FEASIBILITY OF USING VASCULAR PERFUSION CHILLING FOR RED MEAT CARCASSES

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ABSTRACT

Meat carcasses must be chilled to below 7°C before leaving the slaughterhouse. Typically cold air is circulated over the surfaces of the carcasses, which can take many hours to reduce centre temperatures to below 7°C. In vascular perfusion chilling (VPC), a cold fluid is circulated through the intact vascular system, offering significant reductions in cooling time.

This paper describes a small feasibility study to evaluate VPC for rapid chilling of lamb carcasses. VPC was found to be capable of rapid initial reduction of carcass temperatures, but uptake of perfusate into the carcasses limited the time for which perfusion treatment could be applied. Samples from carcasses treated with VPC were lighter and more yellow than samples from conventionally chilled carcasses, and had lower shear force values when cooked. This was most probably due to the added water in the meat. Microbial quality of the meat was not significantly affected.

1. INTRODUCTION

EU legislation requires all fresh meat carcasses to be chilled to an internal temperature of 7°C in the deep round before cutting or dispatch (CEC, 1964 and amendments). Research trials have shown that in conventional chillers, average weight beef sides (James & Bailey, 1989), pig carcasses (Brown & James, 1992) and lamb carcasses (Swain & James, 1988) require at least 24 h, 16 h and 10 h respectively to cool to 7°C. Even in rapid chilling systems with low air temperatures such as -31°C, up to 8 h are required for the deep legs in pig carcasses to cool to 7°C (e.g. Tomovic, Petrovic & Dzinic, 2008).

Such slow chilling is inefficient and costly. For 2 day beef chilling, Gigiel & Collett (1989) measured an average weight loss of 1.93%, and an average energy consumption of 0.035 kWh.kg^{-1}. At that time a typical UK carcass deadweight price was £2.15 kg^{-1} and electrical energy cost £0.042 per kWh. Using these figures, the cost of weight loss was 28 times that of the energy used to chill. Perhaps surprisingly, while updating this comparison does alter the ratio, the cost of weight loss still far exceeds that of energy. It is safe to assume that performance of the chillers has not significantly changed, and while beef prices are almost identical at £2.30 kg^{-1} (Meat and Livestock Commission, 2008), energy costs even for small industrial users have only risen to an average of £ 0.076 per kWh (Department for Business Enterprise & Regulatory Reform, 2007). The cost of weight loss based on these figures reduces to 17 times that of the energy used. To put these costs into a wider perspective, European beef carcass throughput for 2006 amounted to 7.3m tonnes (Eurostat, 2008), for which the cost of energy for refrigeration based on the above calculation was €26.0m and the cost of evaporative weight loss was €437.4m.

Faster chilling offers increased throughput within the same floor space, the possibility of continuous rather than batch operation, reduced evaporative weight loss, reduced drip loss and reduced growth of pathogenic or food spoilage organisms on or in the meat. Much experimental work has been carried out throughout the world to reduce chilling times in carcasses (e.g. Robertson *et al.*, 2002, Sheridan, 1990, McGeehin *et al.*, 1999 and Redmond *et al.*, 2000). Most of this work has concentrated on using very low temperatures (-10°C to –70°C) in single or multi-stage air, immersion or cryogenic systems. In all cases substantial reductions in

time were only achieved at the expense of extensive freezing of the surface tissues, which reduces both meat quality and sales appeal. The overriding problem that restricts chilling rates is the poor thermal conductivity of meat coupled with the thickness (300 mm in beef) to be cooled. The use of heat pipes and other high conductivity inserts such as those used by Ketteringham & James (2000) has been found to reduce chilling times by up to 30%, but their introduction is not currently cost-effective.

The effective thickness of the carcass can however be reduced by using the vascular system to circulate a chilling medium through the intact arteries and veins (perfusion). This removes heat from deep within the carcass. A possible implementation for lamb is shown in Figure 1.

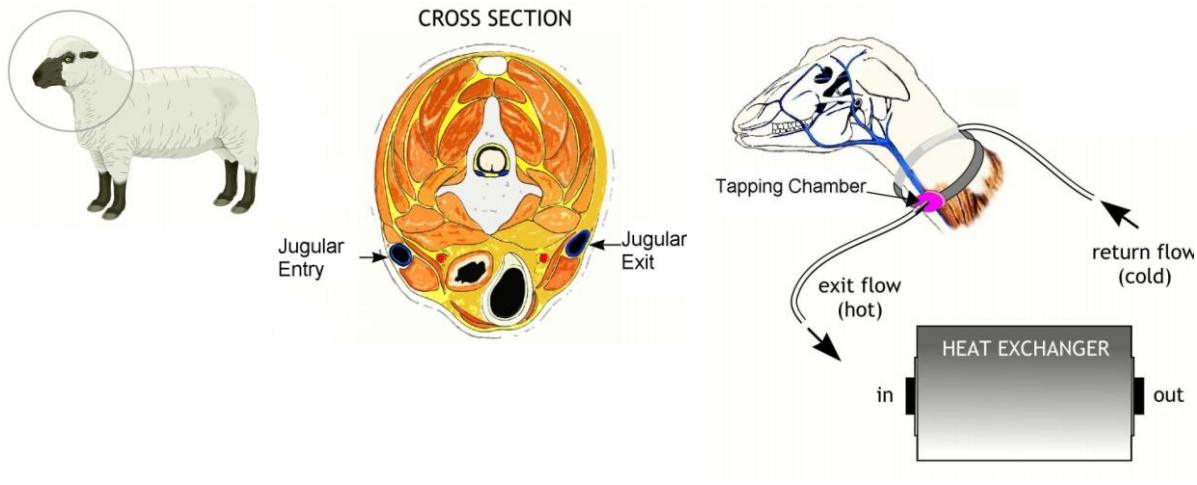

Figure 1. Potential perfusion system for lamb

Vascular perfusion has never been utilised for complete carcass chilling. However, Rinse and Chill™ technology (Meat Processing Service Corporation, Minnesota, USA) which circulates an isotonic solution for limited time periods was developed to enhance pre-rigor bleed out, with a quicker drop in pH and temperature, and thereby achieve better food quality and safety. The process has limited effects on temperature reduction, but improvements in terms of weight loss, microbiology, meat colour and eating quality have been demonstrated (Fiertag & Pullen, 2003 and Wang *et al.*, 1995).

The cooling performance of VPC could be improved either by longer perfusion or by use of more effective coolants. In particular, the use of pumpable ice slurries greatly enhances the cooling capacity per unit volume of coolant due to the latent heat required to melt the ice. The work described in this paper aimed to determine the feasibility of VPC and evaluate its impact on chilling times, evaporative weight losses and meat quality. For ease of handling and to limit costs, lamb carcasses were used for all trials.

2. MATERIALS AND METHOD

2.1 Materials and equipment used

2.1.1 Perfusate production and delivery

The perfusate used was Flo-ice™ (Star Refrigeration Limited, UK), a pumpable suspension of very fine ice particles in a solution of sodium chloride and water. A sodium chloride concentration of 0.9% (similar to that found in blood) and a temperature of -1.3°C were used to give a nominal delivery ice content of 20%. An insulated delivery hose with a small booster pump supplied the perfusate via a specially designed catheter arrangement consisting of the plastic outer sheath from a 10-gauge BD Angiocath (Beckton Dickinson, UK), attached via a Luer connector to 4 mm internal diameter polyurethane flexible hose.

2.1.2 Perfusion method

The catheter was inserted into the left carotid artery and secured in place with surgical suture material. The right jugular was clamped to prevent the perfusate from bypassing the body by going straight through the heart. Once the catheter was attached, the carcass was hung by the hind legs with fleece on in an un-refrigerated holding area. After perfusion, fleeces were removed and the carcasses eviscerated. The control carcasses were de-fleeced and eviscerated and hung in the same un-refrigerated holding area. At a post-slaughter time of 60 minutes, all carcasses were transferred into a chill room with the following nominal conditions - air temperature of 2°C, air velocity 0.5 $m.s^{-1}$ and relative humidity 80%.

2.1.3 Initial trials to determine optimum parameters

Preliminary trials were conducted to determine the main trial parameters. These indicated that long periods of perfusion resulted in significant weight gains due to perfusate uptake, so relatively short durations of 4 and 8 minutes were chosen for the main treatments. They also indicated that uptake of perfusate occurred whether its delivery pressure was relatively high (300 kPa) or low (110 kPa). Analysis of chilling rates indicated that low pressure delivery was insufficient to circulate perfusate to all parts of the carcasses (particularly the legs). Flo-ice™ concentration and temperature were also varied, again with no appreciable effect on uptake. Several carcass variables were explored. Removal of fleece prior to perfusion was found to result in a slight degradation to surface appearance. To minimise uptake and retention of perfusate, orientation of the carcasses was also varied. Normal vertical hanging from the hind legs was found to give the best drainage. An attempt to increase drainage by severing femoral arteries was unsuccessful.

2.1.4 Animals and treatments

Thirty Suffolk cross sheep of approximate live weight 40 kg were electrically stunned and bled according to standard abattoir practices. They were assigned at random to one of three treatments, 4-minute perfusion, 8-minute perfusion or conventional control, to give a total of 10 carcases for each treatment. High pressure (300kPa) was used for both perfusion treatments, giving a typical flow-rate of 0.043 $kg.s^{-1}$ of perfusate.

2.2 Measurements

2.2.1 Temperature

Before chilling, calibrated T-type thermocouple probes were inserted into the legs and loins of each carcass. Each probe consisted of three thermocouples spaced at 1 cm intervals on a thin plastic rod. The probes were connected to Comark EVO N2014 dataloggers (Comark, UK) programmed to record at 60 s intervals.

2.2.2 Weight

Carcasses assigned to perfusion treatments were weighed immediately before perfusion, and control carcasses were weighed at the same corresponding time (approx. 10 minutes post-bleed). Following perfusion, all carcasses were re-weighed. They were weighed again after evisceration and at 24 h after being held overnight in the chill room. The same calibrated abattoir scales were used for all measurements.

2.2.3 Microbiology

Surface samples were removed from the lateral thorax, flank, brisket and breast of one side of each carcass (varied between carcasses) after dressing, but before chilling, using the technique described by Pepperell *et al* (2005). A 5 cm^2 sample from each site was aseptically removed and all four pieces pooled into a sterile stomacher bag. Carcasses were re-sampled at 24 h on the opposite side to the pre-chill sample. Deep tissue samples were removed from the leg and loin immediately before placement in the conventional chill (i.e. after perfusion for the VPC treatments). A 10 x 10 cm area of the loin on one side of each carcass was sterilised using alcohol wipes. A 5 x 5 cm area approximately 2 cm deep was then cut out from within this area using a sterile scalpel, and discarded. A smaller square within this area, measuring approximately 1.5 x 1.5 cm and 0.5 cm thick, was removed using aseptic techniques and added to a sterile stomacher bag.

Samples of 'clean' perfusate and samples of used perfusate draining from each of treated carcass were collected in sterile containers. All samples were stored on ice for brief transport to the laboratory. In the laboratory, 100 ml of maximum recovery diluent (MRD; Oxoid, UK) was added to the excised pieces of surface tissue and 50 ml to the deep muscle tissue samples. Tissue samples were stomached for 1 minute, and perfusate samples vortexed for 1 minute. The resulting diluents were designated the 10^0 samples. These were serially diluted in MRD as required and each dilution plated onto plate count agar (PCA; Oxoid, UK) and violet red bile glucose agar (VRBG; Oxoid, UK) using the 0.1 ml spread plate method. Plates were incubated at 30°C for 72 h (PCA) and 37°C for 24 h (VRBG) with appropriate controls. After incubation all colonies were enumerated on the PCA agar and the dark/pink purple colonies enumerated on the VRBG agar for determination of a total aerobic count and *Enterobacteriaceae*, respectively. Counts were then used to determine the $CFU.cm^{-2}$ or $CFU.g^{-1}$ for each tissue sample or $CFU.ml^{-1}$ for the perfusate.

2.2.4 Appearance

After chilling for 24 hours the m. *longissimus thoracis et lumborum* (LTL) muscle was removed from the left side of each carcass. Two 2.5 cm steaks were cut, placed on a polystyrene tray and over-wrapped with oxygen permeable film, allowed to bloom for 1 h and then measured for surface colour with a Chromameter 300 (Minolta Camera Company, Milton Keynes, UK). Values recorded included the L, a and b values. L represents the lightness of the meat, with greater values indicating lighter meat. The a value is a measure of greenness to redness, the greater the value the more red the sample. The b value is a measure of blueness to yellowness, the greater the value the more yellow the sample.

2.2.5 Texture

The remainder of each sampled LTL muscle was divided into two, placed into a polythene bag and vacuum packed. One sample was placed in a chill room at 1°C and aged for 7 days and the other was immediately placed in a freezer at –20°C. Seven days later the frozen samples were defrosted in air at 3°C. All samples were cooked in their packs to an internal centre temperature of 78ºC by immersion in a water bath at 80ºC. They were allowed to cool and ten 2 x 1 x 1 cm blocks cut from each sample, with fibres parallel to the long axis. These slices were sheared across the direction of the fibre axis using Volodkevitch jaws. Force to first shear was measured using a TA-XT analyser (Stable Micro Systems Ltd, UK.).

2.2.6 Water and sodium content

The bloomed samples of the LTL muscles taken from carcasses at 24 h post slaughter were vacuum packed and frozen. For analysis, they were thawed and minced, taking care to re-incorporate all free water in the pack, after which they were freeze-dried and residual moisture removed in a vacuum oven at 70ºC. Sodium content was measured on an ashed sample of muscle by atomic absorption spectroscopy.

2.2.7 Carcass grade and conformation

External fatness and conformation scores were assessed by the same trained and experienced individual using the EEC carcass classification scheme as described by Kempster *et al.* (1986). Categorised scores were transformed into numerical values for analysis using the values 'U' = 4, 'R' = 3, 'O' = 2 for conformation and '1' = 4, '2' = 8, '3L' = 11, '3H' = 13, '4L' = 15 and '4H' = 17 for fat cover.

2.2.8 Statistical analysis

Data were analysed using Statview statistical software (SAS Institute Inc., USA) to perform analysis of variance (ANOVA) and Fisher's protected least significant difference (PLSD) test for datasets with relatively small numbers of replicates.

3. RESULTS

3.1.1 Temperature

Although limited by the short treatment durations, considerable temperature reduction was achieved by perfusion in the initial hours after slaughter. As time in the chill-room increased, the effect of these reductions diminished (Table 1).

Table 1. Mean times (h) to various temperatures in leg and loin.

Values in columns with different superscript letters are significantly different (P<0.05).

Treatment		Times to temperature (h)							
		20°C		15°C		10°C		7°C	
		Mean	*S.D.*	Mean	*S.D.*	Mean	*S.D.*	Mean	*S.D.*
Control	Leg	2.6[a]	*0.4*	3.8[a]	*0.6*	5.6[a]	*1.0*	7.2	*1.3*
4 min perf	Leg	1.9[b]	*0.2*	3.2[a]	*0.2*	5.1[ab]	*0.4*	6.8	*0.5*
8 min perf	Leg	1.3[c]	*0.4*	2.6[b]	*0.8*	4.6[b]	*0.9*	6.2	*1.2*
Control	Loin	1.5[x]	*0.4*	2.5	*0.7*	3.9	*1.0*	5.1	*1.3*
4 min perf	Loin	1.0[y]	*0.4*	1.9	*0.5*	3.3	*0.6*	4.5	*0.6*
8 min perf	Loin	1.4[xy]	*0.3*	2.1	*0.6*	3.7	*0.8*	5.1	*0.9*

3.1.2 Weight

Weights and percentage weight changes for the perfusion and control treated carcases are shown in Table 2. Weight gain after perfusion was significantly higher for the longer treatment, and weights of carcasses from this treatment retained significantly more weight after evisceration and storage.

Table 2. Weights of treated and control carcasses and change as percentage of initial weight.

Values in columns with different superscript letters are significantly different (P<0.05).

Treatment	Weight (kg) and Change (% of initial weight)										
	After slaughter		*After perfusion*			*After evisceration*			*After 24h*		
	Mean	*S.D.*	Mean	*S.D.*	Change	Mean	*S.D.*	Change	Mean	*S.D.*	Change
Control	36.3	*2.7*				18.4[a]	*1.1*	*50.9*	18.0[a]	*1.0*	*49.6*
4 min perf	35.6	*2.1*	46.6[a]	*3.6*	*130.8*	19.6[a]	*1.6*	*55.2*	19.1[a]	*1.6*	*53.5*
8 min perf	36.9	*2.8*	57.9[b]	*3.9*	*156.8*	23.5[b]	*2.0*	*63.7*	22.5[b]	*1.7*	*60.9*

3.1.3 Microbiology

There were no differences between total viable counts (TVCs) on the pooled surface samples (mean 3.3, *S.D. 0.5* log CFU.cm^{-2}) and in the deep tissue samples taken from the leg and loin before the carcases were placed in the chillroom (mean 1.9, *S.D. 0.7* log CFU.g^{-1}). Mean TVCs in the perfusate leaving the 4 and 8 minute perfused carcases were 3.6 (*S.D. 0.6*) and 3.5 (*S.D. 0.9*) log CFU.ml^{-1} respectively, which were not significantly different. Numbers of *Enterobacteriaceae* on the surface samples and in the deep tissue samples taken from the loin before chilling and at 24 h were below the detection limits for all but two samples (1.4 log CFU.cm^{-2} on one of the control carcass surfaces before chilling, and 2.0 log CFU.cm^{-2} on one of the 4 minute perfusion carcass surfaces at 24 h). Mean numbers of *Enterobacteriaceae* in the perfusate were also mostly below the detection limit, except for three samples for which the maximum count was 2.0 log CFU.ml^{-1}. There was no significant difference between the perfusate from the two treatments.

3.1.4 Appearance

Mean values for colour attributes are presented in Table 3. Samples from carcasses treated with VPC were significantly lighter (represented by greater L values, $P<0.05$) and more yellow (represented by greater b values, $P<0.05$) than samples from conventionally chilled carcasses.

Table 3. Surface colour attributes from Chromameter measurements.

Values in columns with different superscript letters are significantly different (P<0.05).

Treatment	Surface colour values									
	L		a		b		C		h	
	Mean	*S.D.*	Mean	*S.D.*	Mean	*S.D.*	Mean	*S.D.*	Mean	*S.D.*
Control	43.4[a]	*2.0*	16.3[a]	*1.0*	6.7[a]	*0.7*	17.7	*1.1*	22.4[a]	*1.7*
4 min perf	46.8[b]	*1.2*	15.3[b]	*0.9*	7.9[b]	*0.6*	17.2	*1.0*	27.3[b]	*1.1*
8 min perf	46.2[b]	*1.7*	15.9[ab]	*0.9*	7.9[b]	*0.9*	17.7	*1.1*	26.3[b]	*2.1*

3.1.5 Texture

Results from the texture analysis are shown in Table 4. Samples taken at 24 h from carcasses from the 8 minute perfusion treatment were not as tough as those from the other treatments ($P<0.05$). At 7 d, samples from the 8 minute perfusion treatment were still the least tough, but were only significantly different to control samples. Variability within treatment groups was high, particularly in the control group.

Table 4. Forces to first shear of cooked samples at 24 hours and 7 days post mortem.

Values in columns with different superscript letters are significantly different (P<0.05).

Treatment	Force to first shear (kg) and Change (%)				
	At 24 h		At 7 d		Change
	Mean	*S.D.*	Mean	*S.D.*	7d / 24h
Control	10.0[a]	*4.1*	7.1[a]	*4.8*	71.6
4 min perf	9.6[a]	*2.0*	6.1[ab]	*3.0*	63.8
8 min perf	6.8[b]	*1.9*	3.4[b]	*1.4*	50.4

3.1.6 Water and sodium content

Mean water contents were 77.8% (*S.D. 1.6*) for 4 minute perfusion treated samples, 79.6% (*S.D. 1.4*) for 8 minute perfusion samples and 75.9% (*S.D. 1.6*) for controls. Each of these was significantly different to each other ($P<0.05$). Sodium content followed a similar pattern, with means of 686 $mg.kg^{-1}$ (*S.D. 179*) for 4 minute perfusion samples, 937 $mg.kg^{-1}$ (*S.D. 123*) for 8 minute perfusion samples and 456 $mg.kg^{-1}$ (*S.D. 28*) for controls. Again, each of these was significantly different to each other ($P<0.05$).

3.1.7 Carcass grade and conformation

Transformed carcass grades and the grades which these scores represent are presented in Table 5. Statistically, all carcasses had similar conformation, but the controls were perceived to have less fat cover.

Table 5. Scores and grades for conformation and fat cover.

Values in columns with different superscript letters are significantly different (P<0.05).

Treatment	Transformed carcass grades and average for each group					
	Conformation			Fat cover		
	Mean	*S.D.*	Grade	Mean	*S.D.*	Grade
4 min perf	2.5	*0.5*	O/R	10.3[a]	*1.7*	3L
8 min perf	2.6	*0.7*	O/R	12.8[a]	*2.2*	3H
Control	2.5	*0.5*	O/R	8.5[b]	*2.1*	2

4. DISCUSSION

During perfusion, chilling rates were accelerated. However, the uptake of perfusate into the carcasses was such that the duration of perfusion had to be limited to very short applications of just 4 and 8 minutes, which were too short to realise the full cooling potential of the perfusion treatments. Once perfusion was terminated, the differences between treatment and control carcass temperatures began to diminish. Attempts to reduce uptake and allow longer perfusion by lowering supply pressure and flow rate were deemed unsuccessful as it was found that perfusate did not reach all parts of the carcases. However, such 'partial perfusion' may be part of an acceptable combined air chilling and perfusion treatment.

The perfusion treatments produced substantial weight gains due to leakage and uptake of perfusate into the cavity, organs, muscles and fat. Weight gains averaged 30.8% and 57.9% of initial hot weight for the 4 minute and 8 minute treatments. Although much of this was subsequently lost during evisceration and time in the chill-room, the perfused carcasses retained some of the gain at 24 h. Wang *et al*, 1995 found similar results when infusing beef carcasses with amounts of chilled water up to 10% and 20% of liveweight.

Although no significant differences between bacterial counts were found, there were some interesting results. TVCs in the deep tissues of all carcasses prior to their placement in the chillroom were in the 2 log cycle range, i.e. not sterile even in the control carcasses. It was also evident that chilling did not reduce bacterial counts, although multiplication was effectively suspended during the time in the chillroom. TVCs on lamb carcasses either spray or conventionally chilled by Brown *et al* (1993) showed similar behaviour.

As mentioned above, uptake of perfusate was a major problem in these trials, limiting the duration for which perfusion could be applied. Despite these short durations, moisture and salt contents in the perfused muscles were both raised and the effect of duration of perfusion was significant. This suggests that the perfusate as a solution was taken up by the meat, and not just the water it contained.

Several quality traits were apparently affected by the uptake, such as improved (lower) texture values, lighter and more yellow appearance and greater perceived fat cover. The first of these effects may have resulted from a tenderising effect of the added water. A lighter and more yellow appearance in infused lamb carcasses was also observed by Farouk and Price (1994), most probably a result of the increased water content of the meat which tended to produce a more translucent, 'washed out' appearance. Greater perceived fat cover may have resulted from absorption of water or trapping between muscle and fat layers.

The underlying reason for the extensive perfusate uptake was not entirely clear. Pressure is likely to have been the most important factor, although in initial trials with pressure similar to live ovine systolic blood pressures (110 kPa) leakage and uptake still occurred. Other perfusate factors were also found to have little effect on uptake, as was the case for carcass factors such as orientation, clamping of vessels, severing of hind leg vessels and presence of fleece. It was unfortunate that the limited nature of the study did not allow identification of the cause and remedy for this uptake. Without this, the applicability to carcass chilling is questionable, as concluded by Wang et al, 1995. A fundamental study of the problem from a physiological view-point, drawing on experience from the medical and veterinary sectors, is recommended.

5. CONCLUSIONS

A feasible experimental method of perfusion delivery was developed for lamb carcasses. However, uptake of perfusate by the carcasses limited the duration for which perfusion could be applied. This meant that enhanced chilling rates were only possible during the early stages of carcass temperature reduction. In addition, the added water was found to influence appearance and texture. Before commercial use, further study of the underlying reasons for perfusate uptake and its avoidance is required.

6. ACKNOWLEDGMENTS

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