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Review of new and emerging technologies for red meat safety

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Summary

The complexity of the pre-harvest, harvest, and post-harvest environment of the food supply chain makes it impossible to control all potential sources of microbial contamination, as opportunities for contamination arise at many points. Thus, multiple control measures must be implemented throughout the food production and processing system to ensure the wholesomeness of the final product.

This report reviews a number of interventions that may be applied during red meat production to reduce microbial numbers on the product, including those that are currently available and those that are being developed. All parts of the red meat production chain are considered, and information on demonstrated efficacy and regulatory acceptance in Australia, the EU, the US and other countries is included, where available. Some suppliers of equipment and consumables have been identified, and attempts made to indicate approximate costs, although these are very dependant on factors such as plant throughput, available labour and existing facilities. Advice is also given on the issues to be considered prior to implementing a new intervention in a process.

This information will be available to producers and processors on the Meat Industry Services website (www.meatupdate.csiro.au), in the form of downloadable factsheets summarising the findings relating to each intervention.

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Objective

The objective of this review is to highlight those food safety technologies that are known to make or have the potential to make a significant impact on the safety of meat products and to provide concise information both on those technologies that are readily available to the Australian meat industry and those that are emerging from Australian and overseas research. Technology may be understood, for the purpose of this review, not only to encompass equipment solutions, but also the use of antimicrobial agents at various points in the supply chain, including pre-harvest. The objective of the technology must be to make a significant impact on the safety of meat products. Microbiological testing technologies are excluded from the scope of this project because these are monitoring techniques, not proactive preventative measures. Monitoring procedures such as microbiological testing technologies are excluded from the scope of this review because they are not interventions that will reduce the microbial load on the product; they merely identify the degree of load present. They are, however, mentioned as they may be useful in conjunction with a particular intervention technology.

The information contained in this review is of a general nature, and when considering a new intervention, it is important to consult AQIS or the relevant State authority before implementation.

Introduction

Despite the extensive scientific progress and technological developments achieved in recent years, microbial foodborne illness remains a global concern. Specific sources that contribute microbial contamination to animal carcasses and to fresh meat during slaughter and dressing include the faeces, the hide, oil, water, air, intestinal contents, lymph nodes, processing equipment, and humans. The types of microorganisms and extent of contamination present on the final product are influenced by sanitation procedures, hygienic practices, application of food safety interventions, type and extent of product handling and processing, and the conditions of storage and distribution (Sofos 2005).

Cattle are a major reservoir for *E. coli* O157:H7, which is carried in the intestinal tract of healthy animals and excreted in faeces (Chapman *et al.* 1993). Other organisms of concern to meat processors throughout the red meat supply chain (particularly during packaging and retail) include spoilage microorganisms and pathogens such as *Salmonella enterica*, *Listeria monocytogenes* and *Clostridium perfringens*. All these may be found in the faeces and on the hides of cattle presented for slaughter (Reid *et al.* 2002; Nightingale *et al.* 2004; Fegan *et al.* 2005a; 2005b) and can be transferred to the carcass during harvest, particularly through hide removal and evisceration (Bell 1997).

Australian meat processors have generally relied upon strict hygienic practices during processing to ensure that fresh meat is safe and wholesome. With new information on the public health implications of low levels of contamination with pathogenic microorganisms, however, and with regulatory bodies applying increasingly stringent performance criteria, it is becoming increasingly difficult to design systems that can be shown to consistently result in product that meets these requirements – particularly requirements of 'zero tolerance'. Some food safety intervention strategies are already in place in Australian abattoirs. For example, knife-trimming is common practice in Australian abattoirs and is required by AQIS for the removal of visible contamination of the carcass, such as ingesta, milk, hair/wool and faeces. Steam vacuuming is also commonly used in sheep processing plants to specifically target wool fibres and wool dust. Hot water decontamination is used in some beef abattoirs. These food safety technologies may be used in conjunction with new technologies that you may be considering as part of a whole of supply chain, food safety strategy.

Many countries such as the USA have implemented intervention-based HACCP, where a specific procedure is applied to the product during processing in order to reduce the microbial load present. An intervention is a procedure or process (mechanical or human) that significantly reduces the number of pathogens and other microorganisms present on a meat surface, be it a carcass or carcass piece. Using interventions can consequently lead to improvements in shelf life of the fresh or further processed product. Such interventions include knife trimming, hot water washes, organic acid washes, and steam vacuuming. These technologies and new food safety technologies are continually being developed to help processors to meet the increasingly stringent microbiological criteria that are being applied through the red meat supply chain. Regulatory bodies in a number of countries are accepting the use of intervention technologies as part of the fresh meat processing chain. For example, the US Food Safety and Inspection Service (FSIS) document '*E. coli* O157:H7 contamination of beef products' (USDA/FSIS 2002) and accompanying guidance documents were published in the Federal Register in October 2002. *Inter alia*, they stated that beef slaughter establishments should consider interventions that can be validated and verified as CCPs for reducing or eliminating *E. coli* O157:H7.

Food safety technologies such as hot water/steam pasteurisation have been implemented in Australian abattoirs, mainly because this technology is acceptable to the EU market as it only uses potable water on the carcass during the washing process, but Australian processors are also considering and trialling interventions such as acidified sodium chlorite, rinse-and-chill and ozone. At present, if these establishments are also processing product destined for the EU, the EU product is not treated with the non-approved intervention. EU Regulation 853/2004, provides a legal basis to permit the use of a substance other than potable water to remove surface contamination from products of animal origin. Previously, such a legal basis did not exist in the EU legislation for red meat and for poultry meat. The regulation provides guidance to Decision 1999/468/EC (Article 5) that a committee shall deliver an opinion on any proposal requiring amendment to the regulatory procedure. For example, the European Food Safety Authority recently posted the opinion of the AFC Panel (Panel on Food Additives,

Flavourings, Processing Aids and Materials in Contact with Food) related to treatment of poultry carcasses with chlorine dioxide, acidified sodium chlorite, trisodium phosphate and peroxyacids. AFC is a panel providing comment on food additives, flavourings, processing aids and materials in contact with food. The Panel concluded that processing of poultry carcasses (washing, cooking) would take place before consumption, and therefore treatment with trisodium phosphate, acidified sodium chlorite, chlorine dioxide, or peroxyacid solutions, under the described conditions of use, would be of no safety concern.

There will always be continued improvements during the slaughter process, but an alternative long-term strategy may be to minimise the presence of human pathogens on the incoming live animals. However, this approach requires changes to farm management practices and supported by scientific research. At present, many of these potential food safety technologies are still at the 'research' stage. In terms of microbial reductions, the results of scientific research, both under laboratory scale and commercial scale systems, is highly variable regardless of the food safety technology evaluated. A decision on which technology to implement will rely entirely on the required outcome, the constraints of the market, whether export or domestic, and on space availability and infrastructure in the existing premises.

The reason for implementing an intervention is to reduce the likelihood of pathogenic micro-organisms being present on the carcasses and meat. *Salmonella* and *E. coli* O157:H7 are the main target organisms in contemporary fresh meat production. No single intervention technology can provide 100% assurance of the safety of a food product, and systems that provide reductions of 1-2 log units would be considered to provide appropriate improvements in the microbiological status of the product. One cannot emphasise sufficiently the need for good hygienic practices throughout the meat supply chain, supported by proper temperature control. No intervention can be expected to correct a highly contaminated product. Interventions such as those described in this review should form part of a multiple-hurdle approach to the production of safe, wholesome meat. Operators should not view any of these technologies as a way of rendering product with an initially high microbial loading "clean" and therefore pay less attention to the strict hygiene procedures necessary.

Food Safety Technologies

The food safety technologies described below can be applied at one or more points in the supply chain: pre-slaughter, slaughter, chilling, packaging and retail.

Most of the technologies have been focused at the slaughterhouse phase because studies have shown that most contamination of faecal origin occurs during hide/skin removal and evisceration processes (Newton *et al.* 1978; Bell 1997; Sofos *et al.* 1999), and is best removed immediately, before bacteria attach firmly to the meat surface. The extent to which carcasses are contaminated with bacteria varies between plants, and is influenced by many factors including plant design, speed of slaughter, degree of adherence to good handling practices, and the skill of the operators (Biss and Hathaway 1996a; Hudson *et al.* 1998; Vivas-Alegre and Buncic 2004). Other factors that also contribute include the type and age of animal slaughtered, the feed provided, the season and the lairage conditions prior to slaughter (Davies *et al.* 2000), so there are good justifications for applying intervention technologies on the farm and prior to slaughter as well as during slaughter and dressing.

In applying a microbial reduction step to a carcass, the efficacy of the method used is influenced by factors such as water pressure, temperature, chemicals present and their concentration, time of exposure, method of application and equipment design, and the stage in the process at which the method is applied (eg. before hide removal, after hide removal, after evisceration, after chilling etc) (Bacon *et al.* 2000; Koohmaraie *et al.* 2005).

When choosing an intervention step, there are issues other than microbial efficacy to be considered. They include the influence of the process on product and worker safety, product quality, the environmental contribution in terms of waste and effluent disposal, and cost or value for money. Acceptable intervention systems should not have adverse toxicological or other health effects on workers during their application, or on consumers as a result of their use.

Even if intervention technologies are applied at pre-slaughter or slaughter, the product may still incur microbiological contamination through subsequent handling and packaging operations (Gill *et al.* 2001; Aslam *et al.* 2004). Therefore, further intervention or preservation treatments may be of benefit during chilling or packaging of primals or for retail sale.

The technologies described in this review have been categorised as physical interventions or chemical interventions, and includes those that are currently available and novel technologies. Each intervention treatment is considered in terms of its microbial efficacy, food safety issues, advantages and limitations of the technology, the current regulatory status, market access and potential customer issues.

Novel technologies

Traditional food processing has relied on thermal treatment to kill/inactivate microbiological contaminants. Unfortunately, thermal processing can induce physical and chemical changes in the food. Novel technologies are those technologies that use little heat to preserve the product while minimizing the quality and nutrient losses. Examples include high hydrostatic pressure processing (HPP), pulsed electric field (PEF), high-intensity light, electrolysed water treatment, ultrasonics and irradiation. Chemical treatments such as organic acid spray may not involve heat, but are not considered to be “novel technologies”, as they are widely accepted in some countries.

For many of these technologies much research is still required before commercialisation because: (*i*) the mechanisms(s) of microbial inactivation requires clarification so that the critical processing parameters can be reliably monitored; (*ii*) existing regulatory issues must be adequately addressed to accommodate commercial application processes; and (*iii*) current costs of some of these technologies may be prohibitive to some customers. Most are directed at small volumes of product, such as primal cuts, retail cuts or processed meats.

According to USDA/FSIS (2003) “new technology” is defined as new, or new applications of, equipment, substances, methods, processes or procedures affecting the slaughter of livestock and poultry or processing of meat, poultry, or egg products which could affect product safety, inspection procedures, inspection program personnel safety, or require a waiver of a regulation.

Currently, there are no specific regulations for the novel technologies discussed below. In general, the approach is that standard health regulations apply, and that the process should demonstrate equivalence with traditional processes (eg. pasteurisation). As a rule, good manufacturing practice and a demonstration that the process (i.e. validation and verification) is under control will be required. The EU stance is that if it is possible to show that the new treatment is substantially equivalent to a treatment already in use commercially, then the treatment can be authorised at a national regulation level and the product will not need to comply with the EU “novel food“ regulation (CE 258/97). There is also substantial opposition to any decontamination treatment, partially due to fears of residues in the food, but mainly due to the fear that use of decontamination will encourage poor hygienic practice during production. In the USA, the standard health regulations are applied.

To date, high hydrostatic pressure processing appears to be the most promising novel technology (outside of food irradiation) because of its well-established knowledge base and currently available products in the global market-place (Guan 2005).

Application of Interventions

Meat carcasses are difficult to decontaminate by reason of their shape and structure. Most treatments require physical contact with the carcass surface, and an even coverage of the surface. Carcasses are a very irregular shape, so there is the possibility that one part of the carcass will be over-exposed to the treatment, while another part may be unaffected by the treatment. Crevices and folds in the surface are areas where contamination will collect, and also these areas are often poorly draining, and pools of the treatment solution may collect, adversely affecting the visual appearance of that part of the carcass. Treatments which require direct beam of energy, such as ultraviolet light may not access areas where the beam is blocked by a protruding part of the carcass, leaving an area of meat surface effectively in the shadow. Application methods for food safety treatments must be well designed to overcome such issues.

Spray Application

Spray washing is the most common method of application of a food safety solution. However, the angle of application of the spray and the pressure at which the solution is delivered have a significant effect on the outcome of the treatment, and automated spray cabinets differ substantially in number and positioning of the nozzles. Thus, spray cabinets are not all the same, but neither are the carcasses that pass through them. It is important to choose a cabinet designed to suit the stock handled through the plant.

Manual spray washing systems are impractical under commercial conditions because of speed, and the cost of hot water is excessive (Sheridan 1982), and its efficacy will be directly related to the skill and motivation of its operator. Consequently, research abattoir results tend to be better than those conducted at commercial premises (Bailey and Roberts 1976).

Optimising spray performance involves proper spray nozzle selection (flow rate, spray pattern, particle size and speed), preventative maintenance, spray analysis (nozzle positioning and spacing), and automated spray control. Automated carcass washing systems have been available for a number of years, with water flow rates of 220-270 litres per minute (Powell and Cain 1987; Graham 1978), while in the 1980's a combined washer and sanitiser unit, called the Carcass Acquired Pathogen Elimination/Reduction (CAPER) System was developed, delivering water at up to 378 litres per minute in the wash section, and a sanitising solution at up to 189 litres per minute in the sanitiser unit (Anderson *et al.* 1987).

APV Australia (Invensys Companies)

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Website: http://www.fpe.net.au/home.html

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E-mail: rosey@chadcompany.com

Website: www.chadcompany.com

Deluge

Deluge systems, where the carcass passes through a waterfall of the treatment solution, may be more effective than spray systems, but it is important to realise that the lower surfaces of the carcass, such as the clod and stick area may be shielded from the treatment by the carcass above. A deluge system may be more cost-effective than a spray system (Davey and Smith 1989) using 40 litres of water per carcass and it is possible to recirculate the water. Many modern wash cabinets use multiple spray nozzles to deliver a similar effect to a deluge system with the advantage that sprays can be directed towards the lower 'protected' parts of the carcass. Deluge systems can be produced to order by Food Processing Equipment (FPE) as above.

Immersion

Immersion treatments are suitable for smaller items such as cuts of meat or poultry carcasses. It is often used to decontaminate the outer surface of meat packages prior to opening for further processing.

Spot Treatment

Spot treatment of carcasses is commonly associated with traditional trimming of visible contamination or with steam vacuuming. Not all contamination is visible, however, and many pathogens and spoilage microorganisms may remain on a visually clean carcass. Thus there is a move to use methods other than human sight to detect the spots to which the treatment is to be applied. Some of these detection methods are outlined below.

Visual

Traditionally, carcasses are inspected, and offending areas of contamination trimmed by hand. This is effective for areas of visual contamination, and some bile staining, but can be hampered by poor lighting at the inspection point or a fast-moving chain where there is little time allowed for the QC inspection and trim (It also helps if the operative is not colour blind!).

Chlorophyll detection

The natural constituents of green plants, Chlorophyll *a*, Chlorophyll *b*, and Protoporphyrin IX, absorb electromagnetic radiation of wavelength 400-475nm, and this energy causes them to emit electromagnetic radiation, or *fluoresce*, at a wavelength of 630-700nm. Meats, similarly, absorb and emit electromagnetic radiation, but in different wavelength bands – excitation occurs optimally at 360nm, and emission at 420-520nm. When 420nm radiation is applied to meat, meat fluorescence is suppressed but the plant constituents will fluoresce (Kim *et al.* 2003).

The technology allows the detection of contamination that is not visible to the naked eye, and is truly objective – if there is no plant matter, there will be no fluorescence in the detectable band. It can be used on carcass meat and on other surfaces, and gives an immediate result, so corrective action can be taken in real-time. Because it is detecting green plant matter, it does depend on the animals being fed a chlorophyll-based diet, and there has been little success in its use on animals such as pigs and poultry. Where ruminants are purely grain-fed, and the diet contains little chlorophyll, the technology is less reliable than where the animals are grass-fed. False-positives may occur where light is reflected from the surface at the critical wavelength for detection, and this can happen on excessively wet carcasses, the moisture reflecting the light, and bone and some connective tissues may also reflect the light. Some vegetable-based marking inks have also been noted to fluoresce, as they too contain the green plant constituents. The technology is available as a carcass cabinet, or as a hand-held unit, the latter of which is easy to use with only a little practice, but it is affected by ambient light levels – if the surroundings are too brightly lit, the fluorescence will not be detected so easily.

Preliminary work in the UK has shown that although there is no direct correlation between fluorescence and bacterial contamination, there is a good relationship between the extent of the fluorescence and the probability of having high microbial counts on the carcass (Reid *et al.* 2005).

The Verif-Eye system is manufactured by E-Merge International (www.verifeye.net), and distributed in Australia and New Zealand by:

Argus RealCold Ltd

PO Box 12-915, 9 Prescott Street, Penrose, Auckland, New Zealand

Tel +64 9-526-5757 (Graham Dun)

www.realcold.nz

Bacterial Fluorescence

AgroMicron are carrying out final testing of a harmless chemical spray which contains a luminous molecule that will bind to pathogens such as *Salmonella enterica* or *E. coli* O157, so that it will glow on the surface of the meat. They have applied for FDA approval, and are hoping that the technology will be commercially available mid-2006. (www.agromicron.com).

Infrared Spectroscopy

Infrared spectroscopy (IR) works on the basis that the chemical bonds within an organic molecule will absorb or emit infrared light when they change from one energy level to another, in response to excitation by light at a particular wavelength, or heat. The emitted infrared light can be detected in a similar fashion to that outlined above for chlorophyll detection. Currently, IR is used to a very limited extent in the meat industry, for detecting the fat content, and has been evaluated for assessing spoilage (Ellis and Goodacre 2001), but it has the potential to be used for detection of bacterial contamination on meat, as bacterial cells will produce a different emission wave from the meat itself (van Kempen 2001). This technology is not yet commercially available, but trials are underway in order to gain FDA approval.

Bacterial ATP detection

All living cells are powered by energy units of adenosine triphosphate (ATP), and this energy unit can be used to drive a bioluminescence reaction, that occurs naturally in fireflies. The more ATP there is, the more power, so the brighter the luminescence, just as in a bicycle dynamo powering the lamp. This technique has been used to detect residual organic material on surfaces after cleaning, as it detects the presence of living cells. The kits available are very easy to use, giving a result in the form of a luminosity figure in minutes, the greater the figure, the more cells there are on the swabbed surface. Total ATP measurement, however, does not distinguish between bacterial cells and body or meat cells, so is not useful for carcass testing.

Sophisticated ATP systems have been developed where the carcass can be sponged, and the sponge treated with a chemical to remove the body cells, so that the ATP detected is of bacterial origin only. These systems give results in 5 minutes, and can detect levels as low as 2-3 $\log_{10}$ cfu/cm² on carcasses (Siragusa *et al.* 1995). Further research is in progress to produce systems that will detect specific organisms, allowing processors to target particular pathogens of concern.

ATP detection currently is probably of more use as a hygiene monitoring tool than for targeting contamination on an individual carcass.

www.biothema.com www.berthold.com.au www.bestlab.com.au

Detection of microbial phosphatase

Phosphatase is an enzyme that occurs naturally in most raw foods and in microorganisms. Testing for this enzyme is commonly used in the dairy industry to assess the efficacy of pasteurisation. The phosphatase produced by microorganisms is more resistant to heat than body/meat phosphatase, so a sample of carcass surface is heated to 75℃ for 7 minutes, to remove the meat phosphatase. The microbial phosphatase can then be detected using a simple chemical reaction, the products of which can be measured by colour analysis or fluorescence techniques, giving a numerical result in approximately 10 minutes. The greater this number, the more microorganisms present on the sample.

This test also is probably of more use as a hygiene monitoring tool than for targeting contamination on an individual carcass, although a kit aimed at carcass monitoring gave a good correlation with carcass microbial count (Kang and Siragusa 2002).

www.cytoskeleton.com (Note: These are very technical kits, and are more targeted at commercial laboratories rather than in the field.)

Intervention options at different parts of the supply chain

The most effective intervention at slaughter is likely to be one that is applied when the risk of contamination has passed, for example as a final carcass wash or rinse just before the carcass goes into the chiller. Post-skinning interventions could, however, reduce the microbial load on the carcasses entering the evisceration phase, and thus reduce the risk of subsequent cross-contamination. Many studies have shown that using combinations of interventions throughout the process (the multiple-hurdle approach) gives greater microbial reductions than using any single intervention (Bacon *et al* 2000; Sofos 2005).

No single intervention is 100% effective. In the USA researchers have investigated a "multiple-hurdle" system of sequential interventions at various processing steps to ensure the safety of their products. Studies have evaluated the effectiveness of sequential, multiple hurdle intervention systems to improve meat safety (Arthur *et al.* 2004; Bacon *et al.* 2000). The use of two or more food safety technologies in a sequence may achieve a synergistic effect, or at least an additive effect. Arthur *et al*. (2004) demonstrated that by minimizing deposition of bacteria onto the carcass and using subsequent effective food safety technologies, processors can maintain *E. coli* O157 populations below detectable levels on all of the carcasses tested after chilling.

Hardin *et al*. (1995), using beef primals, found that a wash with 35℃ water, followed by a rinse with acetic or lactic acid is more effective than single treatments of knife trimming or water washing at reducing inoculated levels of *Salmonella enterica* serotype Typhimurium and *E. coli* O157:H7. Bacon *et al.* (2000) also showed progressive decreases in total plate counts *E. coli* counts as carcasses moved through multiple stages of treatment (*E. coli* count reduced from 2.6-5.3 log cfu/100cm² to 1.0-3.0 log cfu/100cm²).

The technologies that are listed in Table 2 below are those which have received regulatory approval (in at least one country) and there is published scientific literature available to support the validation procedures. Any attempt to determine the optimal food safety technology, solely based on reductions reported in the scientific literature should be approached with caution, and validation of the method under actual in-plant conditions will ultimately be necessary. Many of the published studies are carried out under controlled or laboratory conditions, rather than in a commercial situation, so the real-life outcome may not be the same.

Table 1: Approved food safety technologies for the red meat supply chain

Red meat supply chain	Food safety technology	Microbial Efficacy (log reduction)*	Regulatory Approval or acceptance#			
			USA	EU	Australia	Other
On-farm	Diet modification		Yes	Yes	Yes	
Slaughter – Before hide removal	Clipping or shearing		Yes	Yes	Yes	Most Countries
	Chemical dehairing		Site by site	No	No	
	Chemical hide wash		Yes	No	Yes	
	Plain water hide wash		Yes	Yes	Yes	Most countries
Slaughter – After hide removal	Acid wash (organic acid, peroxyacids etc)	1-3	Yes	No	Yes	
	Hot water/steam pasteurisation	1-3	Yes	Yes	Yes	Most countries
	Irradiation (E-beam)	Up to 4 logs	Yes	No	No	
	Electrolysed water	1.5-3	Yes	No	No	Japan
	TSP	0.7-1.5	Yes	No	No	
	Rinse and Chill	0.2-2	Yes	No	Yes	Imminent for Japan, Korea
	UV/ozone	1-2	Yes	No	Yes	
	Activated lactoferrin		Yes	No	No	Japan, Korea
	ASC	Up to 4 logs	Yes	No	Yes	
Chilling	Organic acid spray	Up to 3 logs	Yes	No	Yes	
	UV/Ozone	Up to 2 logs	Yes	No	Yes	
	ASC	Up to 4 logs	Yes	No	Yes	
Packaging and retail	Natural antimicrobials					
	Nisin	Up to 3.5 logs	Yes	No	No	
	Oil extracts		Yes	Yes	Yes	
	Irradiation	Up to 4 logs	Yes	No	No	
	HPP	Up to 5 logs	Yes	Yes	Yes	
	Activated lactoferrin		Yes	No	No	
	Carbon Dioxide		Yes	Yes	Yes	

* where known

Specific approvals may be required for individual operations eg. Use of a substance may be approved if equivalence is demonstrated, or approved as a processing aid.

Pre-slaughter

Farm and Feedlot

The farm or feedlot is the origin of microorganisms introduced onto carcasses during slaughter and dressing. During rearing, numerous factors interact to affect the visual cleanliness and pathogen shedding characteristics of livestock. Age, coat length, clipping, journey time, feeding and abattoir have been found to influence coat cleanliness, while sex, breed, transport vehicle floor type, transport vehicle dirtiness and housing prior to transport were not significantly related to visual cleanliness of cattle (Davies *et al.* 2000). A lot of interest has been taken in the effects of modifying the diet or feeding probiotics to animals to reduce the shedding of pathogens such as *E. coli* O157:H7, but results are conflicting, probably because of the complexity of the interactions between all the factors involved.

It appears that change in diet and management practices could precipitate increased shedding of pathogens, perhaps as an outcome of the "stress" caused by the change *per se*. An extract from the brown seaweed *Ascophyllum nodosum* has been used as a feed additive to promote stress tolerance. Researchers found that feeding this brown seaweed supplement to feedlot cattle 14 days prior to slaughter was associated with decreased prevalence of *E. coli* in faeces and on hides, but more research is necessary to confirm these results (Barham *et al.* 2001).

There is also significant research into the feeding of probiotics, or "good bacteria", to livestock to competitively exclude the pathogens. In the poultry industry, a product containing a cocktail of 29 organisms (Preempt™) has been approved by the US FDA for reducing the incidence of *Salmonella* in flocks. Some organisms have shown promise in reducing the incidence of *E. coli* O157:H7 in calves (Zhao *et al*. 1998), while natural products of some other *E. coli* strains, the colicins, seem to have some inhibitory effects on *E. coli* O157:H7 (Murinda *et al.* 1996, Etcheverria *et al.* 2006). Sodium chlorate, given by mouth to research pigs, has been shown to reduce *Salmonella* Typhimurium and *E. coli* O157:H7 in the intestinal content (Anderson *et al.* 2001), and work is underway to see if this can be used in the field. No regulatory approvals have been granted to date in either the US, EU or Australia.

Water troughs have been shown to support *E. coli* O157, and be a source of colonisation of previously "clean" animals, so control of pathogen populations in the water could be a means of reducing the incidence. Chlorine appears to be the treatment of choice, through chlorinating the water supply, but some strains of *E. coli* are particularly resistant to chlorine, and animal water troughs often contain large amounts of organic material, which would inactivate the chlorine.

Vaccination of poultry against *Salmonella enterica* serotype Enteritidis PT4 has been very effective in reducing the incidence of this organism within poultry flocks and eggs and has had a substantial impact on the incidence of salmonellosis in humans in the UK (Adak *et al.* 2002). There is substantial research into the production of a vaccine against *E. coli* O157:H7 for cattle, and preliminary trials in Canada showed promise (Huffman 2002), though there is currently no regulatory approval.

Table 3 below (adapted from Brashears *et al.* 2005) summarises the most promising technologies under consideration in the USA for addressing meat safety at the farm or feedlot level.

Table 2: On-farm food safety intervention strategies for *E. coli* O157 in beef cattle

Intervention strategy	USDA approved	Cattle type	Effective?	Estimated Cost (A$)
Diet formulation				
Forage-based diets	Yes	Mature dairy	Yes	Unknown
Grain-based diets	Yes	Sheep model, dairy, steers	Yes	Unknown
Whole cottonseed	Yes	Finishing beef	No	Variable based on season & geographic location
Diet supplements				
Probiotic bacteria	Yes	Finishing beef, weaned calves	Yes	~2-3¢ per animal per day in feedlot
Brown seaweed	Yes	Finishing beef	Yes	~$5-$6 per animal
Vaccination	No	Finishing beef	Yes	~$1.50-$3.00/animal
Sodium chlorate	No	Mature dairy	Yes	Unknown
Antibiotics				
Neomycin	No	Finishing beef	Yes	~$2/animal

Lairage

The cleanliness of the lairage environment is also important in the maintenance of coat cleanliness. Grau and Smith (1974) found that sheep fleeces became contaminated with salmonellae within one day of entering contaminated animal pens, and this contamination increased with the length of time spent in the lairage and with the degree to which the pen floors were contaminated. In the first two days of lairaging, only a few sheep excreted *Salmonella* in the faeces, but there was a rapid increase in the numbers excreting *Salmonella* after 2-3 days. Lambs carrying less contamination on their fleeces will decrease the level of contamination brought into the abattoir environment but wet pens can increase the microbial load on sheep fleeces (Duffy *et al.* 2000). Large numbers of Gram negative and Gram positive organisms have been found in cattle lairages, including contamination of the air and water (Patterson and Gibbs 1978), and the normal cleaning and disinfection procedures in lairages have been found to be insufficient to remove environmental contamination with *Salmonella* spp. (Swanenburg *et al.* 2001) and other foodborne pathogens (Small *et al.* 2002). Fresh cattle faeces are reported to contain an aerobic plate count of 6-7 log/g (Bell 1997), and an adult bovine can void up to 25.5 kg of dung and 12-22 litres of urine in 24 hours (McGrath and Patterson 1969). So, if there is insufficient bedding or drainage in animal accommodation, faecal soiling of the skin can occur (Gregory 1994), and under conditions of close contact and consequent body soiling, animals, by licking, can become regularly infected with larger numbers of faecal organisms than when kept under more spacious conditions (Heard *et al.* 1972). It is often the practice within Australian abattoirs to either reject animals that are delivered to an abattoir in an 'exceptionally dirty' state, or they can be separated and held for treatment before they are processed. These 'higher risk' animals are then processed at the end of the day.

Slaughter and dressing

Before hide removal

Clipping or shearing of sheep prior to slaughter is widely practised in many countries, the entire fleece being removed in countries where the wool market is good, and in other countries, merely the belly being clipped to reduce the potential for fleece contamination of the carcass during skinning. Full shearing is normally carried out prior to slaughter, but "bellying out" may be carried out on the bleed rail. Clipping of cattle hides has been advocated as a method of removing visible tag and contamination, and the brisket, belly and hind legs are targeted. This process, when carried out on the live animal involves considerable operator risk, as the animals often kick out and are confined in unsuitable crushes for the purpose. Clipping of cattle immediately prior to slaughter results in numerous short clippings of hair being present on the hide, and these are observed to be transferred to the carcass during the skinning process. Clipping also increases the microbial load recoverable from cattle hide by swabbing, probably as a result of these free short hairs (Small *et al.* 2004). These authors also showed that singeing of the cattle hide after clipping gave the greatest reductions in recoverable microbial load when compared to washing with warm water (50℃) or washing with a food-safe chemical s olution.

Chemicals can be used, as part of a wash step, to clean the hides before hide removal with the aim of lowering microbial contamination. Compounds such as sodium hydroxide, trisodium phosphate, acidified chlorine (sodium hypochlorite with acetic acid), and phosphoric acid have been evaluated for this purpose (Bosilevac 2005a). These chemicals do not have a neutral pH, and thus a water rinse is needed to remove the residual chemical and to minimise exposure to risks for plant personnel.

There have also been investigations into the use of steam condensing at sub-atmospheric pressures for the treatment of hide-on cattle. *E. coli* O157 levels were shown to be reduced by 5.46 log units on visually clean hides, inoculated with a broth culture of the organism, and by 4.17 log on hides contaminated with liquid faeces seeded with *E. coli* O157 (McEvoy *et al.* 2001). When the seeded faecal matter was drier, the reduction in *E. coli* O157 numbers was greater, of the order of 5.99 log. This study was conducted under laboratory conditions and reductions may not be as significant in a commercial operation.

After hide removal

The majority of interventions used in meat processing are applied to the carcass following hide removal. Wiping cloths were used in the past to remove visible contamination and hairs, and when this practice was outlawed, trimming and washing became commonplace. Whole carcass spray washing has continually evolved over time from ambient temperature water, to warm water washes to use of antimicrobial agents, hot water and steam (See Table 2). During dressing, there are numerous opportunities for microbial contamination of the carcass surface, and although excellent hygienic practices in place at modern plants limit the amount of contamination present on carcasses, it cannot be prevented totally. In modern meat production, the major food safety hazards are microbial, and to continue to improve meat safety, a combination of proactive good hygiene measures during dressing and application of intervention technologies will be required.

Chilling

Chilling itself causes a slight reduction in microbial count on carcasses, and has been shown to reduce *E. coli* counts from 1-3 log/cm² to 0.9-1.3 log/100cm² over 24-36 hours (Bacon *et al.* 2000). Spray chilling is commonly practised in North American meat processing but has had limited uptake in Australia. Some studies have investigated the incorporation of an organic acid and acidified sodium chlorite into a spray chilling system. If an establishment chooses to apply this technology, it must satisfy the Food Standards Code definition of a processing aid (FSANZ 2006) i.e. there is no residue on the final product. Also, it should not result in any increase in carcass weight.

Packaging and retail

Interventions suitable for controlling pathogens in trimmings and ground meat include acidified sodium chlorite and organic acids. Brashears (2004) evaluated the antimicrobial effect of these interventions on beef product processed in a commercial facility. Treatment with 2 or 4% organic acid (acetic or lactic) and Acidified Sodium Chlorite (ASC) significantly reduced (up to 2.5 log cycles in *E. coli* O157:H7 and *Salmonella*) on beef trim prior to grinding and the results were sustained during 5 days refrigerated storage and 30 days frozen storage. Modification of packaging atmospheres can be used to suppress microbial growth, and various additives can be used in meat products to the same end. Carbon dioxide is commonly used in modified atmosphere packs to suppress microbial growth. "Liquid smoke" additives have been advocated in the US, but are prohibited in the EU.

Contamination in processed and ready-to-eat (RTE) meats often occurs after cooking during packing and re-slicing. Post-package food safety technologies, such as in-package thermal pasteurisation and irradiation, and formulating meat products with antimicrobial additives, are common approaches to control pathogens such as *Listeria monocytogenes*. The effectiveness of in-package pasteurization in inactivating pathogenic organisms depends upon package size and the roughness of the product surface as well as the time or temperature of the treatment (Zhu *et al*. 2005).

Implementing a Food Safety Intervention Strategy

When planning an intervention, the most important variables to consider are the method, stage and time of application, equipment design and maintenance, pressure and nozzle type, temperature, chemicals, and the duration of application.

It is important to identify whether or not a chemical is to be used because non-chemical interventions have some distinct advantages such as:

- The cost of chemicals and the hazards associated with chemical storage, transportation and handling are eliminated.
- Operating costs are reduced by eliminating the need to mix or meter chemicals into water flow.
- Regulatory authorities (particularly in the EU) have significant restrictions on the use of chemicals for fresh meat.

The information contained in this review is of a general nature, and when considering a new intervention, it is important to consult AQIS or the relevant State authority before implementation.

Validation and verification

If any of the intervention technologies are to be used as a pathogen control CCP in a hazard analysis and critical control point (HACCP) system, validation of control will be required. There are two approaches to validating the efficacy of intervention treatments; either to monitor the natural contamination (total microbial flora which may include *E. coli* and *Salmonella*) or to specifically inoculate a portion of the carcass or carcass part with a known quantity of bacteria (usually *E. coli* strains).

If naturally contaminated carcasses are used, it can be quite difficult to measure the true influence on food safety of the intervention treatment because the infrequent presence of pathogens (such as *E. coli* O157:H7), *E. coli* and *Salmonella* means that it would be necessary to treat and test many hundreds, perhaps thousands of carcasses or carcass parts in order to achieve a measurable effect. Therefore, inoculating the carcass or carcass part is the preferred option for validation. This can be done either under laboratory conditions using the pathogenic bacteria of choice, or if it is done in the processing environment, it must be conducted under controlled conditions, using the appropriate bacterial inoculum. Advice should be sought from the relevant controlling authority (i.e. AQIS) and an independent laboratory.

Unfortunately, no single microorganism can realistically demonstrate the effectiveness of an intervention treatment for the reduction of all pathogens that may be present, so it is appropriate to choose a combination of indicator organisms. These indicator organisms should have similar characteristics to the target pathogen. The following microbial characteristics are desirable and suggested by the Institute of Food Technologists Expert panel (IFT, 2000):

- Non-pathogenic;
- Behaviour similar to target microorganisms when exposed to processing parameters (eg. pH stability, temperature sensitivity, oxygen tolerance);
- Stable and consistent growth characteristics;
- Easily prepared to yield high-density populations;
- Once prepared, population is constant until utilised;
- Easily enumerated using rapid, sensitive, inexpensive detection systems;
- Easily differentiated from other microflora.

Food Science Australia has used such an inoculum in intervention studies for carcasses, studies of carcase chilling procedures and for challenge testing in uncooked fermented meat products. The inoculum contains a cocktail of *E. coli* strains that contain no known virulence

markers for pathogenic *E. coli* (i.e. are considered to be non-harmful). These generic strains are used as surrogates for *E. coli* O157:H7 and *Salmonella.* Other researchers have also suggested a cocktail of indicator strains (Marshall *et al*. 2005) for pathogen-specific testing. They isolated a range of bacterial indicator isolates from beef cattle (including *E. coli*, *Enterobacter*, *Serratia* and *Providencia*) and found that *E. coli* had the greatest potential to represent *E. coli* O157:H7 and that a cocktail of the strains should be used.

Cost Analysis

There are many potential benefits of intervention technologies such as a more consistent microbial standard of product; better management and clearer worker responsibilities; reduced cost through insurance premiums; stable and even expanded markets (domestic or export) following increased levels of trust by key customers. The financial cost of food safety interventions is difficult to calculate because there are many ancillary costs which will influence the feasibility of a particular intervention in a particular establishment such as:

- Does the plant operation need to be modified (production lines, laboratory tests, sanitation/plant clean-up, waste management etc.)?
- Is capital investment required for construction of new buildings or modification of premises to accommodate the new equipment or work station?
- Is there an existing space available to accommodate any equipment required?
- Are there licensing agreements that need to be put in place?
- Do worker management/education programs need to be implemented for the new technology?

Therefore, each food safety intervention will need to be assessed on a plant-by-plant basis. For some of the food safety technologies described, indicative costs have been estimated, particularly for commercially available technologies. Installation of a wash cabinet can cost A$500,000 to A$1 million, and chemical costs may be 50¢ to A$2.00 per carcass. Treatments which involve manual application, such as trimming or steam vacuuming also involve the cost of the labourer. For most of the emerging technologies, it is very difficult to provide a costing, particularly where multiple technologies may be used in combination within a process. Many packing plants in the United States employ multiple interventions. Such a system may include a pre-evisceration lactic acid wash, steam vacuuming and trimming, and a final hot water treatment or steam pasteurisation. Given this scenario, the estimated cost (for a plant killing around 70 head per hour) of a combination of water wash, lactic acid spray and hot water is around A$1.50 per carcass; that of water, steam pasteurisation and lactic acid at A$2.00; and steam vacuuming, lactic acid and hot water at A$2.50 per carcass. This does not include the capital cost of setting up each food safety technology.

Efficacy/Microbial Reductions

The main driver for companies implementing some of these food safety technologies is the assurance of a further microbial reduction on their products. In the case of processors, this is a reduction in *E. coli* and *Salmonella*, and for further processors, this is more often targeted towards post-processing microbial contamination from spoilage microorganisms and pathogens such as *Listeria monocytogenes*. Consideration should be given, however, to the long-term consequences of some food safety technologies and their effect on the microbial ecology of meat environments. For example, is there increased survival of pathogens during refrigerated storage because of a potentially altered natural flora – particularly do we risk increasing virulence of pathogens or resistance to other treatments such as heat?

Research studies often show better reductions in microbial count than commercial trials for a number of reasons. Firstly, research studies often use artificially contaminated product, so the initial level of bacteria present are high. As numbers decrease, it becomes more and more difficult to remove the remaining organisms. Secondly, the inherent variability in the product will affect the outcome of any treatment: wether the surface is predominantly fat or lean, or if the shape of the product is such that parts of the product are not exposed to the treatment. Thirdly, in a commercial situation, the product may undergo a number of processes after the intervention, which can themselves result in increases or decreases in microbial load. It is also important to realise that as bacterial counts are expressed as

logarithms, a 90% reduction equates to 1 log, a 99% reduction to 2 log, and a 99.9% reduction to 3 log.

Objections to the use of Intervention Technologies

There are two main schools of thought with regard to control of food safety during meat production, normally referred to as “Non-intervention HACCP” and “Intervention HACCP”.

Non-intervention HACCP relies on inspection at the end of the line to identify contamination and then remove it. It is really a monitoring activity, and carcass hygiene is controlled by strict adherence to GMP, and proactive measures to prevent contamination occurring. This is the system in place in the EU.

Intervention HACCP uses strategically positioned interventions to reduce levels of microbial contamination. These interventions may be applied at any of a number of positions on the production line, and more than one may be used. This is the system used in the US.

Defendents of the non-intervention system object to interventions on a number of issues such as:

- Washing may not remove the contamination – it just moves it to another part of the carcass;
- High pressure washing may drive bacteria into the deeper parts of the carcass, where it is not exposed to heat treatment during traditional cooking;
- The bacteria that are not removed may just become dormant, and can recover and grow later in the chain;
- Use of chemicals may kill off the bacteria that are sensitive to the chemical, but resistant bacteria will survive and become dominant;
- Using interventions encourages unhygienic practices on the line, and poor adherence to GMP, as the workers believe that the intervention will clean the carcass for them.

This last point is a major obstacle to acceptance of intervention HACCP by a number of regulatory authorities, but advocates of the intervention system agree that good adherence to GMP is an important pre-requisite to any HACCP system, intervention-based or not. The intervention system gives a further level of control over the non-intervention system, which is required, because even with the best processing practices, a degree of contamination is inevitable.

Physical Interventions

Animal washing

Pre-slaughter washing of sheep is widely used in New Zealand (Biss and Hathaway 1995), particularly in groups of sheep that have extensive faecal staining or smearing of the pelt, faecal material collected around the hind legs and/or excessive accumulations of mud or dust in the fleece. The pre-slaughter wash described by Biss and Hathaway involved an initial cold water (10°C) shower wash, with water directed up from floor level to the bellies, as well as from above. Clean lambs were showered for 2 minutes, and dirty lambs for up to 10 minutes. The wet lambs were then immediately swum for approximately 1 minute in a trough of counter flow cold water which was emptied and cleaned daily. After this, the lambs were allowed to drip-dry overnight. When lambs have been washed prior to slaughter, less visible contamination can be seen on the carcasses (Petersen 1978), but the microbiological counts can be up to 0.3 log higher than on lambs that have not been washed (Biss and Hathaway 1996a). The detrimental effect of the pre-slaughter wash was found to be greater on carcasses derived from woolly lambs than from shorn lambs. Numerous swims could also have an adverse effect on sheep welfare – the muscle pH increases with greater number of swims, and the duration of the post-swim rest phase did not improve this (Petersen 1983). There is a highly significant increase in the prevalence of bruising in lambs that have been swum as compared with unwashed lambs (Petersen 1978). Wet animals moving from the bath to the drying pens were seen to slip and fall, or run into rails and gates because of the slippery surface of wet gratings underfoot. Sheep with excessive accumulations of faecal material around the anus generally undergo shearing of the affected perineal area ("crutching") prior to slaughter, but this has not resulted in significant improvements in carcass microbiology (Roberts 1980).

In cattle, the contact of the carcass surface with faecally soiled hide that had been washed prior to slaughter can result in a microbial load on the carcass surface similar to that resulting from contact with fresh faeces (Bell 1997). Van Donkersgoed *et al.* (1997) found that although slowing line speed or shaving off of tag could reduce carcass microbial contamination, this reduction was not statistically significant, but on a slow line there was a weak positive correlation between wet hides and coliform or *E. coli* counts. Strict sanitary dressing procedures, including a cold water wash of cattle the day before slaughter and pre-chill decontamination of the resultant carcasses, can result in reduced mean aerobic plate count and improved shelf life when compared to conventionally dressed cattle (Dixon *et al.* 1991), but with pre-slaughter washing alone, there may be no statistically significant reduction in carcass contamination. Byrne *et. al.* (2000) found that a three-minute wash of dried faecal matter on cattle rumps reduced the levels of marker organism present but had no statistically significant reduction in the microbial load of the resultant carcass.

Chemicals can be used as part of a wash step to clean hides and fleeces prior to hide removal, with the aim of lowering microbial and/or visible contamination. Sodium hydroxide has been used as a hide wash intervention. Bosilevac *et al*. (2005a) evaluated a 1.6% solution, followed by a water rinse, in an on-line hide-wash cabinet. Results showed 2.1 and 3.4 log reductions in aerobic plate counts and *Enterobacteriaceae* counts respectively, and the prevalence of *E. coli* O157 was reduced from 44 to 17%. Washing of cattle hides prior to slaughter, using cetylpyridinium chloride, has resulted in improved carcass microbiology, and reduced incidences of *E. coli* O157 (Bosilevac *et al.* 2004a), but the incidence of DFD (dark, firm, dry) doubled in the carcasses of cattle that were washed live, suggesting that washing the live animal increased the animal's stress.

The USA company Cargill Meat Solutions (formerly Excel Corp.) has implemented hide washing systems in all of their plants. Cargill's choice of compounds to use in the automated hide wash cabinets involved consideration of cost, ease of implementation and efficacy. Sodium hydroxide at 1.5% was chosen as the wash because it does not lose activity, as acids often do, in a recirculating system using 1ppm chlorine. In addition, as the carcass exits the cabinet, plant personnel use a steam vacuum to remove excess liquid and loosened material along the hide opening pattern lines (Koohmaraie *et al.* 2005).

Trimming

Since 1994, AQIS has prescribed 'zero tolerance' for the carcase contaminants: ingesta, faeces, milk and urine (AQIS Notice, 1994). Trimming of the affected product is an acceptable corrective action and can be combined with other technologies to help remove contamination. Research groups are working on combining automatic detection methods with robotic trimming machines to automatically remove the offending material.

Where beef carcasses are subject to inspection and trimming, the mean TVC can be around 3 log less than on carcasses where no trimming is carried out (Prasai *et al.* 1995). These authors also evaluated the combination of carcass washing and trimming, but found that the microbiological status of the carcasses was substantially poorer than when the carcasses were trimmed without washing. This was considered to be a result of cross-contamination during the washing process. Other studies, however, have shown greater reductions using both trimming and washing than using either treatment alone, but no combination resulted in the elimination of pathogens such as *E. coli* O157:H7, *Salmonella* or *Listeria* from the carcasses (Reagan *et al.* 1996). Conversely, others have found no conclusive evidence that trimming and washing improves the microbiological status of carcasses (Gill *et al.* 1996), and it may be that the efficacy of trimming and washing depends very much on the skill of the operator, the extent of visible contamination compared with non-visible contamination, and the temperature, angle and pressure of the wash waters used in each of these studies.

In addition to the personnel required, trimming involves costs to the industry in loss of carcass meat removed during trimming, followed by possible loss of the underlying surface post chilling, as it may dry during chilling and become aesthetically unacceptable. Excessive trimming can also downgrade the resultant cuts of meat through removal of the surface fat and tissue that may be important factors in complying with commercial specifications. Manual trimming requires personnel, protective clothing and good lighting, and the contaminated material removed must be disposed of properly.

Hot water

Hot water as an intervention step has been extensively researched and a number of automated cabinet designs are in use around the world. Sheep and beef sides are treated for up to around 15 s with 75-95°C water, with reductions of up to 3 log of pathogenic and spoilage bacteria being reported. Heat kills bacteria mainly by inactivating the most sensitive vital enzymes for bacterial life, and a 95℃ spray for 10s raises the carcass surface temperature to 82℃ (Barkate *et al*. 1993). Sprays of 95℃ for 5s at 165 kPa from 12. 5cm gave reductions of up to 3 log in total coliforms, thermotolerant coliforms, *Salmonella* Typhimurium and *E. coli* O157:H7 (Huffman 2002), but maintaining such a high delivery temperature may not be easy. Ultimately, the greater the temperature of the water applied to the carcass, the better the overall food safety result. For example, 80℃ sprays reduced the total plate count of lamb carcasses by <1.0 log (Kelly *et al*. 1981), 74℃ is better than 35℃, and 1889 kPa is better than 276 kPa for removing visible contamination and *E. coli* from beef tissue (Gorman *et al.* 1995). Scientific studies show very variable results, which may be due to differences in initial microbial load, microbial attachment or the specific organisms studied. Attachment would increase with time from application, and results would also vary dependent on the tissue sampled, be it fat, muscle or connective tissue.

One researcher found that hot water (74°C) spray-washing was more effective in reducing contamination of beef tissue than solutions of 2% acetic acid, and the USDA/FSIS acknowledges that significant scientific evidence exists to conclude that hot water (>74℃) will produce a sanitizing effect on carcasses (USDA/FSIS, 1996).

Hot water treatments remove faecal material and improve visual appearance of the tissue as required by the USDA 'zero-tolerance' policy. The position of the intervention on the chain is important – washing carcasses immediately after dehiding may inhibit further attachment of bacteria later in the process (Dickson 1995). Hot water applied before the final wash gives a mean reduction in total count of 1.3 log compared with a mean reduction of 0.8 log if the hot water intervention is applied after a cold water wash (Barkate *et al.* 1993).

Hot water can be applied during slaughter in a number of different forms; either as a whole carcass wash, or to specific areas of the carcass. Application can be by spray (high or low

pressure, manual or automatic), by deluge in a cascade or by immersion (more applicable to poultry or small cuts of meat). Immersion in hot water is effective at removing bacteria from a meat surface – 10 sec at 60℃ gave 1 log reduction in inoculated organisms, while 10 sec at 80℃ gave greater than 2 log (Smith and Graham 1978), but meat exposed in an immersion tank may gain weight, which is not permitted under USDA/FSIS or AQIS legislation. When researchers tried to decontaminate beef trimmings by immersion in hot water and lactic acid prior to grinding - 95℃ for 3 sec – they achieved 0.5 log reduction in *E. coli* and 0.7 log reduction in *Salmonella* Typhimurium, but the trimmings gained 1.31% in weight during treatment (Ellebracht *et al*. 1999). Flooding the tissue by immersion or prolonged deluge with high temperatures should achieve high temperatures on and throughout irregularly shaped cuts or carcasses (Sofos and Smith 1998), and investigations of small-scale hot water immersion of packaged meat products found good reductions in *Listeria monocytogenes* in wieners and beef sticks (Ingham *et al.* 2005). The appearance of the wieners was enhanced, but that of the beef sticks deteriorated after 1 minute in boiling water.

Spraying may not achieve the desired temperatures at the contact surface, and may generate condensate and aerosols, but may remove visible contamination. Low pressure spraying would give higher tissue temperatures than high pressure, as it allows for a longer contact time, but high pressure is more able to remove visible contamination. The disadvantages of hot water sprays include occupational health and safety issues for operators, possible visual colour effect on meat, and penetration of bacteria into the tissue, depending on the pressure of the sprays used. Hot water treatment can cause a cooked/bleached appearance, depending on the treatment time and temperature, but the discolouration is usually unnoticeable after a few hours of chilling (Castillo *et al.* 2002).

Hot water treatment systems are installed in Australian plants. From the cost analysis performed by Texas A&M University some years ago for the Meat Research Corporation, we estimate that for a plant killing around 70-100 head per hour, the fixed cost of a hot water treatment, preceded by a warm water wash, is approximately A$400,000-500,000. This, together with the variable costs (water, steam, labour etc.) gives a total cost of around A$0.60-0.70 per carcass.

Wash cabinets are built to order by companies such as Food Processing Equipment (FPE), or APV Australia.

APV Australia (Invensys Companies)

National Sales & Service Centre

Ph. 1-800-100-278

Email: tony.harris@invensys.com

Website: www.apv.com.au

Food Processing Equipment (FPE).

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Website: http://www.fpe.net.au/home.html

Steam pasteurisation

Steam at 100℃ has a much higher heat capacity than water at the same temperature, so if steam condenses on a surface, the temperature of that surface rises more rapidly than if it were water that was deposited on the surface. Steam droplets are far smaller than bacteria and steam can penetrate into the cavities on the surface, and it will condense onto any cold surface. For example, a steam droplet could be less than a millionth of a millimetre in diameter, where a *Salmonella* bacterium is around four thousand times larger. So, steam will pass around the bacteria in the cavities on the meat surface (Morgan *et al.* 1996b).

Steam pasteurisation *in vitro* gives significant reductions in *E. coli* O157 levels on artificially inoculated samples, but few studies have examined the effects on naturally contaminated carcasses in a commercial environment. A 1998 study found significant reductions in total aerobic plate count and *E. coli* counts on beef carcasses (Nutsch *et al.* 1998). A recent commercial trial showed significant reductions in *E. coli* and *Enterobacteriaceae* at sites where initial numbers were high, but it did not result in complete elimination of these bacteria (Minihan *et al.* 2003). Combining two treatments - steam condensation on meat surfaces and hot water immersion, particularly chlorinated hot water - has also been shown to effectively decrease the bacterial load on lamb (James *et al.* 2000).

Steam pasteurization for even a short (<15s) duration results in initial surface greying of carcasses, but after 24hrs chilling, the acceptable colour returns (Phebus 1996; cited in Huffman 2002). A system of rapid cycling of steam under pressure and vacuum cooling has been designed which can give a 1.9 to 2.5 log reduction in *Listeria* numbers on beef after treatment for 48 milliseconds at 121℃ (Morgan *et al.* 1996a; 1996b). Steam has also been used on processed meat products; flash steam heating under pressure followed by cooling by evaporation can give up to 4 log reductions in microbial populations with a 30-40s steam treatment time, without severely affecting colour or weight of beef frankfurter sausages (Cygnarowicz-Provost *et al.* 1994).

A steam pasteurisation cabinet for beef carcasses was originally designed by a consortium involving Kansas State University, Frigoscandia Equipment Group, Bellevue, and Cargill Inc. It uses a two-stage cabinet system, each “the size of a subway car” (Smith 1996). The first cabinet applies a blanket of pressurised steam, raising carcass surface temperatures to 90℃ in 10-15s, and the second spray-cools the carcass before chilling. Microbial reductions of 3-4 log have been reported using this equipment. Production of condensation is a concern if adequate space is not provided to ventilate the cabinet. Steam production requires a fair amount of energy, and water, although condensate may be collected, treated and recirculated.

For steam pasteurisation, the fixed cost for an installation would be around A$650,000 and the total cost A$0.75-0.80 per carcass. Steam pasteurisation cabinets were developed in the 1990s by Frigoscandia. Their agents in Australia are FMC Technologies. Other companies that meay be able to construct steam cabinets are Food Processing Equipment (FPE), or APV Australia.

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Website: www.apv.com.au

Steam vacuums

Steam vacuuming uses steam and/or hot water to loosen soil and kill bacteria, followed by application of a vacuum to remove contaminants. The effectiveness of steam vacuuming depends on employee diligence of application and the operational status of the equipment. It is only useful when applied to specific areas of the carcass that are known to be heavily contaminated i.e. it is not conceivable to 'vacuum' an entire carcass.

Steam vacuum systems are used in Australia for removal of wool fibres and wool dust from sheep carcasses but they are used infrequently as interventions for beef sides. AQIS Meat Notice 98/1 states that the unit must be used for localised 'spot' treatment only and should be applied to a particular area of the carcase surface for a five-second contact time (AQIS Notice, 1998).

The equipment is a hand held device consisting of a vacuum wand with a hot spray nozzle, delivering water at 88-94℃ to the carcass surface under pressure, while simultaneously vacuuming the area (Dorsa *et al.* 1996a; 1996b). These authors found that the technique reduced the aerobic plate count by 3 log (6.2 log cfu/cm² to 3.2 log cfu/cm²), total coliform count by 4.0 log (5.0 log cfu/cm² to 1.0 log cfu/cm²) and *E. coli* count by 4.0 log (4.8 log cfu/cm² to 0.8 log cfu/cm²) on artificially inoculated beef short plates. Other researchers have found aerobic plate counts and total coliform counts to be reduced by 1.1-2.3 log and 1.2-2.2 log respectively using two different hot water/steam vacuum systems (Kochevar *et al.* 1997). Some bleaching of the carcass surface was noticed using the system, but this was not a permanent discolouration. Further trials have shown steam vacuuming to be very effective at reducing the number of *E. coli* O157:H7 on beef (Dorsa *et al.* 1996a). It has gained wide acceptance by the US industry as an effective tool for spot treatment on the slaughter floor prior to final inspection and chilling (Huffman 2002), and is approved by USDA/FSIS as a substitute to knife trimming for removal of faecal and ingesta contamination where spots are <2.54cm diameter (Huffman 2002). It is applied prior to chilling; trials on use after chilling failed to remove artificially inoculated *Salmonella* organisms, possibly because the organisms had been allowed the time during chilling to become firmly attached to the surface and form biofilms (Bacon *et al.* 2002).

Hand-held steam vacuum units are available from Kentmaster (the Vac-San system), and from Jarvis ANZ (the CV-1 system). Current research is looking at automation of the system unit using robotics.

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Cold treatments

Chilling slows the growth of most bacteria and temperatures just above the freezing point can kill or injure bacteria. Ice crystals may form within the bacteria and rupture the cell membrane, or chemical changes may occur which kill the organism. Chilling is the most widely used method for the preservation of meat (Ingram and MacKey 1976). Whatever the final microbial load of the meat, the maximum potential shelf-life will be achieved if the non-frozen meat is held at -1.5℃ and for each 2-3℃ ri se in temperature, the storage life will halve (Gill 1986). Air chilling is most commonly used in the Australian Meat Industry but spray chilling, as used in the US, or blast chilling (ultra-low temperature) may be considered.

Conventional chilling can reduce the microbial populations on carcasses by 0.3-0.7 log (Nortjé and Naude 1981; Thomas *et al.* 1997), and can reduce *E. coli* counts by up to 2 log over 24-36 hours (Bacon *et al.* 2000) but there is little effect on microbial populations when spray-chilling is used (Greer and Dilts 1988, Kinsella *et al.* 2006). Ultra-low temperature chilling has been suggested as potentially being more effective with regard to microbial inactivation, but researchers working on pork carcasses found little difference in the efficacy of conventional chilling versus ultra-low temperature chilling on the reduction of bacterial numbers on the carcases, whether they were skin-on or skin-off (Chang *et al.* 2003). Spray chilling is commonly practiced in North American meat processing but has had limited uptake in Australia. Some studies have suggested the incorporation of an organic acid and acidified sodium chlorite into a spray chilling system. If an establishment chooses to apply this technology, it must satisfy the Food Standards Code definition of a processing aid (FSANZ 2006) i.e. there is no residue on the final product. Spray chilling should result in no increase in carcass weight. In export-registered establishments, the process will be subject to AQIS approval.

In the poultry sector, research has been focussed on crust freezing, where the outer surface of the meat is rapidly frozen, then thawed before the freeze can penetrate into the tissue. Freeze-thaw cycles can reduce *Salmonella* Typhimurium on poultry wings (Olson *et al.* 1981), using a combination of CO_2 freezing followed by microwave defrosting. These authors achieved substantial reductions in microbial load from initially already low levels of 0.9 log cfu/g to 0.02-0.05 log cfu/g. It is important to note that as initial levels are reduced, it becomes increasingly difficult to remove the residual microbial contamination.

After a slaughter floor intervention step, some bacterial cells remain alive, but injured, and they can recover to cause spoilage or food-poisoning. Good chilling practices can elicit a further 0.5-2 log reduction in microbial load due to death of injured cells, which through their injury, are more susceptible to cold stress (Gill and Bryant 1997; McEvoy *et al.* 2004; Chang *et al.* 2003).

Novel Technology

There is a Japanese patented system called CAS (Cells Alive System) freezing which involves magnetism and modulated waves of cold air. Conventional freezing freezes the product from the outside in, and thus penetration of the cold to the centre of the food gets more difficult as the exterior freezes solid. The CAS technology claims to retain the texture and flavour of food by first supercooling the product, then freezing it. Supercooling is achieved by subjecting the target product with a low-intensity magnetic field, which lowers the freezing temperature of the product. Thus the entire body of the product can be uniformly cooled below freezing point without freezing occurring. Then, when the magnetics are turned off, the products', supercooled body freezes quickly and uniformly, suppressing the migration of fats and oils, and the formation of ice crystals. This technology is not yet available in Australia but is distributed by ABI (Japan).

Oscillating magnetic fields themselves have shown some promise as a means of reducing microbial numbers on foods. A technique involving passing foods through an electromagnetic coil emitting pulses of oscillating magnetic fields was patented in 1985 by Maxwell Laboratories Inc (Anon 1985), which claimed that microorganisms could be killed or deactivated without affecting the organoleptic properties of the food. The theory was that rapid variations in magnetic field would rupture the DNA within the microbial cells. The patent claimed 2-3 log reductions in microbial counts in milk, yoghurt, juice and dough, with minimal treatment times. A single pulse of intensity 5-50 Tesla at a frequency of 5-500 kHz, reduced

microbial numbers by 2 log, and treatment times of 25µ sec to 10 msec were used to successfully decontaminate milk, yoghurt and dough (Hofmann 1985, cited by Pothakamury *et al.* 1993).

Suppliers of cold treatments include:

Tri Tech Refrigeration

43-47 Northgate Drive

Thomastown

Victoria 3074

Phone: +61 3 9465 0099

Fax: +61 3 9464 1327

Website: www.ttrerig.com.au

Scantec Refrigeration

360 Lytton Road, Morningside, QLD

Ph: +61 7 3370 6501

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Email: sales@scantec.com.au

Gordon Brothers Industries

21 Michael Street

Brunswick

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Email: info@gordonrefrig.com.au

Website: www.gordonrefrig.com.au

Realcold Milmech Pty (Aust) Ltd

Colin Giles or Roy Robinson

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PO Box 68, Coopers Plains, QLD4108

Ph: +61 7 3277 0100

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Email: sales@realcoldmilmech.com

Website: www.milmech.com

Ice King Ozice Australia

PO Box 2230

Victoria 3121

Phone: +61 3 9421 3172

Fax: +61 3 9427 7250

ABI Institute for Technology

Tokatsu Techno Plaza

Kashiwa City Chiba

Japan

Contact: David Doral (Meat & Livestock Australia)

Rinse-and-Chill

Rinse & Chill™ is marketed by MPSC Inc. and is a pre-rigor, enhanced bleeding technique that rinses a chilled isotonic solution containing dilute concentrations of approved common substrates (sugars and salts) through the carcass, improving meat quality, palatability and appearance. It also appears to improve hygiene. While the initial application of this technology was to remove the blood and reduce the internal temperature of the carcass, it also seems to reduce the microbial count on carcasses, and this effect also appears to extend to the subsequently vacuum packaged product and in ground beef.

When Rinse & Chill™ has been used in commercial cattle slaughterhouses, reductions in total count of around 0.2 log were seen, 0.2-2 log reductions in coliform count and 1 log reductions in *E. coli* count (Feirtag and Pullen 2003).

Researchers at Kansas State University and at the University of Minnesota claim that the solution (present in the capillaries below the hide) assists in easier hide separation, which means less aerosolizing of contaminants, and it also appears to put a coating the surface of the carcass – making it slippery to the touch, instead of sticky. The coating of solution over the carcass surface is thought to provide mechanical interference with bacterial attachment. Blood removal, temperature reduction and pH control are also important in controlling bacterial growth on carcass surfaces (Feirtag and Pullen 2003).

AQIS has approved the use of Rinse and Chill™ on an individual application basis, at export plants in Australia and it is in use at some plants in Victoria. The patented process is also in use in plants in the US.

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Irradiation (gamma rays, electron beam)

Ionizing radiation is a process in which products are exposed to radiant energy which includes gamma rays, electron beams, and x-rays. Gamma irradiation uses high-energy gamma rays with high penetration power, and thus can treat bulk foods on shipping pallets. Electron beam (E-beam) irradiation uses a stream of high-energy electrons, known as beta rays, which can penetrate only about 5 cm, while X-irradiation has intermediate penetration (Zhu *et al*. 2005). Irradiation damages the bacterial cells' genetic material, disrupting their normal functions, and can result in significant extensions in shelf-life of the product treated. The biggest obstacle to irradiation as an intervention is consumer acceptance. There is a perception that irradiation is dangerous to health, which in large doses, it is, but the doses required to treat foods are tiny and considered to be safe.

The organisms responsible for meat spoilage and food-borne illness are readily destroyed using irradiation. Doses of 1.0 to 10.0 KGy have been shown to be effective in food decontamination, while 0.4-0.6 KGy would give a 1 log reduction in *Listeria monocytogenes* (Radomyski *et al.* 1994). Considering the fact that the numbers of pathogens present on fresh meats are usually below 2 $\log_{10}$ cfu/cm², an irradiation dose of 1.5 KGy would in theory remove this level of contamination (Murano 1995).

Irradiation also increases the shelf-life of meats, by reducing the initial load of spoilage organisms present. Most authors agree that irradiation at medium doses does not affect the organoleptic properties of red meat, with no significant difference being found between pork chops that had been treated with 1 KGy and those that had not after fourteen days of vacuum-packed storage (Mattison *et al.* 1986). In a trial on beef patties, the only difference

noted was that the irradiated patties were considered to be juicier than the non-irradiated patties (Murano *et al.* 1998). Low-dose/low-penetration electron beam (E-Beam) irradiation has now evolved to the point where large non-uniform surface areas can be effectively treated, which allows whole carcasses to be treated after chilling. Only the surface (about 15mm penetration) receives a significant radiation dose (Koohmaraie *et al.* 2005). A recent study showed that a 1 kGy dose of E-beam radiation applied to chilled beef primals reduced *E. coli* O157:H7 numbers by 4 log, with no adverse effects on the sensory attributes of the meat, as judged by a trained taste panel (Arthur *et al.* 2005). The packaging method used for the meat will affect the efficacy of the irradiation treatment. Irradiation is far more effective on packs containing air than on vacuum packs or MAP packs (Thayer & Boyd 1999).

Irradiation is approved by more than 40 countries and endorsed by such international and governmental organisations as the World Health Organisation (WHO) and the FDA. It offers a significant opportunity to reduce pathogens and extend the shelf life of meat, but consumer acceptance is still a hurdle. In Australia, Food Standard 1.5.3 of the Food Code governs irradiated food and to date, only herbs and spices and some tropical fruits have been approved to be irradiated, as is the case in the EU. Labeling requirements vary from country to country. Some, like Australia, New Zealand and the EU, require the labeling of any food that contains an irradiated ingredient, however small the percentage of that product, whereas in the United States, labeling applies only where the whole food item is treated. Ionizing radiation has been approved in the US for use in treating refrigerated or frozen uncooked meat, meat by-products, and certain other meat food products to reduce levels of foodborne pathogens and to extend shelf life (USDA/FSIS 1999). Irradiated product must bear a particular logo and must either have the word “Irradiated” in the product name, or the pack must be labelled “Treated with radiation” or “Treated with irradiation”.

Like other physical processes such as cooking and freezing, irradiation can cause some alteration of the chemical and sensory profiles of a food, but, in general, most nutrients are unaffected by irradiation with the exception of some vitamins for which minor decreases may occur. It is unlikely that any vitamin deficiency would result from the consumption of irradiated food (IFT 2000). The two most important concerns related to the microbiological safety of irradiated foods are: (1) the potential to create highly virulent mutant pathogens; and (2) the potential that reducing the harmless background microflora could eliminate competitive microbial forces and allow uncontrolled pathogen growth (IFT 2000). A key advantage of food irradiation is that it reduces the microbial load at the point at which the product has been packaged, which increases the likelihood that the product the consumer receives will be safe.

Electron beam ionising radiation has been successfully used for irradiation of ground beef in the US and now has significant consumer acceptance there. However the main proponent of the technology, SureBeam Corporation filed for bankruptcy in January 2004, halting virtually all meat E-beam irradiation activity. It appears that the company is unlikely to resume trading, and this is likely to deal a severe blow to E-beam irradiation as a commercially viable technology.

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Ultraviolet light

Ultraviolet (UV) light irradiation is commonly used in hospitals and laboratories for decontamination of surfaces, air and water. UV treatment has been used for a number of years in water purification and research is ongoing into the application of UV directly to foods. UV is an electromagnetic wave, lying outside the band of visible light. It has low penetrating power because it is a low energy wave, and its effectiveness is markedly affected by irregularities on the surface treated.

UV light causes permanent cross-links to form in the microbial DNA, preventing the cell from carrying out its normal functions (Sastry *et al.* 2000). The lethal effect of UV light varies with intensity and length of exposure, but temperature, pH, relative humidity and degree of initial contamination also affect its performance (Banwart 1989). UV light has low penetrating power, because its inherent energy is low in comparison with ionising radiation, so any obstruction to the path of the rays, such as dust, shadowing or clumping of bacteria can reduce efficacy. So, the effectiveness of UV light is less on a rough surface than on a smooth one (Huang and Toledo 1982; Stermer *et al.* 1987). The effective wavelength is between 210 and 300nm (Banwart 1989). Sykes (1965) gave the ideal as between 240 and 280nm. Most commercial UV lamps deliver 90% of their radiation at 253.7nm.

UV light rapidly inactivates microorganisms in culture, killing up to 4 log before the death rate slows (Shapton and Shapton 1991). UV irradiation can sensitise bacteria to other food safety treatments such as heating or hydrogen peroxide treatment, and a synergistic effect may be obtained (Tyrell 1976; Bayliss and Waites 1980; 1982). Certain wavelengths produce ozone, which enhances the antibacterial effect (Kaess and Weidemann 1973), but excessive ozone can cause rancidity. UV treatments have also been associated with accelerated lipid oxidation and browning due to metmyoglobin formation, particularly in pork and poultry.

In general, anaerobic organisms are more sensitive to UV light than the aerobes, and Gram negative bacteria and rods are more sensitive than Gram positive bacteria and cocci (Sykes 1965), but successes have been reported against *Salmonella* on poultry (Wallner-Pendleton *et al.* 1994), and against *Pseudomonas aeruginosa* (Abshire and Dunton 1981). Most studies have used low intensity UV for 9 minutes or more, but if high intensity UV light was used, exposure times could be less than 10s (Stermer *et al.* 1987). Due to poor penetrative properties, UV light is more or less limited to surface applications, but it shows promise as a post-packaging treatment. Djenane *et al*. (2001) irradiated beef steak packaged in polyethylene pouches with modified atmosphere (70% O_2, 20% CO_2, and 10% N_2) and stored at 1℃ and found that the shelf life was extended from 12 to 28 days. The UV was applied continuously at 1000 lux in a retail display cabinet. Under a standard fluorescent tube light, colour and odour deteriorated rapidly from day 6, whereas with the UV lamp, deterioration only became noticeable after day 17, and was still scored as “slight” at day 28. Microbial counts from day 22 were 2 log lower in the UV-exposed packs than in the standard fluorescent light-exposed packs.

Coolroom UV units and UV water treatment systems can be obtained from Australian Ultra Violet Services Pty Ltd and Ultra Violet Products (Aust) Pty Ltd. From overseas, Safe Foods Corporation markets a UV system under the Fresh*Light* brand for use in liquids including brines and marinades, and Aquionics or Hanovia supply air and water treatment systems.

Suppliers of UV equipment include:

Australian Ultra Violet Services Pty Ltd

23 Northgate Drive

Thomastown, Victoria 3074

Phone: +61 3 9464 3855

Fax: +61 3 9464 3866

E-Mail: austuv@austuv.com.au

Website: http://www.austuv.com.au

Ultra Violet Products (Aust) Pty Ltd

6 Dundee Avenue

Holden Hill

South Australia 5088

Phone: +61 8 8369 2864

Fax: +61 8 8266 0760

Website: www.uvp.com.au

Safe Foods Corporation

4801 North Shore Drive

North Little Rock AR 72118

United States of America

Phone: 501 758 8500

E-Mail: Mark Hill SafeFoods@SafeFoods.net

Website: www.safefoods.net

Aquionics

21 Kenton Lands Road

Erlanger KY41018

United States of America

Phone: 800 925 0440

Website: www.aquionics.com

Hanovia Ltd

145 Farnham Road

Slough, Berkshire SL1 4XB

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Phone: +44 1753 515 300

Fax: +44 1753 534 277

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Website: www.hanovia.com

Pulsed light technology

Visible light can effect microbial destruction through the photo-dynamic effect, where toxins such as singlet oxygen ions are formed by light-absorbing molecules (photosensitisers). The intensity of visible light used for decontamination must be many times greater than the intensity of sunlight to have any practical benefit. Sunlight has been shown to reduce *Salmonella* enterica on stainless steel (Nyeleti et al. 2004), and to have a lethal effect on *Bacillus* spores (Abad-Lozano and Rodriguez-Valera 1984), but both these studies were carried out over a 12 to 24-hour exposure to sunlight, which would be somewhat impracticable for meats. Issues to consider are possible discolouration of the meat due to high heat at the surface of the product, and OH&S.

Pulsed visible light at wavelengths of 170-2600nm at energies of 0.01-50J/cm² in bursts of one millionth to one tenth of a second has been evaluated for treatment of beef and pork (Mertens and Knorr 1992). At these levels, the surface temperature of the meat rises rapidly and causes thermal inactivation. This treatment has been combined with an ultraviolet (UV) treatment to achieve greater microbial reductions. "PureBright" is a combined pulsed light/UV system reported to give reductions in total viable organisms of 1-3 log (Dunn *et al.* 1995). In this system, the energy was multiplied up using a capacitor, and it delivered several flashes of light per second, allowing fast throughput of product, and low energy usage. The intensity of pulsed white light is about 20,000 times the intensity of sunlight. PureBright (PurePulse Technologies) is owned by Maxwell Laboratories: www.maxwell.com. Unfortunately, at present, they have suspended operations due to financial reasons, and much research is still necessary to evaluate the application of pulsed light treatment in its application to meats.

Pulsed UV-light has been used to inactivate *E. coli* O157:H7 and *Listeria monocytogenes* on salmon fillets (Ozer and Demirci, 2006). About a 1 log reduction was achieved after a treatment time of 60s at 8 cm distance from the surface, with no detrimental effect to the product quality. The researchers used a laboratory-scale unit available from Xenon Corporation, distributed in Australia by Warsash Scientific Pty Ltd.

Suppliers include:

Xenon Corporation

37 Upton Drive

Wilmington, MA 01887-1018

United States of America

Website: www.xenoncorp.com

Warsash Scientific Pty.Ltd

PO Box 1685

Strawberry Hills NSW 2012

Phone: +61 2 9319 0122

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E-Mail: sales@warsash.com.au

Gas plasma

Plasma-based sterilization effectively involves producing controlled lightning by applying microwaves to gases or vapours such as inert gas, oxygen or moisturised air. This results in free moving electrons, ions and neutral particles, which are contained in a field between two plates. Items to be sterilized are passed between these plates, and the contaminating microorganisms undergo intense electron or ion bombardment, so their spore coatings or cell wall materials are eroded, with fatal outcomes (Laroussi 2005).

Early work on ionisation of air showed that the surface of meat could be decontaminated using this kind of technology, and there have been claims of 80% reductions in microbial load on carcasses (Gysin 1986), and that growth was inhibited, resulting in a 1 log difference during storage of beef or pork (Mackey and Mead 1990). Ionisation of the air in a chill chamber could reduce the microbial load of the air, and thus reduce further aerogenous contamination of the stored carcasses, but studies were difficult to repeat and the decontamination effects were difficult to prove.

Recently, stable electron fields have been established as outlined above, and researchers have been able to inactivate cultures of *E. coli* in times ranging from 4.5 seconds to 5 minutes (Maeda *et al.* 2003). The technique is currently being investigated for use in food pasteurisation. It is a clean and environmentally-friendly, non-thermal sterilisation process.

Pulsed electric field

Pulsed electric field (PEF) treatment involves applying a short burst of high voltage to foods between two electrodes, and can be carried out at ambient or at refrigeration temperatures. It is thought that pulsed high-voltage (40kV/cm) stimulation ruptures microbial cell membranes, and decontamination of liquid or semisolid foods such as juices, milk and potato dextrose agar have been successful, achieving reductions of up to 6 log (Zhang *et al.* 1994). The treatment is applied for less than one second, so there is little heating of the food, and it maintains its “fresh” appearance, shows little change in nutritional composition and has a satisfactory shelf-life (Castro *et al.* 1993, Kozempel *et al.* 1998). Microbial reductions of up to 9 log have been achieved in laboratory scale systems using treatments of 2 seconds to 300 seconds, and good results have been achieved in liquids such as water, milk and juices (Qin *et al.* 1995). Some successes have been achieved using pulsed low-voltage (220-380V) stimulation on rabbit meat and chicken legs (Mrigadat *et al.* 1980; Lin *et al.* 1984), but in beef, lamb and pork, no antimicrobial effect has been demonstrated. Further development of the construction of the PEF treatment vessel and the format of the product needs to be considered before this technology could be applied to larger cuts of meat and products, although, for example, an extruded meat paste may be treatable using this technology. Use of the technology in any scaled-up application will need to consider the safety of the equipment, due to the high voltages involved.

Electrical stimulation has long been in use in the meat industry to improve the texture of meat, and some research has been carried out to explore potential antimicrobial effects, as electrically stimulated carcasses seem to exhibit a slower onset of microbial spoilage than those that are not stimulated (Bawcom *et al.* 1995). Artificially inoculated beef steaks were successfully decontaminated using direct application of electrodes to each end of the steak, and reductions in microbial count were improved if the steaks were wetted prior to treatment.

Electromagnetic radiation

Electromagnetic radiation is widely accepted as a method of heating foods prior to consumption, and can cause destruction of bacteria, probably due to heating. Microwave treatment of cooked product can be an acceptable decontamination intervention, but on fresh product, it tends to give uneven heating, and discoloured, partially cooked areas appear. Alternatives include dielectric and infra-red heating.

Dielectric or radiofrequency

Dielectric heating is based on the fact that the oscillation of water molecules produces friction and consequently heat is generated. The word "dielectric" can be used in all the electromagnetic frequencies, including those of the infra-red spectrum, but it is generally accepted that the term "dielectric" is developed at frequencies between 1 and 100 MHz (Hugas *et al.* 2002).

The radiofrequency waves are generated through a device called a magnetron applicator, and essentially the interaction with the food material caused the food molecules to heat themselves – it is not a method of directly applied heat. Therefore, it is important to control the leaks of radiation to avoid interference with radiofrequencies and more importantly for human safety.

Advantages of dielectric heating is that it is more uniform, very precise control of the heating process and less likely to have surface overheating effects causing protein denaturation.

Microwave radiation

Microwaves rely on the same heating principle as radiofrequency but it uses higher frequencies between 300 MHz and 300 GHz. The food safety effects in foods as a result of microwave treatment are probably due to heating effects within the food (Fung and Cunningham 1980). At 915 MHz, the penetration depth of microwaves into red meat reduces as the temperature rises, but at 2450 MHz, the penetration, although much less, is not affected by changes in temperature within the range 5-120℃, and 120 seconds of microwaving will destroy *Salmonellae* (Teotia and Miller 1975), although treatment times of greater than 30 seconds will cause colour changes and partial cooking.

Microwave treatment has been reported to reduce the microbial load in vacuum-packaged beef, when applied to the intact packs for 5-20 seconds (Fung and Kastner 1982; Paterson *et al.* 1995), but other authors have found no significant effects (Kenney *et al.* 1995). The main problems encountered seem to have been uneven heating of the product, and partial cooking of the produce, but research is underway in an attempt to limit the cooking and penetration of the microwaves.

This technology can be used in thawing, heating, cooking, drying and frying of foods. In thawing and/or heating there are significant advantages over the conventional methods as the shortening of the thawing time from hours to minutes, the reduction of the plant space devoted to thawing and the elimination of thawing chambers, an increase in the hygienic conditions and a decrease in the microbial load of the thawed product (Hugas *et al.* 2002).

Infra-red

Unitherm Food Systems manufactures an infra-red pasteuriser for pre-package surface pasteurisation for the control of *Listeria* in RTE products such as roast beef and corned beef. The radiant oven provides a quick surface treatment (45 – 60 seconds) prior to packaging. Published research using this system indicated a 2.15-2.45 log reduction in *Listeria monocytogenes* (Gande and Muriana 2003). The manufacturers recommend using this system in combination with a postpackage pasteurisation system.

Unitherm Food Systems

502 Industrial Road, Bristow, OK 74010, USA

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Email: David Howard: unitherm@unithermfoodsystems.com

Website: http://www.unithermfoodsystems.com/

Electrolysed water

Electrolysed water (EO) is produced by passing a current of electricity through a dilute saltwater solution. One product of the reaction is sodium hydroxide (NaOH), and the other is hypochlorous acid, which has a low pH, contains active chlorine, and has a strong oxidation-reduction potential similar to that of ozone. The properties of EO water can be optimised by increasing the voltage and increasing the salt concentration, resulting in a more acidic solution and higher residual chlorine.

EO has been shown to give good reductions in *Listeria monocytogenes* (4.3-5.2 log) and *Staphylococcus aureus* (1.7-1.9 log) on stainless steel, and in *Campylobacter jejuni* on poultry carcasses (4.9 log) (Kim *et al.* 2005; Ayebah *et al.* 2005a; Park *et al.* 2002).

A USA company markets disinfection fluids, called Primacide A, Primacide B and Primacide C, which are manufactured using an electrolysed water system called Empowered Water™. The different fluids are produced with different pH levels, which have different potencies that can be matched to specific target organisms. Safety approvals for Primacide A and B have been granted by FDA and USDA for use in food processing.

Primacide A is designed for use on beef hides as well as on the carcass immediately following hide removal. The manufacturer has conducted tests in conjunction with USA researchers evaluating the effect of electrolysed water in a model hide washing system (Bosilevac *et al*. 2005b). EO water reduced total aerobic count on hide by 3.5 log, and Enterobacteriaceae counts by 0.9 log. It also reduced *E. coli* O157:H7 prevalence from 82% to 35%. Plain water, by comparison, had no effect on *E.* coli O157:H7 prevalence.

Research by Ayebah *et al.* (2005b) showed that EO water was relatively non-corrosive when applied to common materials used in the food industry (carbon steel, stainless steel, aluminium and PVC).

Electric Aquagenics Unlimited, Inc.

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Fax: 801.443.1029

Website: www.eau-x.com

High pressure processing

High pressure processing (HPP) works by submerging packaged food in a liquid medium (usually water) in an enclosed vessel. The pressure within the vessel is increased either by pumping more liquid into the pressure vessel or by reducing the volume of the pressure chamber. HPP kills microorganisms by interrupting their cellular function without the need for heat. Studies show that the process extends product shelf life by inactivating spoilage organisms. When appropriately used, HPP does not alter the texture, appearance or flavour of foods.

HPP was reviewed by Hugas *et al.* (2002). Pressures of 101 MPa to 1013 MPa have been explored as potential food safety treatments for meat. The effects of extreme pressure on microorganisms are not fully understood, but substantial reductions (> 5 log cycles) in numbers of *Pseudomonas fluorescens*, *Citrobacter freundii* and *Listeria innocua* in ground beef have been demonstrated (Carlez *et al.* 1993), and high pressure treatment slowed the development of spoilage organisms during subsequent storage of ground beef (Carlez *et al.* 1994). Microbial reductions are enhanced when high pressure treatment is combined with mild heating or chilling, but colour changes were observed after 10 minutes of treatment. The use of pulsed high pressure can be more effective than continuous single application, so treatment times can be reduced (Hayakawa *et al.* 1994).

High pressure processing is a very promising technology for ready-to-eat (RTE) meats because there are few barriers to approval by regulatory authorities, no special labelling requirements because no chemicals are used, and if used appropriately there are no changes to texture or flavour of the product. Researchers found that in RTE meats pressure treated at 600 MPa at 20℃ for 180 s, there was no deteriorati on in sensory quality, no difference in

consumer acceptability; a 4 log reduction in *Listeria monocytogenes* in inoculated product and the refrigerated shelf life was extended (Hayman *et al*. 2004). Hugas *et al*. (2002) reported that HPP treatment (600 MPa for 10 minutes at 30℃) could extend the shelf-life of pressure treated food including cooked ham, dry cured ham and marinated beef loins. Avure Technologies markets HPP technology as *Fresher Under Pressure®.*

Avure Technologies Inc.

23500 64th Avenue South

Kent, WA 98032

Website: http://www.fresherunderpressure.com/

Ultrasonics

Ultrasound has various applications in the food industry, including killing or inhibiting bacteria. Historically, the effectiveness of low intensity ultrasound in inactivating bacterial cells has been limited by the protection afforded to the organisms by the food environment. Recently, however, systems with high output of ultrasonic energy at low frequency have greatly increased the lethal effect on bacteria. High power ultrasound – within the frequency range 20-100 kHz and of energy intensity 10-1000 Wcm^{-2} – generates intense pressure, shear and temperature gradients within food that can disrupt the structure of bacteria in the food. The efficacy of the treatment depends more on the intensity of the wave than on the frequency, and as frequency increases, the effect reduces (Sykes 1965). The effect of ultrasound on microorganisms is complex, but the disruption of cell membranes and DNA chains is thought to be mainly responsible for the lethal effect.

Vacuum-packaged meat has been experimentally treated with ultrasound by USA researchers. Whilst the treatment caused an immediate reduction in the numbers of viable bacteria, after five days there was no longer evidence of a significant benefit of the treatment, the microorganisms having recovered and grown back to the same level as in the untreated meat (Pohlman *et al.* 1997). The energy intensity of the system used was low (just 1.55 Wcm^{-2}), and application of much higher intensity – up to 500 Wcm^{-2} – will very likely have a much more dramatic effect on meat bacteria in vacuum packs. Ultrasound could be potentially applied to premium quality, vacuum-packaged meat if an immersion system was used, for example during heat shrinking of the bag in a waterbath.

Ultrasound used in conjunction with chemical treatments can give a synergistic effect (Ahmed and Russell 1975), and ultrasound in combination with mild heat treatment has been investigated for its potential application on vacuum-packed primals. Manothermosonication is the term given to a combination of ultrasonication, increased temperature and increased pressure. Researchers found that as temperature increased, the antibacterial effect of ultrasound decreased. However, if the pressure is increased by only a small amount, this loss of efficacy disappears. It has the overall effect of reducing the bacterial resistance to temperature by 5-20℃, so they are inactivated at lower temperatures (Gould 2001). The process has not yet been commercialised, and little information is available for its efficacy in meats as yet.

Etrema Products Inc

Website: www.etrema.com

Australian Supplier:

Innovative Ultrasonics Pty Ltd

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Castaways Beach

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Chemical Interventions

Chemical interventions involve the application of food grade chemicals to the animal or carcass surface to inhibit or kill microorganisms. Typically, the mode of action of these antimicrobials is by altering the pH of the meat surface, with organic acids, such as lactic or acetic (giving a low pH), being the most commonly used chemicals. The concerns with the use of any chemical intervention process are both the potential to induce resistance in possible human pathogens and the potential to select for resistant organisms out of the overall microbial population – if resistance becomes widespread, more organisms will survive and the process becomes less effective. Other negative aspects of chemicals, both short and long term, are that they can have an occupational health and safety effect on workers, corrosive effects on equipment, and sensory effect on meat.

The efficacy of chemical treatment methods varies depending on the length of time the bacteria have been in contact with the meat surface and whether the bacteria are protected on the surface by fats, small cuts or in hair follicles and the chemical is unable to come into contact with the cell. Also the temperature of the carcass surface, presence of moisture, and solidification of fat surfaces during cooling, are all likely to affect the ability of a chemical treatment to effectively decontaminate a carcass.

In general, chemical intervention steps are applied immediately after dehiding/evisceration but before chilling. The aim is to inhibit further attachment of any bacteria that may have come from the hide or intestines. There are also intervention steps that can be applied before hide removal eg. chemical dehairing/hide washing.

Any chemical applied to meat will be regarded either as a processing aid (where there are no residual effects of the chemical), or as a food additive. Food additives must be declared on the product label.

Processing Aid

The Australia New Zealand Food Standards Code (FSANZ 2006) (Standard 1.3.3) defines a processing aid as “a substance listed in clauses 3 to 18, where –

(a) the substance is used in the processing of raw materials, foods or ingredients, to fulfil a technological purpose relating to treatment or processing, but does not perform a technological function in the final food; and

(b) the substance is used in the course of manufacture of a food at the lowest level necessary to achieve a function in the processing of that food, irrespective of any maximum permitted level specified.”

Food Additive

The Australia New Zealand Food Standards Code (FSANZ 2006) defines a food additive as: “any substance not normally consumed as a food in itself and not normally used as an ingredient of food, but which is intentionally added to a food to achieve one or more of the technological functions specified in Schedule 5.” It or its by-products may remain in the food. Food additives are distinguishable from processing aids (see Standard 1.3.3) and vitamins and minerals added to food for nutritional purposes (see Standard 1.3.2). Food additives must be declared on the package label.

Chemical dehairing

The dehairing process after stunning and sticking results in visually cleaner carcasses and reduces the requirement for trimming faecal contamination. It occurs in a wash cabinet that uses a succession of chemical and water combinations. Scientific studies have shown variable results. Schnell *et al.* (1995) used a chemical solution of 10% sodium sulphide, water washes, and 3% hydrogen peroxide, in an in-plant commercial system, but found that this combination did not significantly reduce the naturally occurring bacterial load (total aerobic bacteria and *E. coli*) on carcasses; Castillo *et al.* (1998) used a similar chemical dehairing process but on small hide pieces (not applied to full carcasses) under controlled laboratory conditions, and found a significant (5 log) reduction in the counts of aerobic bacteria, coliforms and *E. coli*, as well as artificially inoculated *Salmonella* Typhimurium, and *E. coli* O157:H7; Nou *et al.* (2003) ultimately demonstrated that chemical dehairing, as part of

a commercial operation involving other interventions, did contribute to a reduction in incidence of hide-to-carcass contamination with pathogens such as *E. coli* O157:H7.

The implementation of chemical dehairing does have its draw-backs and may not be feasible for industry. A cabinet would need to be incorporated after stunning and shackling of the carcass and this requires an up-front capital investment. A current USA patented in-plant system would require a closed cabinet with an expected dwell time of almost 6 minutes (Schnell *et al.* 1995). There would also be issues dealing with waste both of the sodium sulphide generated (which could possibly be re-used), and also processing of the hydrolysed hair, which could be used as fertiliser. The recommendation (J. Sofos, personal communication) is to kill the animal, rather than stunning it, so that sticking can be delayed until after the dehairing process, as there would be the risk of residues remaining in the meat around the stick wound. This kind of technology may also be relevant for dehairing goats for 'skin-on' export markets; however, there is no published scientific literature supporting this possibility.

An alternative to dehairing all animals is to segregate soiled animals and pay more attention to these particular animals by reducing the line speed while processing and increasing the number of personnel attending these animals.

The equipment proponent in Australia is:

Food Processing Equipment (FPE).

Contact: Shaun Frederick

Address: 878 Main North Road Pooraka South Australia 5095

Ph: 1800 882 549

Fax: 08 8262 5700

Email: shaunf@fpe.net.au

Website: http://www.fpe.net.au/home.html

Chlorine

Chlorine was one of the first chemical treatments to be used for carcass decontamination in the beef industry, and good reductions in microbial count have been achieved using water chlorinated at 200-500 ppm. Unfortunately, such high levels of chlorine are not permitted in the food industry and lower concentrations are not effective.

Water chlorinated to 200 ppm gave 1.5 to 2.3 log reductions in total aerobic bactera on beef carcasses (Kotula *et al.* 1974), but the effects of carcass treatement with solutions of up to 250 ppm chlorine have been variable, with some very poor reductions being reported. For example, Cutter and Siragusa (1995a) reported that sprays of 50, 100, 250, 500, and 900 ppm chlorine were only slightly effective (<1 log reduction in most cases) in reducing two strains of *E. coli* that had attached to the surface of beef carcasses and lean fat tissue. Chlorine at 20-50 ppm was included in a list of approved antimicrobial treatments by FSIS in 1995, but levels above 10 ppm are prohibited in Australia and the EU. Approval would be required if levels above 10 ppm were to be used.

One of the main disadvantages of chlorine is that it is rapidly neutralised by large amounts of organic matter. Therefore, as a hide intervention it cannot be effective because of the large amounts of organic material often attached to hides.

Free chlorine gas, which is used to chlorinate water, is toxic, and chlorine can react with organic compounds to form trihalomethanes (THM) which are carcinogenic compounds (Boorman *et al.* 1999; Richardson 2003). THMs are a group of four chemicals that are formed along with other disinfection by-products when chlorine or other disinfectants react with naturally occurring organic and inorganic matter in water. The trihalomethanes are chloroform, bromodichloromethane, dibromochloromethane, and bromoform. The use of high chlorine levels is not acceptable to EU markets.

Organic Acids

Solutions of organic acids (1-3%) such as lactic and acetic acids are the most frequently used chemical interventions in commercial plants for both beef and lamb dressing. Many other organic acids, however, have been researched either separately or as a mixture for use in chemical washes, including formic, propionic, citric, fumaric, and L-ascorbic acid.

Organic acids have been shown to be most effective when applied as a warm (50-55℃) carcass rinse (Acuff 2005). Unfortunately, the corrosive effect on the equipment seems to increase as the temperature rises. There are conflicting reports as to whether there is greater bacterial inhibition by acetic compared to lactic or citric acid washes. Lactic acid (2%) was shown to reduce *E. coli* O157:H7 on beef carcass tissue by 3.3 log, and 2% acetic acid reduced it by 1.6 log (Ransom *et al.* 2003). These authors also found that lactic acid and acetic acid treatments on cheekmeat, using spray or immersion, resulted in 1.1 log reductions in total bacteria. The lesser reductions were attributed to the physical structure of cheekmeat which may protect microbes from the treatments. Other authors found that lactic acid was ineffective in decontaminating beef tissue under commercial conditions (Gill and Landers 2003). Organic acids (lactic, acetic, and propionic) have been reported to decrease populations of *E. coli* and other bacteria when sprayed on sheep/goat carcasses or used as a wash (Dubal *et al.* 2004; Ramirez *et al.* 2001).

The mechanism of action of organic acids on the microbial cell is not completely understood, but it is hypothesised that it is the undissociated molecule of the acid that is responsible for the antimicrobial activity. There is a lot of variability in the literature in terms of the cited reductions that can be achieved. This is mainly due to differences in the concentrations of the acids used by different researchers, the method of application, and the types of samples tested. There is also some evidence that organic acids may enhance the shelf life of modified atmosphere packaged product, mainly because they increase the lag phase of the microorganisms (Podolak *et al.* 1996).

In the US, organic acids are applied as part of a carcass wash pre-chill and can be applied at levels up to 2.5% of a solution (USDA/FSIS 2004). In addition, lactic acid is approved for use on beef carcasses, sub-primals and trimmings (i.e. pre and post-chill), offal and variety meats at levels up to 5% at temperatures not exceeding 55℃. Organic acids are not permitted under EU regulations, but the USDA has specifically approved lactic acid, acetic acid, and citric acid as antimicrobial agents in the final wash that is applied to livestock carcasses after trimming and inspection but before chilling (21 CFR 101.100 (a) (3): FDA 2003).

Hot carcass surfaces treated with organic acids often display some discoloration of tissue or fat surfaces. However, as with hot water pasteurisation, this often disappears or becomes less evident after chilling. There may be issues with meat surface discolouration, and operators may experience skin/eye irritation when acetic acid is used. Organic acids (acetic and lactic acid) have been evaluated as a method of sanitising beef carcasses in a spray chilling process. The studies found a significant (up to 3 log) reduction in total aerobic count and pathogen populations (Dickson 1991; Hamby *et al.* 1987).

In the literature, there is also mention of the possibility for the use of organic acids to alter the microbial ecology of meat plant environments and potentially that of the beef, and this should be considered when selecting food safety technologies for meat (Acuff 2005). There are also concerns associated with using organic acids in that they may select for the presence of acid-resistant bacteria that may accelerate rates of product spoilage, increase undesirable effects on product appearance, and speed equipment corrosion (Gill 1998).

There are many food-grade acid suppliers in Australia, one larger company being Swift Australia.

Swift Australia (Head Office)

1st Floor, 372 Wellington Rd

Mulgrave, VIC 3170.

Ph: 03 8544 3100

Fax. 03 8544 3299

Website: http://www.swiftco.com.au

Peroxyacetic acids (Peracetic acid)

Peroxyacetic acid functions as an oxidiser and is mainly used as a carcass wash in commercial beef processing plants. Inspexx™ is a 0.02% peroxy acid solution marketed by EcoLab for reducing microbial contamination on processed red meat surfaces. As with other chemicals, there are opportunities for application at the appropriate concentration during spray chilling of carcasses, assuming no unacceptable residues remain on the product (Stopforth 2004).

Under laboratory conditions, researchers have achieved 1.0-1.4 log reductions in *E. coli* O157:H7 inoculated onto beef carcass tissue (Ransom *et al.* 2003b). In a commercial trial, the effect of a solution of 0.02% peroxyacetic acid on chilled beef quarters was investigated at two slaughtering plants (Gill and Badoni 2004). These researchers found little effect on total bacteria or *E. coli* on meat from one of the plants, and no effect in the other plant; a solution of 2 or 4% lactic acid was found to be more effective. A study by King *et al*. (2005) noted that peroxyacetic acid at concentrations up to three times the approved levels result in only minimal reductions (<0.2 log of *E. coli* O157:H7 and *Salmonella* Typhimurium); however, reductions on hot carcass surfaces were marginally better (0.7 log). It was recommended that processors conduct their own in-plant validations for their particular process to ensure its efficacy as an intervention treatment.

Peroxyacetic acid (an equilibrium mix of peroxyacetic acid, octanoic acid, acetic acid, hydrogen peroxide, peroxyoctanoic acid, and 1-hydroxyethylidene-1,1-diphosphonic acid) is approved by FSIS for use on beef carcasses (21 CFR 173.368; FDA 2003). Peroxyacetic acid is not permitted under EU regulations. Peroxyacetic acid requires proper handling such as storage in a cool, well-ventilated area. The approximate cost per beef carcass, in comparison to lactic acid is indicated in Table 3 below (adapted from Reynolds, 2005).

Table 3: Approximate costs for organic acid spray in beef/pork processing plants (A$)

Organic acid	*List price (200 litres)*	*Cost per unit (ml)*	*Cost per litre of solution*	*Cost per carcass**
Lactic Acid (88% food grade) *2% solution = 23 ml + 1 litre H_2O*	$1,063.00	0.5¢	9¢	7¢ (pig) 14¢ (beef)
Peroxyacetic Acid *200 ppm = 2 ml + 1 litre H_2O*	$1,336.10	0.7¢	1.4¢	1.2¢ (pig) 3¢ (beef)

* 8 litres of 2% lactic acid or peroxyacetic acid (180-200 ppm) will treat approximately 10 pigs or 5 beef carcasses.

Peroxyacetic acid (non-patented formula) can be purchased from food-grade chemical suppliers such as Swift Australia. The peroxyacetic-based process approved in the US (21 CFR 173.370) as mentioned earlier is approved for washing, rinsing, cooling, or otherwise processing fresh beef carcasses. The compound mixture must be no more than 0.022% peroxyacetic acid and 0.0075% hydrogen peroxide delivered at a maximum pressure of 1724 kPa and maximum temperature of 50℃ (Inspexx 200, E colab, St. Paul, Minnesota). The supplier in Australia is EcoLab.

Swift Australia (Head Office)

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Ph: 03 8544 3100

Fax. 03 8544 3299

Website: http://www.swiftco.com.au

EcoLab Australia

6 Hudson Avenue

Castle Hill 2154 NSW

Ph: 61-2-9680-5444

Website: http://www.ecolab.com

Acidified sodium chlorite

The antimicrobial activity of acidified sodium chlorite (ASC) is attributed to the oxidative effect of chlorous acid, which is derived from the conversion of chlorite ion into its acid form under acidic conditions. The reactions happen instantly on mixing the sodium chloride with an acid (eg. citric or phosphoric acid) and therefore the antibacterial solution needs to be prepared shortly before spraying.

Some studies have demonstrated a 1.9-2.3 log reduction in *Salmonella* and *E. coli* O157 on beef carcass tissue using a wash/spray of sodium chlorite activated (acidified) with citric acid (Ransom *et al.* 2003b). One laboratory trial showed up to 4.6 log reductions in *E. coli* O157:H7 and *Salmonella* using a water wash followed by an ASC spray (Castillo *et al*. 1999). Other studies indicate limited success (Gill and Badoni 2004).

It appears that the method of activation (i.e. type of acid used), the method of application (eg. sprays), and the contact time with the meat surface are strong influences on the success of this microbial inhibitor. Research using ASC to sanitize beef trim (using SANOVA® system marketed by Alcide Corporation) achieved reductions of 1.4-2.3 log *E. coli* depending on the feed rate of the spray. There is evidence to suggest that ASC may be a long-acting microbial inhibitor and may be suitable for pre-packaged meat. Bosilevac *et al*. (2004b) recently published results using a 300 ppm ASC treatment that reduced total microbial counts by 1.0-1.5 log and maintained desirable organoleptic qualities of the ground beef. SANOVA is available through EcoLab.

Acidified sodium chlorite is approved for use in the US at concentrations between 500-1200 ppm (21 CFR 173.325: FDA 2003). In Australia, FSANZ has made a final assessment for the approval of an application from Alcide Corporation to use acidified sodium chlorite as a processing aid for use on poultry meats, meat and formed meat products at a concentration of 500-1200 ppm. As a result, the Food Standards Code (FSANZ 2006) Standard 1.3.3., Clause 14 permits the use of sodium chlorite as an antimicrobial agent for meat, fish, fruit and vegetables as long as a residual level of chlorous compounds is not detected.

A supplier of acidified sodium chlorite (Grayson Australia) will custom-build a cabinet that is designed for spraying carcasses at the end of dressing but prior to entry into the chiller. Their system mixes the chemicals immediately before application to maximise the oxidising power of the solution. The brand name marketed by Grayson Australia is Vibrex.

Grayson Australia

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Phone: 61 3 8727 6900

Fax: 61 3 8727 6999
Website: http://www.tecnica.com.au/Products.html

EcoLab Australia

6 Hudson Avenue

Castle Hill 2154 NSW

Ph: 61-2-9680-5444

Website: http://www.ecolab.com

Acidic Calcium Sulphate

Acidified calcium sulphate (ACS) works by inactivating bacteria on contact and/or prevents further replication (bacteriostatic effect). As well as effecting decreases in initial counts of any pathogens, this has the potential to extend the shelf life of the treated food and is suitable for applications in ground meat and meat products. Published research studies have concentrated more on the inactivation of bacteria using ACS combined with lactic acid in ground beef (Zhao *et al.* 2004) or with lactic or propionic acid in hot dogs (Nunez *et al.* 2004).

ACS is the basis for commercial food additives called $Safe_2O^{®}$ RTE 01, RTE 03 and ACS 50, produced by Mionix, which consist of a complex blend of calcium hydroxide, sulphuric acid, calcium sulphate and an organic acid (e.g. lactic acid), adjusted to a final pH of ~1.5. Current research using $Safe_2O$ is primarily directed at the control of *Listeria monocytogenes* in processed and ready-to-eat meat products such as roast beef, corned beef and hot dogs.

ACS has received approval in the US (USDA/FSIS 2004). There are minimal organoleptic effects if applied at the concentrations recommended by the manufacturer (see Mionix Corporation website).

Mionix Corporation

4031 Alvis Court, Rocklin, CA 95677

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Email: info@mionix.com

Website: http://www.mionix.com/

Activated lactoferrin

Lactoferrin is a naturally occurring antimicrobial found in milk, saliva and tears, and in trace quantities in meat tissue. A USA company, aLF Ventures, has gained approval for the application of an activated form of lactoferrin (ALF) for carcasses (Activin™). The 'activation' of lactoferrin is a patented process. ALF can be sprayed onto a carcass to help prevent bacterial contamination during processing or it can be applied to a subprimal or finished beef surface prior to final packaging. The recommended level is 2%. It is reported to improve the safety of beef and poultry by interfering with adhesion/colonization, detaches microorganisms from biological surfaces, inhibits multiplication, and neutralizes the activity of endotoxins.

Lactoferrin binds iron and also specifically disrupts cell membranes. Experiments have demonstrated that ALF has activity against a variety of foodborne pathogens such as *E. coli* O157:H7, *Listeria monocytogenes* and *Salmonella*, as well as against spoilage bacteria (Naidu 2000), but there is limited information available on comparative evaluations against other chemical food safety treatments. A recent US study looked at the shelf life of ready-to-eat meat products that were treated with ALF after inoculation with microorganisms, then vacuum-packed and stored at 10-12℃ (i.e. temperatu re abused) for 33 days. The full results are not as yet published in a journal, but the interim report of the study implies that activated lactoferrin is efficacious in inhibiting the growth of *E. coli* O157:H7, *Salmonella* Typhimurium and *Listeria monocytogenes* on vacuum-packaged bologna and beef cuts (Ransom and Belk, 2003a).

ALF is approved for use in the US on beef carcasses at concentrations of up to 2% in water, and its suggested use is as a final rinse following hot water rinsing. There has been interest from the US beef industry and some commercial uptake has occurred. Currently it is not permitted in the EU. Lactoferrin may interfere with effluent treatment through its antibacterial and iron-binding properties.

ALF is manufactured by National Beef Company in the USA (A joint venture between aLF Ventures LLC and DMV International). Contact them via e-mail or the website for further information:

National Beef Company

12200 N. Ambassador Drive, Suite 500

Kansas City, MO 64163

Website: http://www.nationalbeef.com/activinFAQ.stm

Trisodium phosphate

Trisodium phosphate (TSP) is an alkaline cleaning agent that has been used as a household cleaner for many years. It works by disrupting the bacterial cell membrane and causing the contents to leak out, though the exact mechanism is not fully elucidated (Oyarzabal, 2005). Trisodium phosphate solutions are approved for treatment of beef carcasses in the US Code of Federal Regulations (21 CFR 182.1778; FDA 2003).

Research has shown that spray-washing with trisodium phosphate (TSP) reduced contamination of beef brisket, and that it may inhibit bacterial attachment, thereby allowing easier bacterial cell removal by washing (Cabedo *et al.* 1996; Gorman *et al.* 1995; 1997).

A 10% TSP solution has also been trialled for use as an antimicrobial treatment applied to beef trimmings before grinding. Microbial reductions were less than 1 log but there was improved colour stability of ground beef (Pohlman *et al.* 2002). Dickson *et al.* (1994) applied 8-12% TSP solutions at 55℃ to artificially contamin ated meat pieces and recorded reductions of *Salmonella* Typhimurium, *Listeria monocytogenes*, and *E. coli* O157:H7 ranging from 0.8-1.2 log.

Disposal of TSP in effluent is an environmental consideration as it will aggravate eutrophication in ponds and lakes. Eutrophication is the development of excess organic material, e.g. algae blooms, following nutrient (nitrogen or phosphorus) overload. Recycle wherever possible or consult manufacturer for recycling options.

EcoLab Australia

6 Hudson Avenue

Castle Hill 2154 NSW

Ph: 61-2-9680-5444

Website: http://www.ecolab.com

Cetylpyridium chloride

Cetylpyridium chloride is a quaternary ammonium compound and is the active chemical in some human mouthwashes on the market. The antimicrobial activity is due to an interaction of basic cetylpyridinium ions with acidic molecules on bacteria, which subsequently inhibits bacterial metabolism by forming weak ionic compounds that interfere with bacterial respiration. CPC has been shown to be effective for poultry washes at concentrations of 0.5%, giving reductions of up to 2.5 log in *Salmonella* Typhimurium levels, and also reducing cross-contamination (Kim and Slavik 1996). Research by Ransom *et al*. (2003b) and Cutter *et al*. (2000) showed that spray-washing of beef fat with a solution of 1% CPC immediately reduced inoculum levels of *E. coli* O157:H7 and *Salmonella* Typhimurium to virtually undetectable levels, from 5-6 $\log_{10}$ cfu/cm² initial counts. Unfortunately, residual CPC levels after treatment were considered excessive for human consumption. A 0.5% CPC solution has also been trialled for use as an antimicrobial treatment applied to beef trimmings before grinding. Microbial reductions were less than 1 log and there was improved colour during simulated retail display without negatively impacting sensory odour characteristics (Pohlman *et al*. 2002). CPC has also been found to be very effective (almost 5 log microbial reduction after 24 hours) under conditions that simulated the spray-chilling process of beef carcasses (Stopforth *et al.* 2004).

CPC has also been proposed as a hide intervention to be used after stunning and before hide removal. Bosilevac *et al*. (2004a) tested the potential of a combined water wash and 1% CPC treatment under conditions simulating a hide-wash cabinet. Total aerobic bacteria were reduced by 1.5 log on pre-evisceration carcasses. There was no detectable CPC contamination on the chilled carcasses.

CPC has yet to receive approval for use in the US and the EU on beef carcasses. It may first get approval as a hide intervention treatment prior to slaughter. CPC is approved for use in the US to treat the surface of raw poultry carcasses prior to immersion in a chiller (21 CFR 173.375; FDA 2003).

CPC is marketed to the US poultry industry as Cecure™ by Safe Food Corporation.

Safe Food Corporation

4801 North Shore Drive, North Little Rock AR 72118, USA

Phone: 501.758.8500

E-Mail: SafeFoods@SafeFoods.net

Website: http://www.cecure.com/home/home.htm

Ozone

Ozone is a water-soluble, naturally occurring gas which is a powerful oxidising agent. It destroys microorganisms by attacking and oxidising the cellular walls and membranes. Ozone is very unstable, and on exposure to air and water it rapidly decomposes to form oxygen. Hence, it must be generated at the point of use. Ozone is an oxidised form of oxygen and converts readily to ordinary oxygen so there are no residual chemicals generated. However, use of this chemical may elicit oxidation (increased rancidity) of fat and muscle pigments.

Gram positive organisms are more sensitive to ozone than Gram negative, and bacteria are more sensitive than yeasts and moulds. The efficacy of ozone treatment is affected by pH, temperature, relative humidity, concentration, and phase of microbial growth and by the presence of organic material (Sofos and Busta 1991).

Reductions of 2.5 log have been reported on beef tissue using 0.5% ozonated water (Gorman *et al.* 1995), but other researchers have reported reductions of 1.3 log or less (Reagan *et al.* 1996), and Castillo *et al.* (2003) found no difference between a water wash containing aqueous ozone applied to a hot carcass compared to that of water on its own. In a study where ozonated water was used in a simulated hide washing system (Bosilevac *et al*. 2005) there was a reduction of 2.1 log in the total aerobic count on the hides, compared with water alone, which only reduced the total microbial count by 0.5 log. A comprehensive review on the potential applications of ozone treatments for fresh and ready-to-eat red meat products was prepared by researchers at Food Science Australia (MLA 2004).

Recently, researchers at Kansas State University in the US have combined ozone and ionization in a system to reduce pathogens in food processing plants. Essentially, the oxidizing gases are used to fumigate a room, but at levels that are safe and breathable. This research is not yet published.

In Australia, ozone treatment is regarded as a processing aid in the Food Standards Code (FSANZ 2006) Standard 1.3.1, Clause 11. There are currently no restrictions on its use, save that good manufacturing practice (GMP) is followed. Ozone is approved for use in the US on all meat and poultry products in accordance with current industry standards of good manufacturing practice (21 CFR 173.368; FDA 2003).

The Ozone Safe Food website has a cost savings calculator to input data for your process. It is in $US however.

Hi Tech Pacific is the Australian distributor of Delzone™ (marketed by US company Del Ozone). Delzone is an ozone sanitation system that uses ozone-enriched cold water as an antimicrobial for final rinse, no residue surface sanitation of food-contact and non-food contact surfaces. A similar product is produced by the Australian company, Ozone Industries.

Ozone Safe Food

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Applied Ozone Technologies

26 Colrado Court

Hallam Vic 3803

Ph. +61 3 9702 4077

Email: Kevin Finn kevin_finn@bigpond.com

Ozone Industries

PO Box 4556, North Rocks NSW 2151

Phone: (02) 9872 8501

Fax: (02) 9873 3720

Contact: David Hiscock

Email: sales@ozoneindustries.com.au

Website: http://www.ozoneindustries.com.au

Hi Tech Pacific P/L

P.O Box 256 Bentleigh, Vic. Australia

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Email: cdozone@connexus.net.au

Treatments employing carbon dioxide

Carbon dioxide (CO_2) is a colourless, odourless, tasteless and non-flammable gas. The inhibitory effect of CO_2 on pathogens and spoilage microorganisms has been well documented (Guan and Hoover 2005). At the meat surface, CO_2 penetrates the cells, inhibits bacterial enzymes and also disrupts the cell membrane. The inhibitory effect of CO_2 increases as temperature decreases, as the gas becomes more soluble, and the use of increased pressure will improve the penetration of the gas into the cells. Modified atmosphere packaging (MAP) with CO_2 has been shown to be an effective storage technology, but using CO_2 as a means to inactivate microorganisms in foods still requires much research to understand the inactivation mechanisms and the critical parameters (Guan and Hoover 2005). Some authors advocate the use of a small amount of carbon monoxide, CO, in conjunction with the CO_2, which has the added benefit of preserving the red colouration. CO_2 use is permitted around the world, but CO is not permitted in Australia or in the EU.

As an intervention strategy, CO_2 combined with other non-thermal processing technologies such as high pressure and pulsed electric fields have shown some promise (Guan and Hoover 2005). High pressure carbon dioxide (up to 15MPa) has been evaluated, and found to have some success in reducing *Salmonella* numbers in liquids and semi-solid foods (Wei *et al.* 1991). The treatment, however, was applied for 2 hours, and the outcome was very variable between different foods. High pressure CO_2 shows synergistic anti-microbial effect with increasing temperature and decreasing pH (Haas *et al.* 1989).

Sealed Air Corporation

Vic, Ph. 03-9359-2244; NSW, Ph. 02-9721-8900

Qld, Ph. 07-3712-6111; SA, Ph. 08-8283-2300

WA, Ph. 08-9353-5200; Tas. Ph. 03-6224-0415
http://www.sealedair-ap.com/ap/en/contact/locations.html
http://www.cryovac.com/products/food/caseready/default.html

BOC Australia

Phone: 131 262

Fax: 132 427

Website: www.boc.com

Natural antimicrobials

Natural products such as sugar, salt, vinegar, or herbs and spices have long been used to preserve foods and slow the onset of spoilage. Recently, extracts and essential oils of certain plants have been shown to have antioxidant and antimicrobial effects, as well as imparting flavour to foods. Some have shown promise as potential food safety interventions when added to ground beef. Micro-organisms themselves produce substances that are inhibitory to other bacteria, and this property potentially could be harnessed and used in food production. There are also bacteria that prey on other micro-organisms, and bacteriophages, which could be used to prevent spoilage and reduce the risk of food poisoning.

Plant Extracts

Plant extracts have also received a lot of attention for use in meat products due to their antioxidant and antimicrobial activities as well as flavour properties. Such extracts have included garlic, rosemary, clove, and pimento as well as essential oil from *Thymus eigii*, *Picea excelsa*, and *Camellia japonica*. These natural extracts have the potential to be used with other preservation methods to reduce pathogens in ground beef (Zhu *et al*. 2005; Ahn *et al*. 2004).

Microbial Products

Bacteriocins are naturally occurring compounds, such as nisin, that are active against bacteria. Nisin seems to be more effective against Gram positive bacteria and also when used in combination with chemicals such as EDTA. Reductions of 1.8-3.5 log in Gram positive bacteria have been reported (Cutter and Siragusa 1995b). Gram positive bacteria include *Staphylococcus*, *Listeria* and lactic acid bacteria. Gram negative bacteria include *E. coli*, *Pseudomonas* and *Salmonella*. Nisin is approved for use in the US in casings and on cooked ready-to-eat (RTE) meat and poultry products. A blend of encapsulated nisin

preparation (90.9%), rosemary extract (8.2%) and salt (0.9%) is approved for use in frankfurters and other similar cooked meat and poultry sausages.

The cost of extraction of natural antimicrobials can make them expensive particularly when used in complex food systems, and the bactericidal activity can be inhibited by binding of the bacteriocins to food components and inactivation by enzymes such as proteases (Ganzle *et al*. 1999).

A number of lactic acid bacteria have been shown to inhibit pathogen growth in ground beef: for example, *Lactobacillus reuteri* has is a highly effective competitive inhibitor to *E. coli* O157:H7 in ground beef stored under modified atmosphere packaging, and has been responsible for actual reductions of up to 6 log during 20 days storage (Muthukumarasamy *et al.* 2003), while *Lactobacillus plantarum* can reduce the population of *E. coli* O157:H7 by 1.5 log and *Salmonella* by 3 log when added to ground beef before vacuum packaging. Taste panels have indicated that there are no detrimental effects on the ground beef after 5 days storage with the lactic acid bacteria (Smith *et al.* 2005), and there were significant reductions in the numbers of *E. coli* O157:H7 and *Salmonella* in the product. These bacteria naturally produce bacteriocins that are effective against some pathogens such as *Listeria*, *E. coli* O157:H7 and *Salmonella*, and can also be added to cooked meat products as starter cultures, before packaging, to inhibit growth of spoilage organisms.

Bacteriophages and Parasitic Bacteria

Bacteriophages are the viruses of the microbial world – they attack and can destroy their host microorganisms in a similar fashion to how the influenza virus (flu) attacks the human population. Like flu, there are virulent strains and more benign strains. Recently, it has been found that these virulent strains can be purified and used to prevent growth of spoilage and pathogenic organisms in a range of foods, and can reduce shedding of *E. coli* O157:H7 when fed to cattle (Greer 2005). Phages are a natural product, so environmental issues would be minimal, and their host-specificity means that they are safe, as they do not attack the "good bacteria" in the intestine. This specificity, however, also means that their usage is fairly limited in that a phage against *E. coli* would not give protection against *Listeria*, for example. Also, the target microorganisms may develop resistance to the phage through their natural evolutionary process.

Parasitic bacteria, especially *Bdellovibrio bacteriovorus* prey on a range of Gram negative pathogens and spoilage organisms (Hanlin and Evancho 1992). These organisms are present in soil and faecal contents of many species, and can be isolated and purified. Little work has been done on their applications to foods, but *Bdellovibrio* isolates have achieved 2.5 to 7.9 log reductions in *E. coli* and *Salmonella* populations during 7 hours in culture, and 3.0-3.6 log reductions on stainless steel (Fratamico and Cooke 1996), over a period of 24 hours. The organism is most effective at 30-37℃, but betwe en 12 and 19℃, parasitism still occurs, but more slowly (Fratamico and Whiting 1995).

Further information on natural antimicrobials including nisin and protective bacterial cultures can be obtained from:

Danisco Australia Pty. Ltd.

45-47 Green Street, Botany, NSW 2019

Phone: +612 9384 5000

E-mail: info@danisco.com

Website: www.danisco.com.au

Conclusions

A number of current and potential food safety interventions are available to meat processors. Very few are specific to a single foodborne pathogen, most causing an overall reduction in the microbial load on or in the product, and as such result in a decline in the subpopulation representing foodborne pathogens. As an additional benefit, the reduction in microbial load also can contribute to an extension in shelf-life of the product. It is important to note that as microbial numbers are expressed in logarithms, a 90% reduction effectively equates to a 1 log reduction, and a 99% reduction to a 2 log reduction, and also that when initial bacterial numbers drop below 1-2 log, effecting a measurable reduction becomes increasingly difficult. As a result, many researchers advise using a combination of interventions through the production chain, each intervention bringing about a small reduction in bacterial numbers, to achieve low counts on the final product. The disadvantage with this approach is that each intervention has associated costs, space requirement and effluent output, and the overall benefit may be far outweighed by the cost of implementation.

On farm, adherence to good farming practices and the use of some dietary supplements can help to minimise the shedding of foodborne pathogens, while, in the future, vaccination against specific organisms may have a major impact on the incidence of that pathogen in meat.

Prior to slaughter, clipping or shearing can help to reduce microbial contamination of carcasses, and washing of the hide is also a useful intervention. Excessive handling of animals immediately prior to slaughter can, however, have detrimental effects on meat quality, predisposing the carcass to dark cutting (DFD), and hide washing systems utilise large quantities of water, and produce large quantities of effluent.

During dressing, treatments such as, trimming and chilling are currently used and widely accepted around the world, but trimming is very labour-intensive and reduces the overall value of the carcass, through wasted trim, while chilling brings about only slight reductions in microbial count. Hot water or steam pasteurisation are currently the most useful interventions on the dressing line where product is to be sold to the EU, but where the market is the US, and some other countries, treatments such as organic acids or acidified sodium chlorite (ASC) are acceptable.

Following breaking, boning and packing, the use of UV light or ozonation to treat the surface of the product appear to show the most promise, although work on bacteriophages and activated lactoferrin shows that these interventions may be very effective.

At retail level, irradiation would give the greatest reductions in microbial load on a product, and its efficacy on packaged product removes the risk of recontamination, but its use is hampered by unfavourable public perceptions. The use of natural antimicrobials such as plant extracts or colicins in the product would appear to show promise, while high pressure processing may be the treatment of choice for processed meat products.

With all the intervention technologies, the main factors to consider in determining the commercial usefulness of any of the treatments are:

- the method of application and coverage of the meat surface (nozzle size, direction, pressure, slower line speed etc).
- how well the technology suits the current configuration of the process line
- the desired result of the intervention
- the type of carcass, carcass part or meat product to be treated
- the requirements of the customer or the consumer

Further information

There are, in the literature, a number of comprehensive review articles on food safety technologies and strategies that may be effective in producing consistently cleaner meat with minimal contamination. Two of particular note are Huffman (2002), and Koohmaraie *et al.* (2005). There is also a comprehensive book on the subject: “Improving the Safety of Fresh Meat”, edited by J.N. Sofos (2005).

The FSIS has made available on its website information regarding new technologies for use in the production of meat, poultry, and egg products, specifically targeted at assisting small and very small plants.

Website: http://www.fsis.usda.gov/regulations_&_policies/New_Technologies/index.asp).

Also available are ‘New Technology Staff’ who assist in reviewing the technologies that companies intend to use and ensure the technology is consistent with USDA/FSIS regulations.

Website:
http://www.fsis.usda.gov/Regulations_&_Policies/New_Technology_Notification_&_Protocol_Submission/index.asp

Although the above websites are intended for US processors, much of the information is also relevant to Australia, so they are worth a visit.

Listed below are other relevant contact people at Food Science Australia or at Meat & Livestock Australia.

Meat & Livestock Australia

Jenny Sparks

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Level 1, 165 Walker Street, North Sydney NSW 2060
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Free call: 1800 023 100 (Australia only)

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For enquiries regarding novel technologies such as high pressure processing, ultrasonics, UV light, gas plasma, and pulsed electric field.

Appendices

Appendix 1. Suppliers/equipment proponents

Detailed information of each technology can be provided by contacting the relevant supplier/distributor or by requesting any of the reference material cited in this review.

APV Australia (Invensys Companies) National Sales & Service Centre Ph. 1-800-100-278 Email: tony.harris@invensys.com Website: www.apv.com.au
Argus RealCold Ltd 9 Prescott Street, Penrose, Auckland, New Zealand. Ph. +64 9-526-5757 Contact: Graham Dun Website: www.realcold.nz.
Avure Technologies Inc. 23500 64th Avenue South Kent, WA 98032 Website: http://www.fresherunderpressure.com/
BOC Food Safety Company Riverside Corporate Park 10 Julius Ave North Ryde NSW 2113 Australia Ph. 612 8874 4400 Fax. 612 9886 9000 Website: www.boc.com/markets/intervent/index.asp
CHAD Company United States Ph. (800) 444-8360 Fax. (913) 764-0779 E-mail: Rosey Hohendorf – rosey@chadcompany.com Website: www.chadcompany.com

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Website: http://www.ecolab.com

Electric Aquagenics Unlimited, Inc.
1464 West 40 South, Suite 200
Lindon, UT 84042
Ph: 801.443.1031
Fax: 801.443.1029
Website: www.eau-x.com

E-Merge International
10305 102nd Terrace
Sebastian, Florida 32958
Contact: info@verifeye.net
Website: www.emergeinteractive.com/

Etrema Products Inc
Website: www.etrema.com
Australian Supplier:
Innovative Ultrasonics Pty Ltd
441 Wavecrest Drive
Castaways Beach
PO Box 321 Noosa, QLD 4573
Contact: Darren Bates
Phone/Fax: +61 7 5447 5561
E-mail: drdarrenbates@bigpond.com

Food Processing Equipment (FPE).
Contact: Shaun Frederick
Address: 878 Main North Road Pooraka South Australia 5095
Ph: 1800 882 549
Fax: 08 8262 5700
Email: shaunf@fpe.net.au
Website: http://www.fpe.net.au/home.html

Grayson Australia
Contact: Adrian McCarthy
Unit 4, 9 Newcastle Road,
Bayswater. Victoria. Australia. 3153
P.O. Box 134, Bayswater. Victoria. Australia. 3153
Phone: 61 3 8727 6900
Fax: 61 3 8727 6999
Website: http://www.tecnica.com.au/Products.html

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Hi Tech Pacific P/L
P.O Box 256 Bentleigh
Vic. Australia
Tel. 1800 072 777 (Free call)
Fax. 61 3 9596 3437
email: cdozone@connexus.net.au

Jarvis ANZ Pty Ltd
6 Rosa Place, Richlands, QLD 4077
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Fax: 07 3375 3533
Email: sales@jarvisanz.com.au;
Website: www.jarvisanz.com.au

Kentmaster Equipment (Aust) PTY.LTD.
Contact: Bill Smitheram
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Australia
Phl: 07 3806 8400
Fax: 07 3806 7933
Email: Australia@Kentmaster.com;
Website: www.kentmaster.com

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Email: info@mionix.com
Website: http://www.mionix.com/

MPSC Inc.
International Headquarters
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St. Paul, MN 55128
Ph. (651) 222-3647
Fax. (651) 222-4011
Contact: John Marlett John@mpscinc.com
Website: www.MPSCinc.com

National Beef Company
12200 N. Ambassador Drive, Suite 500
Kansas City, MO 64163
Website: http://www.nationalbeef.com/activinFAQ.stm

Ozone Industries
PO Box 4556, North Rocks NSW 2151
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Contact: David Hiscock
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Website: www.ozonesafefood.com.au

Pacific Ozone Technology
California, USA.
Contact: henriks@pacificozone.com
Website: www.pacificozone.com

Realcold Milmech Pty (Aust) Ltd
Colin Giles or Roy Robinson
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PO Box 68, Coopers Plains, QLD4108
Ph: +61 7 3277 0100
Fax: +61 7 3277 0173
Email: sales@realcoldmilmech.com
Website: www.milmech.com

Safe Food Corporation
4801 North Shore Drive
North Little Rock AR 72118
Phone: 501.758.8500
E-Mail: SafeFoods@SafeFoods.net
Website: http://www.cecure.com/home/home.htm

Scantec Refrigeration
360 Lytton Road, Morningside, QLD
Ph: +61 7 3370 6501
Fax: +61 7 3370 6511
Email: sales@scantec.com.au

ScanTech Holdings, LLC
75 Fifth Street NW, Suite 218
Atlanta, GA 30308, USA
www.scantech.com.mx

Sealed Air Corporation

Vic, Ph. 03-9359-2244

NSW, Ph. 02-9721-8900

Qld, Ph. 07-3712-6111

SA, Ph. 08-8283-2300

WA, Ph. 08-9353-5200

Tas. Ph. 03-6224-0415

Email: http://www.sealedair-ap.com/ap/en/contact/locations.html

Website: http://www.cryovac.com/products/food/caseready/default.html

Swift Australia (Head Office)

1st Floor, 372 Wellington Rd

Mulgrave, VIC 3170.

Ph: 03 8544 3100

Fax. 03 8544 3299

Website: http://www.swiftco.com.au

Tri Tech Refrigeration

43-47 Northgate Drive

Thomastown

Victoria 3074

Phone: +61 3 9465 0099

Fax: +61 3 9464 1327

Website: www.ttrerig.com.au

Unitherm Food Systems

502 Industrial Road

Bristow, OK 74010

Tel: 918-367-0197

Fax: 918-367-5440

Contact: David Howard unitherm@unithermfoodsystems.com

Website: http://www.unithermfoodsystems.com/

Zychem Technologies

Contact: Lionel Freedman

Currumbin Valley, Gold Coast QLD

Ph: 07 5533 0092

Email: zychem@quantum-australia.com

Website: http://www.zychem.net/zychem.html

Appendix 2. Quick reference to all food safety technologies discussed

Technology	Documented applications	Treatment time	Approx. microbial reduction	Advantages	Disadvantages, limitations	Regulatory status	Tradename, distributor or proponent
Organic acids (eg, acetic, lactic)	Carcasses, primals, livers, lips, cheekmeat, tongues	10-30 s, depending on T°C	1-3 logs	Applied by spray or immersion. Much literature on effectiveness. Can be used with other interventions	If used on primals, they may be wet for packaging; possible discolouration of lean, organoleptic problems; concerns about acid-resistant pathogens, corrosion of equipment.	USDA approved – 21CFR101.100 Not EU approved	Ecolab-CHAD FPE
Trisodium phosphate	Carcasses, livers, lips, cheekmeat, tongues	10 s	0.7-1.5 logs		May have issues with phosphate removal from effluent and expensive disposal.	USDA approved – 21CFR182.1778 Not EU approved	
Peroxyacetic acid	Carcasses, primals	10 – 30 s	1.4 log	Low concentration	If used on primals they may be wet for packaging; possible discolouration of lean	USDA approved 21CFR173.370; FSANZ – Std 1.3.3 Not EU approved	Ecolab-CHAD (Inspexx®)
Ozonated water	Carcasses, primals	15 – 60 s	1-2 logs	Ozone dissipates quickly	If used on primals they may be wet for packaging; possible discolouration of lean at high concentrations, potential oxidation of fat	USDA approved – 21CFR173.368; FSANZ – Std 1.3.3	Ozone Safe Food Pacific Ozone
Irradiation (gamma rays)	Primals, ground beef	Several mins	2-6 logs	Able to treat packaged food	Expensive to install - central treatment facility only; consumer acceptance issues.	USDA approved – 21CFR179.26 Not EU approved EU consumer rejection	Steritech

Technology	Documented applications	Treatment time	Approx. microbial reduction	Advantages	Disadvantages, limitations	Regulatory status	Tradename, distributor or proponent
Irradiation (electron beam)	Primals, ground beef	Seconds	Up to 4 logs	Able to treat packaged food	Expensive to install - central treatment facility only; consumer acceptance issues.	USDA approved – 21CFR179.26 Not EU approved EU consumer rejection	SureBeam (no longer trading)
Rinse and Chill	Carcasses	10-15 s	0.2-2 logs	Meat quality improvements	Capital outlay	AQIS approved, US, Japan, Korean approvals	MPSC Inc.
High pressure	Primals, ground beef, processed meats	0.5 – 5 min	Up to 4 logs	Increase shelf life by reducing initial microbial count, treat in-pack	Expensive; systems not yet large enough; possible meat colour/texture changes	No particular legislation in US. Required to demonstrate equivalence in EU	Avure Technologies
Pulsed electric fields (PEF)	Ground beef, steaks	<1 s	1 log		Works best for liquids so limited meat applications at present. Commercial development incomplete		PurePulse Technologies (no longer trading)
Pulsed light	Primals	<1 – 10 s	1-3 log	Can be used on packaged product	Probably not suitable for opaque foods; not yet commercially viable for foods		PurePulse Technologies – suspended operations
Ultraviolet light	Meat marinades and brine	10 s- 10 min	Up to 2 logs	Can be used on packaged product	Limited to surface sterilisation or liquids		Safe Food Corporation
Ultrasound	Primals	0.25 – 3 min	0.5-2 logs	Possible to treat VP food.	High power equipment required. Commercial development incomplete		Dr Hielscher, Etrema

Technology	Documented applications	Treatment time	Approx. microbial reduction	Advantages	Disadvantages, limitations	Regulatory status	Tradename, distributor or proponent
Natural antimicrobials (i.e. bacteriocins, nisin, reuterin etc)	Primals, processed meats, ground beef	Residual effect	1-2 logs	Spray application, then VP chilled storage, Used as a surface coating (in alginate).	Some only effective on gram positive microbes.	Not EU approved (Nisin is under consideration) Nisin approved in US	Danisco
Hot water/steam pasteurisation	Carcasses, primals	10-15s at 75-85°C.	1-3 logs	Can use in combination with chemicals for greater effect	If used on primals, they may be wet for packaging; possible discolouration of lean. Recirculation of water may be necessary.	No restrictions, discouraged in the EU Approval required for recirculation of water in Australia and US	FPE, APV (Invensys) CHAD company
Steam Vacuum	Carcasses	Seconds	1-3 logs	Directed at visible contamination	Labour costs, some bleaching of meat survace	No restrictions	Vac San – Kentmaster Australia CV-1 – Jarvis ANZ
Acidified sodium chlorite	Carcasses. Has potential for vacuum packed primals, pork tongues, beef trim, ground meat	Up to 60s	Up to 4 logs.	Not affected by organic load. Possible continual effect on stored product	If using strong acids as the activator, may need to consider storage and operator safety	USDA approved – 21CFR173.325; permitted by FSANZ Not EU approved	Vibrex - Grayson Australia, Zydox - Zychem Technologies, Sanover - Alcide Corporation
Activated lactoferrin	Carcasses, primals, ground beef		0.7-2.5 logs	Can be used on VP beef; natural product. Possible continual effect on stored product	If used on primals, they may be wet for packaging	USDA approval – 21CFR170.36; no specific EU regulation; permitted in Japan and Korea	National Beef Company

Technology	Documented applications	Treatment time	Approx. microbial reduction	Advantages	Disadvantages, limitations	Regulatory status	Tradename, distributor or proponent
Cetylpyridium chloride (CPC)	Carcasses, hide, trimmings	15-30 s at 1% CPC	1.5-2 logs on hides 2.1 logs on beef tissue	Effect on hide maintained up to 4 hrs (1 study); does not impact flavour, texture, appearance, or the odour of foods	Residual levels if used on meat at 1% CPC.	Currently undergoing USDA review Not EU approved	CHAD – wash cabinet Safe Foods Corp (Cecure)
Electrolysed water	Carcasses, poultry, surfaces	Spray or dip	1.5-3 log on inert surfaces 2-2.5 log on poultry	Salt is the only chemical used	Initial capital needed – but may be substantially cheaper than other methods.	FDA and USDA considered safe Awaiting full approval	Primacide - Electric Aquagenics Unlimited
Acidic calcium sulphate	Ground beef, ready-to-eat products			Makes pathogens (*Listeria*) more sensitive to heat eg. during temp abuse/cooking.	An additive not yet approved	Under consideration by USDA Not EU approved	Mionix

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