with an extensive literature search of subsequent papers (2000-2005). Most of these were either confirmatory of the information reviewed by Stringer *et al* (2000) or not directly relevant to the remit of the Group. The following papers, however, were significant:

- Byrne *et al* (2002) determined the heat resistance of *E. coli* O157:H7 in burgers prepared in different ways. *D*-values were significantly lower in burgers processed in line with commercial practice (i.e. tempered and stored frozen) than in burgers made with fresh ('unprocessed') meat. Moreover *D*-values in 'quality' processed burgers (100% beef) were significantly lower than in 'economy' processed products (70% beef, 30% soya, onion, etc.). The authors concluded that "commercial processing and product formulation have profound effects on the heat resistance of *E. coli* O157:H7 in beef burgers."

- Murphy *et al* (2004) described the use of a range of temperatures from 55-70°C for thermal inactivation of *E. coli* O157:H7 in ground beef. They observed "no obvious shoulders or tails..... in the log survival....versus heating time plots", and they reported a $D_{60°C}$ value of ~2 minutes, a $D_{70°C}$ value of ~3 seconds, and a *z*-value of 5.4°C, all consistent with the data compiled by Stringer *et al* (2000).

42. This is in contrast with an earlier technical report from CCFRA (1995), which did demonstrate non-linear thermal inactivation kinetics of *E. coli* O157:H7 in tests using a range of temperatures from 54-74°C in minced beef and burger preparations.

- An initial rapid decline in viability was followed by a tailing effect during which cells remained viable for long periods of time. The authors pointed out that they were unable to obtain a *D*-value using linear regression of all of the data points; instead they used a part of the curve that was linear.

- $D_{70°C}$ values were between ~4 and ~19 seconds (in line with previously published figures), but *z*-values were generally higher (7.0-10.5°C) than others reported in the literature, with, interestingly, some hint of dependence on fat content of the meat (the lowest *z*-values were observed in the preparations with the lowest fat levels).

- The authors note that "the presence of tails in the death curves.....could be a source of major concern for the food industry".

43. Blackman *et al* (2005) showed that oxidative stress can modulate (both upwards and downwards according to the level) the thermal resistance of *E. coli* O157:H7 strains. The authors note that oxidative compounds such as iron salts, ADP and ascorbic acid are naturally present in meat and meat-based products. This provides an example of the uncontrolled influence of the environment on heat killing of bacteria.

44. On the basis of the data compiled by Stringer *et al* (2000), a 6-log kill would take 10.8 minutes at 60°C, and 0.108 minutes (6.5 seconds) at 71°C, i.e. 2*z*°C higher. Similarly, the $D_{70°C}$ value reported by Murphy *et al* (2004) implies a 6-log kill in ~20 seconds, and a seemingly excessive 36-log kill at 70°C for 2 minutes.

45. However, two confounding factors mean that such data cannot be taken at face value:

- First-order reaction kinetics imply (a) that a bacterial population is homogeneous in terms of cell biology, and (b) that each cell has a single target for killing – i.e. no account is taken of sub-lethal injury, which is, in fact, well described in the literature. Moreover, the existence of shoulders and tails in inactivation profiles is clear evidence of heterogeneity. Thus, while first-order reaction kinetics may be adequate to describe the population in general terms, it should always be borne in mind that thermal inactivation of sub-populations may have significantly different kinetics.

- Thermal resistance values are significantly affected by a variety of parameters, including inherent strain variation, the physiological state of the cells, and the composition and characteristics of the environment in which the bacteria are present.

46. In light of these sources of variation, any time/temperature recommendations clearly need to incorporate an appropriate safety margin. Some of the variation can be considered by taking a modelling approach to a large data-set, as considered in the following section.

Modelling approaches

Thermal inactivation of Shiga toxin-producing *Escherichia coli* in minced meat

47. Previous advice on the safe cooking of burgers, given by the ACMSF in 1995 and 1998, has centred on the risks posed by Shiga toxin-producing *E. coli* (STEC). Therefore strains from this pathogroup of *E. coli* were chosen as the subject of a data modelling exercise performed in Unilever's Safety and Environmental Assurance Centre, to demonstrate the application of this approach to the setting of thermal process criteria. This approach could be extended to other organisms of concern, or applied using different data sets to other or more specific food products. The outcomes of the modelling exercise are not time/temperature recommendations but instead provide the information and a framework within which risk management decisions can be made.

48. The study included a statistical analysis of previously and more-recently published data, and compared the results with current safety recommendations. A review was made of the existing literature on the thermal resistance of *E. coli* O157:H7 in ground meat products. Relevant recent publications on the topic were included in the report that utilized a relevant range of cooking temperatures, various heating media, and meat samples containing different fat levels. Most of these publications report studies where STEC O157:H7 inoculated meat products were exposed to temperature values in the range 50-70°C.

Methodology

Thermal inactivation data

49. To obtain a suitable overview of the available information about the heat resistance characteristics of *E. coli* O157:H7, *D*-values (n = 234) were collected from the literature[1] in the temperature range 50°C to 70°C. The resulting data set includes the following information (when available): strain(s) used, source of isolation, heating medium, heating temperature (°C), *D*-value (min), log *D*-value, *z*-value (°C), growth conditions, additional chemicals added to heating media/sample, and recovery medium. All the thermal inactivation studies used the *E. coli* serotype of interest (i.e. O157:H7), frequently with various other strains combined in a cocktail before inoculation.

1. See references marked with *

50. To increase the transparency of the analyses, all data reported in the publications were included in the current evaluation. The only exclusion of data was done when sorbitol MacConkey (SMAC) agar only (i.e. not in combination with a procedure that allowed the recovery of injured cells) was used for recovery. The justification for this is the inability of SMAC agar to support colony formation by heat-injured *E. coli* O157:H7 cells, leading to underestimation of thermal resistance. As for the heating medium, in the majority of cases it was ground beef or another type of ground meat (e.g. turkey). In some of the reviewed publications, the microbial cells were heated in peptone water or pre-warmed tryptic soy broth (TSB). Recovery media used to count the remaining *E. coli* populations after heating were: tryptic soy agar (TSA), plate count agar (PCA), phenol red sorbitol agar (PRSA), modified Levine's eosin methylene blue agar (MEMB), and TSA overlaid with SMAC or with rainbow agar (RA).

Statistical analysis

51. *D*-values (in minutes) were log-transformed and linearly regressed against temperature, using Equation 1

$$\log D = \alpha + \beta\ (T - T_{mean}) + error \qquad \text{(Eq. 1)}$$

where:

$\log D$ is the 10-base logarithm of the *D*-value (log min)

α is the log *D*-value at T_{mean} (log min)

β is the slope of the regression line which is equivalent to the negative inverse of the *z*-value (1/°C)

T is the temperature at which each *D*-value is reported (°C)

T_{mean} is the arithmetic mean of all the temperature values reviewed from the literature (°C)

$error$ is the random experimental error (i.e. assumed to be normally distributed with a mean of zero and a variance of σ^2).

52. With $\log D$ as the response variable, and $(T - T_{mean})$ at the predictor variable, a linear regression procedure (SAS PROC REG routine) was performed to obtain the estimates of α and β and the predicted response with its 95% and 99% upper confidence limits (SAS®9, SAS Institute Inc., Cary, NC, USA). The value of T_{mean} for the data collected in this study was 58.45°C.

53. Additionally, the time necessary to achieve a 6-log reduction in the number of *E. coli* O157:H7 cells as a function of temperature was calculated by using a first-order kinetic model as described by Eq. 2:

$$time_{\text{6-log reduction}} = D_T \bullet \log \left(\frac{N_0}{N}\right) = 6 \bullet D_T \qquad \text{(Eq. 2)}$$

where:

D_T is the predicted response from Eq. 1 at temperature T (for $50°C \leq T \leq 70°C$)

N_0 is the initial population level of *E. coli* O157:H7 cells (cfu/g or cfu/ml)

N is the population level after the heat treatment at temperature T (cfu/g or cfu/ml)

Results and Discussion

Statistical analyses

54. The output of the linear regression analysis is presented in Table 3

Table 3. Analysis of variance and parameter estimates for the linear regression of *E. coli* O157:H7 thermal inactivation data set (n = 234) fitted to Eq. 1

	Analysis of Variance				
Source of variation	DF	Sum of squares	Mean square	F value	Pr > F
Model	1	126.3263	126.3263	813.25	< 0.0001
Residual Error	232	36.0380	0.1553		
Corrected Total	233	162.3643			
	Parameter Estimates				
Variable	DF	Parameter estimate	Standard error	t value	Pr > | t |
α	1	0.6079	0.0258	23.59	< 0.0001
$\beta = -1/z$	1	-0.1677	0.0059	-28.52	< 0.0001

55. Figure 2 depicts the complete data set (n = 234), as well as the predicted linear model and corresponding probability contour lines (95% and 99% upper limits). As can be observed, a sufficient number of values in the temperature range of 50°C to 70°C were obtained to support a linear modelling approach. Only two data were found at 70°C, and two at 67.5°C. The rest of the data reported were collected at temperatures below 65.6°C. No D-values were found at > 70°C. In previous work by Stringer *et al* (2000), no values were included at temperatures above 66°C (with the exception of one value reported at 68°C). The majority of the data fell within the 95% probability range, with the exception of 18 points.

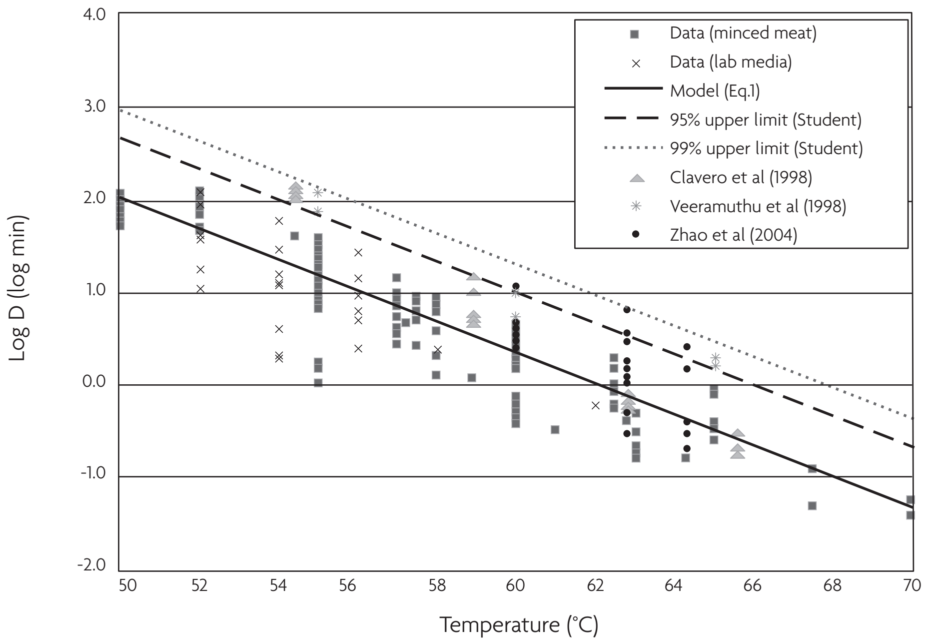


Figure 2. Thermal death curve for *E. coli* O157:H7 in minced meat or lab media. Observed data and predicted model (Eq. 1) with its 95% and 99% upper limits. Data from the three publications where points fell above the 95% upper limit are shown separately (all collected in minced meat).

56. To support a suitable risk management decision, it is important to look in detail at the few points that fall outside the appropriate confidence limits (e.g. upper 95% probability range). If the 95% upper limit is used, all data requiring such scrutiny come from three publications: Clavero *et al* (1998), Veeramuthu *et al* (1998), and Zhao *et al* (2004). There could be several reasons for the variability between heat resistance properties such as strain-to-strain variability, heating methodology, history of the cells and recovery conditions. The model used in this report to fit the 234 data (Eq. 1) does not include specifically the natural variability due to strains; this variability is incorporated into uncertainty due to experimental conditions and into model imprecision. A careful revision of these three publications does not indicate that the experimental factors used to generate the data were selected in order to obtain atypical and artificially high heat-resistance results. Thus, there is no reason to exclude these data from the current study.

Practical application

57. The resulting predicted z-value from the model was calculated as follows:

$$z = -\frac{1}{\beta} = -\frac{1}{-0.1677} = 5.96\ ^\circ C = 6.0\ ^\circ C$$

58. Reported z-values (n = 86) in the literature (same references used for collection of D-values fitted to Eq. 1) range from 3.60°C (Smith *et al,* 2001) to 9.25°C (Juneja *et al,* 1997). The mean value of literature data collected in the current study is 5.30°C and the median 4.74°C (Fig. 3). Stringer *et al* (2000) had reported a z-value of 5.5°C from the regression analysis of the data evaluated in their study, and a mean z-value of 4.8°C from the published data. Hence, the predicted z-value (6.0°C) in the current study is in good agreement with published data and with the model predictions from Stringer *et al* (2000).

59. In one particular publication (Juneja *et al,* 1997), a z-value of 9.25°C was found and it was attributed to the behaviour of a subpopulation shown to have a more significant thermal resistance compared to the majority of cells heated (i.e. tailing behaviour). There is evidence from some of the other studies used that, even though D-values are reported, data showed non-log-linear kinetics (e.g. Zhao *et al,* 2004).

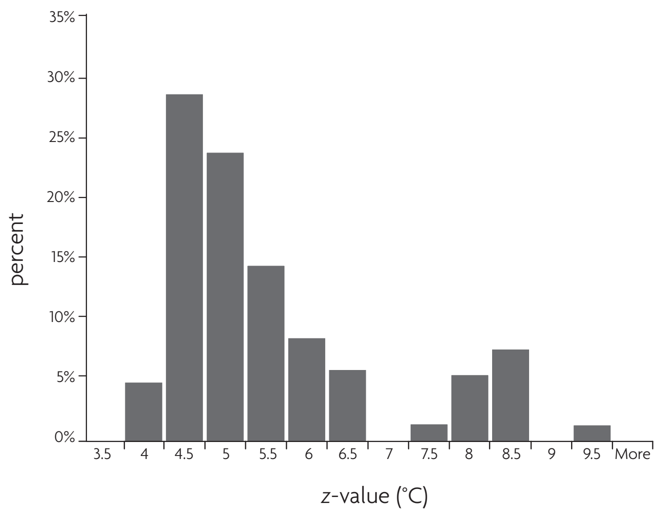


Figure 3. Histogram of individual z-values (n = 86) reported in the literature for *E. coli* O157:H7 in minced meat or lab media.

60. Figure 4 shows the predicted required time for a 6-log reduction of *E. coli* O157:H7 cells with its corresponding upper confidence limits (95% and 99%). According to the model predictions 1.3 and 2.4 minutes at 70°C would be required to achieve a 6-log reduction using the 95% and 99% upper confidence limits, respectively. Also shown are the ACMSF recommended time/temperature equivalents, from which it can be calculated that a z-value of approximately 7.4°C was assumed in these recommendations.

61. Very few experimental data reported in the literature are currently available on the thermal inactivation of *E. coli* O157:H7 at or above 70°C. This may be due to the difficulty in obtaining survival curves at such temperatures. Consequently, there are not sufficient data to support the definition of an upper limit of application of the model. On the other hand, the lowest temperature at which thermal inactivation data could be collected from the literature was 50°C. This temperature should be used as the lower limit of application of the model.

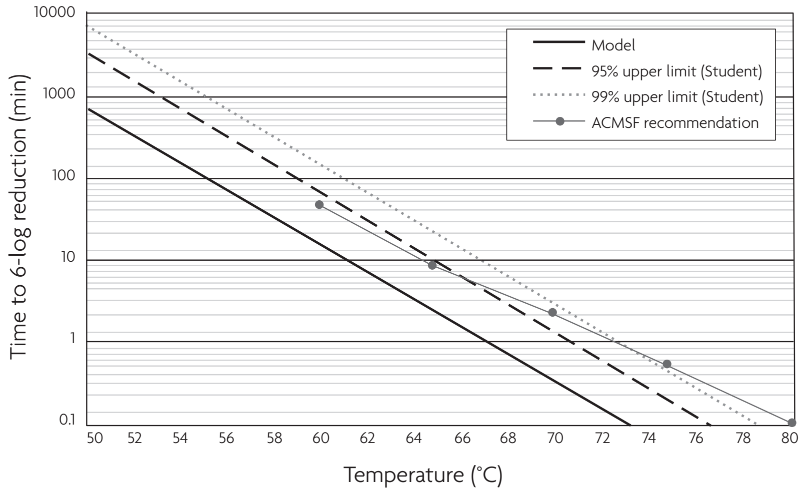


Figure 4. Time to obtain a 6-log reduction of *E. coli* O157:H7 in minced meat or lab media. Predicted values with 95% and 99% upper limits based on the fitting the thermal inactivation data set (n = 234) to Eq. 1. Current ACMSF recommendations for safe cooking of beefburgers also depicted.

62. Figure 5 benchmarks the data collected in this study (n = 234) and the predicted values (with 95% and 99% upper limits) from the model described by Equation 1 against a thermal death model derived from the ACMSF recommendations, using a z-value of 7.4°C and considering 70°C as the reference temperature to establish equivalencies at other temperatures.

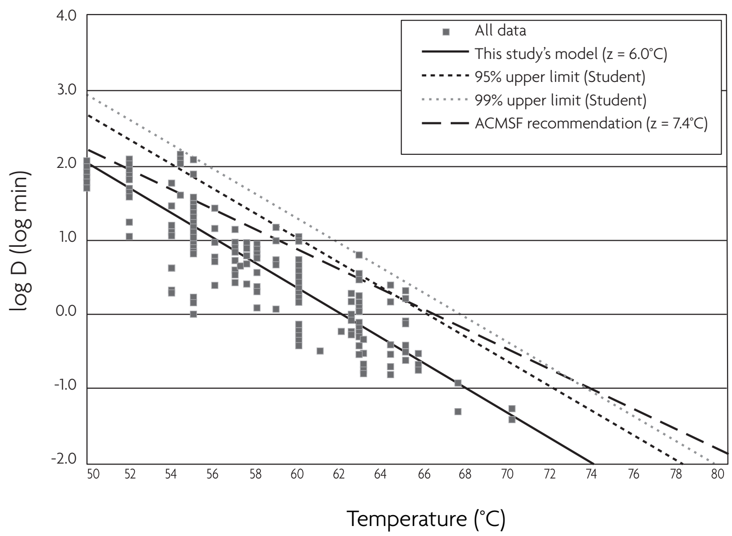


Figure 5. Comparison between the thermal death curve for *E. coli* O157:H7 obtained in this study and the thermal death curve derived from the current ACMSF recommendations for safe cooking of beef burgers.

63. Table 4 shows a comparison between the predicted time/temperature equivalent treatments to obtain a 6-log reduction of *E. coli* O157:H7 cells from this study and the current ACMSF recommendations. The required times at 70°C have been shaded to facilitate visualisation.

Table 4. Equivalent heat treatments for a 6-log reduction of *E. coli* O157:H7 - Comparison between current ACMSF recommendations and predictions obtained in this study based on the fitting of thermal inactivation data published in the literature (*n* = 234) to Eq. 1.

Temperature (°C)	Time			
	ACMSF recommendations	Predictions from this study		
		Expected value	95% upper limit	99% upper limit
60	45 minutes	13.4 minutes	60 minutes	112.5 minutes
65	10 minutes	1.9 minutes	8.8 minutes	16.5 minutes
70	2 minutes	0.3 minutes	1.3 minutes	2.4 minutes
75	30 seconds	2.4 seconds	11.5 seconds	22 seconds
80	6 seconds	0.4 seconds	1.7 seconds	3.3 seconds

Equivalent temperatures based on a z-value of 6°C

Temperature (°C)	Time
60	93 minutes
65	13.6 minutes
70	2 minutes
75	18 seconds
80	3 seconds

64. The effect of the lower *z*-value obtained in this study (and supported by the study of Stringer *et al,* 2000) can clearly be observed in Figures 4 and 5, as well as in Table 4, in comparison to the current ACMSF recommendations. For instance, considering the 95% upper limit of the model, the use of a lower *z*-value would result in longer required times for a 6-log reduction of STEC O157:H7 cells below 65°C compared with the ACMSF recommendations. Conversely, above 65°C, the use of a lower *z*-value would result in shorter required times for the same level of inactivation.

65. A final discussion point is the effect of fat content on the heat resistance of *E. coli* O157:H7 cells. Ahmed *et al* (1995), Smith *et al* (2001) and Line *et al* (1991) reported higher *D*-values when the percentage of fat in the meat used as the heating medium was higher. This effect seemed to be more noticeable at temperatures ‹ 58°C; that is, as the heating temperature increased, the *D*-values were similar in ground beef with different fat-contents (Table 5). Whether this is due to a true fat protection effect or to any other experimental or methodology factors is not fully understood and may warrant further investigation.

Table 5. Effect of fat content on *D*-values of STEC O157:H7 cells heated in ground beef at selected temperatures.

Heating temperature (°C)	Fat content (%)	*D*-value (min)	Reference
50	7	55.3	Ahmed *et al*, 1995
	10	80.7	Ahmed *et al,* 1995
	20	92.7	Ahmed *et al,* 1995
52	2	78.2	Line *et al,* 1991
	30.5	115.5	Line *et al,* 1991
55	7	11.4	Ahmed *et al,* 1995
	10	15.3	Ahmed *et al,* 1995
	10	20.1	Smith *et al,* 2001
	19.1	22.5	Smith *et al,* 2001
	20	19.3	Ahmed *et al,* 1995
57	2	4.1	Line *et al,* 1991
	30.5	5.3	Line *et al,* 1991
58	10	1.2	Smith *et al,* 2001
	19.1	2.1	Smith *et al,* 2001
60	7	0.45	Ahmed *et al,* 1995
	10	0.46	Ahmed *et al,* 1995
	20	0.47	Ahmed *et al,* 1995
61	10	0.32	Smith *et al,* 2001
	19.1	0.32	Smith *et al,* 2001
63	2	0.30	Line *et al,* 1991
	10	0.16	Smith *et al,* 2001
	19.1	0.18	Smith *et al,* 2001
	30.5	0.47	Line *et al,*1991

Conclusions

66. The assessments made and the conclusions reached by the Group reflect evidence, oral and written, drawn from the scientific community, industry, government departments, and the scientific literature. The *Ad Hoc* Group has considered documentary and verbal evidence relating to the epidemiology of *E. coli* O157 and other key pathogens, and guidance and cooking conditions for burgers used in the USA, UK and other countries. The Group has also reviewed published scientific evidence and information submitted by a fast food chain.

67. Historical and recent evidence on the heat resistance of *Listeria monocytogenes* heated in various food substrates was provided by scientific experts from Campden and Chorleywood Food Research Association involved in work on *L. monocytogenes* which contributed to the development of the original CMO advice. This information confirmed that a heat process of 70°C for 2 minutes would be sufficient to give at least 6 log reductions of *L. monocytogenes.*

68. The Group also sought information from the British Meat Processors Association who considered that there should not be any reduction in the current cooking advice for burgers in the UK. The Group recognised that, whilst it was theoretically possible to eliminate food pathogens such as *E. coli* O157 and *Salmonella* at a lower cooking temperature, any reduction would put consumer safety at risk due to the need for more sophisticated domestic cooking control. It was also noted that the cooking process was carefully controlled in certain foodservice establishments, and as such, time and temperature guidelines could be reconsidered. However, any changes would need to be supported by microbiological and food safety criteria and a full risk assessment.

69. Epidemiological evidence for the UK reviewed in paragraphs 15 to 20 indicates that there have been very few reported outbreaks of *E. coli* O157 associated with the consumption of under-cooked ground beef in the UK since the CMO's guidance was issued in 1998. There are no recent outbreaks in which burgers eaten outside the home have been implicated. This suggests that the recommended time/temperature combination of 70°C for 2 minutes is effective in terms of minimising the risks posed by this pathogen. In North and South America eating undercooked ground beef is reported to continue to pose a risk to the population.

70. From the evidence outlined in paragraphs 21-28, on prevalence and concentration of *E. coli* O157 in meat, and in paragraphs 36 to 46, on the thermal resistance of the organism, the *Ad Hoc* Group recognises that a recommendation of 70°C for 2 minutes seems excessive. However, having consideration to sources of variation and of confounding factors, any recommendation should incorporate an appropriate safety margin.

71. The use of a large data set allows for better consideration of the strain-to-strain variability found in the heat resistance of an organism, and increases the robustness of predictions from a thermal death model. The model presented in paragraphs 47 to 65 for *E. coli* O157:H7 in minced meat can provide the basis for a risk management decision to be made transparently. While a 6-log reduction was used here for demonstration purposes, the model can be adapted to predict any required level of inactivation, e.g. if contamination data point to a lower level of contamination.

72. The current advice of cooking burgers at 70°C for 2 min falls in between the 95% and 99% confidence limits for a 6-log reduction of *E. coli* O157:H7 cells in minced meat, using the data set modelled in this report. However, using the ACMSF equivalent time/temperature parameters, published in 1995, the confidence will increase for temperatures above 70°C and decrease for those below. Based upon this study, it is recommended that time/temperature equivalents when cooking beef burgers be set using a *z*-value of 6.0 °C where *E. coli* O157:H7 is the organism of concern, particularly if the intended cooking temperature is below 65°C.

73. From the information presented in this report it is evident that a time/temperature combination for cooking of burgers of 70°C for 2 minutes (or equivalent) delivers a significant pathogen reduction which is sufficient to minimise the risks posed by foodborne pathogens such as *E. coli* O157, *Salmonella* and *Listeria monocytogenes.* However, the report further identifies that a safe product can be delivered using lower time/temperature combinations. When setting thermal process criteria, consideration needs to be given to the organisms likely to occur in the raw materials, the prevalence, concentration, and thermal resistance of those organisms, the level of confidence required that a safe level is reached in the final product and one's knowledge and control of the process.

74. The Group concluded that the advice for cooking of burgers should remain at 70°C for 2 minutes as it presents a high level of confidence of delivering a widely accepted inactivation standard (6-log), and ensures a wide safety margin in the face of considerable real-world variation. Moreover, the Group recognised that, while an argument could be made for a lower time/temperature combination (e.g. 70°C for 1.3 minutes, if a 95% confidence of achieving a 6-log reduction of *E. coli* O157 was deemed acceptable), the implications of any changes to time/temperature requirements for cooking of burgers would need to be considered more widely, as the 70°C for 2 minutes time/temperature recommendation is currently applied to a wide range of foods for a wide range of pathogens. Consideration would also need to be given to the need for appropriate compliance factors.

75. Whilst concluding that the advice should remain at 70°C for 2 minutes, the Group agreed that lower time/temperature combinations could be used where producers can demonstrate the safety of their products using risk assessment approaches with associated effective process control.

Recommendations

76. That the advice of the CMO for the safe cooking of burgers should not change and, in line with current advice, should remain at 70°C for 2 minutes or equivalent.

77. That a *z*-value of 6.0°C should be used for time/temperature equivalents for burgers, e.g. 65°C for 13.6 minutes or 75°C for 18 seconds.

78. That, also in line with current advice, use of other time/temperature combinations should not be ruled out where producers are in a position to consistently demonstrate that they can ensure that the final product is safe, and that the process is under effective control. It is therefore recommended that the FSA produces guidance on appropriate use of such time/temperature controls for industry and enforcement officers.

79. That the FSA consider using a modelling approach to set recommended time/temperatures for specific hazard(s) of concern, based upon the level of inactivation required and appropriate confidence limits. This approach could also be set within a risk assessment for *E. coli* O157 in burgers to establish the burden of disease to consumers and evaluate the impact of various risk management options, including changes to time/temperature criteria.

80. That manufacturers are encouraged to provide clear instructions to ensure that products are cooked safely, and that the following advice on safe cooking of burgers should be reiterated to consumers and caterers: to follow manufacturers' instructions and to observe that burgers are piping hot throughout, thoroughly cooked until the juices run clear and there are no pink bits inside. Consumers should also be reminded that a change in colour, in isolation, is an unreliable indicator of safe cooking and it does not necessarily mean that burgers are cooked properly. Advice to consumers and caterers encouraging the use of temperature probes to check whether burgers are fully cooked should be given.

Annex I: *Ad Hoc* Group on Safe Cooking of Burgers

Terms of Reference

To review the current advice issued by the Chief Medical Officer in 1998 on the safe cooking of burgers and to report back with recommendations to the ACMSF.

Membership
Chairman
Professor P Williams

Members
Mr J Bassett
Ms S Davies
Professor A Johnston
Mr A Kyriakides
Professor S O'Brien

Secretariat

Dr L Foster	Administrative Secretary
Dr P Cook	Scientific Secretary
Miss S Butler	
Mrs L Stretton	

Annex II: List of people/organisations who assisted the *Ad Hoc* Group

Alejandro Amezquita, Unilever plc

Dr C Baylis, Campden and Chorleywood Food Research Association

British Meat Processors Association

Dr J Gaze, Campden and Chorleywood Food Research Association

Dr P McClure, Unilever plc

McDonalds Restaurants

Dr N Simmons, Independent consultant

Adriana Velásquez, Michigan State University

Kaarin Goodburn, Chilled Food Association

Annex III: Text of Department of Health Press Release 98/316 Published 31 July 1998

Revised Guidance On Safe Cooking Of Burgers

Revised guidance on the safe cooking of burgers was announced today by Sir Kenneth Calman, Chief Medical Officer.

In addition to revising existing advice to consumers, the guidance has been expanded to include guidelines to the food industry on labelling by wholesale suppliers to caterers, manufacturers and retailers. It also emphasises the need for training in catering establishments.

The changes are based on the recommendations of the Government's independent expert Advisory Committee on the Microbiological Safety of Food (ACMSF).

Sir Kenneth's advice on the safe cooking of burgers includes:

> *Consumers cooking burgers and similar minced meat products* should follow the manufacturer's instructions. It is particularly important to ensure that burgers and similar minced meat products are thoroughly cooked so that they are piping hot throughout. Eating undercooked burgers which are rare in the middle may be dangerous;
>
> *Barbecues*- the cooking process is variable and difficult to control which means it is absolutely vital to ensure that burgers are thoroughly cooked so that they are piping hot throughout;
>
> *Manufacturers and retailers*- minced meat and minced meat products including burgers should be cooked to a minimum temperature of 70 degrees centigrade for two minutes or equivalent. Vendors of raw burgers should ensure that all burgers and similar minced meat products are supplied with adequate cooking instructions to comply with this recommendation. Cooking instructions should take into account factors such as whether the burger is frozen or chilled, the thickness and formulation of the burger, and the prescribed method of cooking.
>
> The absence of pink meat in a burger after cooking is not, in itself, a guarantee that the burger has been adequately cooked, but despite its limitations it may provide an additional safety check for consumers.
>
> It is therefore recommended that the advice to cook burgers until the juices run clear and there are no pink bits inside may be used where appropriate (eg when a burger contains only beef and no added salt) but it should always be accompanied by the other cooking instructions which achieve a minimum temperature of 70 degrees centigrade for two minutes or equivalent.

Wholesale supplies to caterers- cartons of burgers (and other similar minced meat products) supplied by wholesalers for caterers should be labelled with a clear instruction that the product must always be cooked thoroughly so that it is piping hot right through to the centre. Minced meat and minced meat products including burgers should be cooked to a minimum temperature of 70 degrees centigrade for two minutes or equivalent;

Caterers- vendors of cooked burgers and other similar minced meat products, for example caterers, have a specific legal obligation to identify and control any process steps that are critical to food safety (Food Safety (General Food Hygiene) Regulations 1005, regulation 4(3)). The thorough cooking of minced meat products, including burgers to a temperature of 70 degrees centigrade for two minutes or equivalent, will be one such critical control. Caterers must ensure that their procedures achieve this and they should take into account the type of cooking equipment, its operating temperature, the temperature of the meat at the start of cooking, its thickness and any other relevant factors.

Caterers should consider the potential for undercooked burgers to cause disease and should not provide them to customers or, if specifically requested to do so, should remind the customer of the potential hazard.

Training- verocytotoxin producing *Escherichia coli* (VTEC) infections could be significantly reduced if there was a better understanding of the need to avoid cross-contamination and to cook food properly. It is recommended that commercial food handlers focus training on methods for the safe and hygienic handling of food. Catering establishments should ensure that the staff know precisely what to do (eg the routine for safe cooking) and why it must be followed.

Notes to Editors

1. Previous advice to consumers was issued on 14 February 1991 by the then Chief Medical Officer, Sir Donald Acheson, who said that "(burgers) should be thoroughly cooked throughout...until the juices run clear and there are no pink bits inside."

2. The role of the Advisory Committee on the Microbiological Safety of Food is to provide independent expert advice to the Government. The chairman, Professor Douglas L Georgala, CBE, FIFST, was Director of the Institute of Food Research until his retirement, and is an independent scientific consultant.

List of Tables and Figures

Tables

Figures

Glossary

Confidence limits	Either of the two numbers that specify the endpoints of a confidence interval (a statistical range with a specified probability that a given parameter lies within the range).
First order in reaction kinetics	Usually used to describe the reaction rate of a chemical which the rate is proportional to the concentration (in moles) of only one of the reactants. When applied to a dynamic biological reaction such as the inactivation of bacteria by heat, the implication is that the rate of inactivation is proportional to the amount of heat applied.
Haemolytic uraemic syndrome	A clinical condition which may arise from a variety of causes including STEC infection, and is characterised by anaemia and kidney failure.
Log reduction	Logarithm (to the base 10) reduction in the levels of a microorganism.
Sub-lethal injury	A level of cellular or molecular damage caused by heating that can be tolerated or repaired by the bacterial cell.
Thermal resistance	The ability of bacteria to withstand the effects of heating.
Shiga-like toxin Escherichia coli	A particular sub-type of *E.coli* often of producing the serogroup O157 that is capable of (STEC) producing a toxin which is associated with haemorrhagic colitis and haemolytic uraemic syndrome. Also referred to in the literature as verocytotoxin producing *Escherichia coli* (VTEC or enterohaemorrhagic *Escherichia coli* (EHEC).
D-value	Decimal reduction time (in minutes). The time required, at a given temperature, to reduce the number of viable cells or spores of a given microorganism to 10% of the initial number.
z-value	The increase in temperature (°C) required for a 10-fold decrease in the D-value.

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