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VASCULAR INFUSION OF BEEF CARCASSES; EFFECTS ON CHILLING EFFICIENCY AND WEIGHT CHANGE

Y.W. WANG[1], D.S. McGINNIS[2], R.R. SEGADO[2] and S.D.M. JONES[2]

1 Department of Food Science and Nutrition, University of Alberta, Edmonton, Alberta, Canada
2 Agriculture Canada Research Station, Lacombe, Alberta, Canada

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INTRODUCTION

Chilling of meat is recognized as an effective means to minimize microbial growth and prolong shelf life. Improvements in chilling technology have traditionally focused on maximizing throughput by reducing chilling time and minimizing processing costs associated with energy consumption and moisture loss from meat during chilling.

EEC regulations require that beef should not be shipped after slaughter until the maximum temperature in the carcass side has been reduced to 7°C (Council of the European Communities, 1964). Thus typically requires 48 hours to 74 hours in conventional, single stage chillers and is associated with substantial shrinkage due to evaporative weight loss from carcass sides. Although rapid chilling using sub-zero air can improve chilling rate and reduce shrinkage, it has high capital and operating costs and may have adverse effects on meat quality due to cold shortening, surface freezing and increased drip loss (James and Bailey, 1989). Water spray-chilling can also be used to reduce shrinkage but the wet carcass surface is likely to be more susceptible to microbial contamination.

Vascular infusion of pre-chilled water or solutions into intact beef carcasses immediately after slaughter can accelerate chilling and increase carcass yield. Heat removal during vascular infusion is very efficient due to the large internal surface of the vascular system and the reduced distance between muscle and chilling medium. Also, high muscle pH in hot carcasses provides improved water holding capacity that can increase yield.

Vascular infusion could also be used to control post-mortem conversion of muscle to meat. Thus, vitamin E could be added to prevent meat rancidity and colour loss while addition of proteolytic enzymes, minerals, amino acids, vitamins and sugars could improve tenderness and flavour (Bradley *et al.*, 1987; Koohamaraie *et al.*, 1988; Asghar *et al.*, 1989; Cunningham and Francis, 1981).

The aim of this study was to examine the effects of various vascular infusion parameters, including water temperature, flow rate and total infused volume on the chilling rate and weight change of carcass sides that are subsequently subjected to conventional air chilling.

MATERIALS AND METHODS

Forty young bulls were slaughtered and divided into two groups. The six animals in the first group were subjected to conventional slaughter and chilling procedures and served as control while the remaining 34 animals were infused with different volumes of pre-chilled water at various temperatures and flow rates.

Whole beef carcasses, fitted with temperature and load sensors, were vertically suspended by means of straps. Animals were slaughtered and bled by severing the jugular veins and a catheter was inserted into the left carotid artery

immediately after bleeding. Chilling medium was pumped through the catheter into the vascular system, while fluid drained from the jugular vein was collected into a receiving vessel where the bulk temperature and total effluent weight were determined. During the infusion tests, the temperature, pressure and flow rate of chilling medium at the carcass inlet and/or outlet locations were electronically recorded. Variations in carcass weight and ambient temperature during each infusion experiment were recorded also. Infusion experiments were conducted at water temperature of 1 and 10°C, medium flow rates from 12 to 17 litres per minute (l/min) and the total amounts of infused water equalled 10 to 20% of the animal live weight. Total infusion times ranged from five to nine minutes depending on the carcass size and medium flow rate.

The temperatures of deep semimembranosus (SM) muscle and centre of longissimus dorsi (LD) at the 12th rib were determined immediately after dressing each carcass (45 minutes after slaughter). Since carcass temperatures remained essentially constant during the dressing period, temperature measurements taken immediately after dressing were considered as representative of post-infusion carcass temperatures.

All left and right carcass sides were weighed after completion of dressing and prior to washing. The sides were then chilled by air at 1°C and 1m/s for 23 hours. During the first six hours in the cooler, carcasses were spray-chilled using a 60-second cycle every 15 minutes (24 cycles). Time-temperature profiles in deep SM muscle and centre of LD muscle at the 12th rib were recorded for each side using a 16-channel MPM 4000, solomat, datalogger. Recorded temperatures were manually verified at three and 24 hours after slaughter.

RESULTS AND DISCUSSION

Effect of total amount of infused medium on carcass temperature

The effect of the total amount of infused water on the temperature fall of LD and SM muscles for carcasses of similar weight is shown in Table 1. Vascular infusion with pre-chilled water reduced LD muscle temperature by about 1.8°C compared with control carcasses. As the total amount of infused water increased from 10 to 20% of animal live weight, the loin muscle temperature decreased an additional 2.3°C. On the other hand, vascular infusion of water to 20% over live weight reduced deep SM muscle temperature by only 1.6°C as compared to 4.1°C for LD muscle, while infusion to a 10% level barely reached the hind limb and had no significant effect on the temperature of deep SM muscle. Since infused water reached the loin muscle shortly after entering the carcass, the LD muscle experienced the greatest chilling effect. However, due to the vertical orientation of carcasses during infusion, water only reached the hind limb portion after about 12% of the live weight had been infused. Thus, the hind limb part of the carcass experienced the least chilling effect since it was exposed to less water over a shorter period.

As shown in Figure 1, 180kg sides from carcasses infused to 20% over live weight with pre-chilled water reached an LD muscle temperature of 7°C in the cooler seven hours faster than control carcasses. However, vascular infusion had little effect on the chilling rate of deep SM muscle.

The increased chilling rate of pre-infused LD muscle in the cooler is probably due to evaporative cooling, since the latent heat required to evaporate moisture from the carcass surface must be lost by the meat. Excess water gained during vascular infusion may continuously migrate to the carcass surface transporting its own sensible heat and contributing to keep the surface wet, thus extending the evaporative cooling period.

The temperature of deep SM muscle was found to rise slightly during the initial chilling period as depicted in Figures 1 and 2. A similar behaviour has been reported by Bendall (1972). This phenomenon is possibly due to generation of heat by anaerobic formation of lactate from glycogen and loss of phosphocreatine (PC) during the early post-mortem period.

Time-temperature curves for infused and control carcasses (180kg per side) can be described with 2.5% accuracy by the following relationships:

LD muscle	Control	$T = \exp(3.717 - 0.1434t)$ (1)
	Infusion	$T = \exp(3.661 - 0.2638t)$ (2)
SM muscle	Control	$T = \exp(3.890 - 0.0729t)$ $(t>3h)$ (3)
	Infusion	$T = \exp(3.832 - 0.0749t)$ $(t>3h)$ (4)

where: T = the muscle temperature
t = post-mortem time.

Time-temperature profiles for SM muscles in Figures 1 and 2 exhibit a characteristic lag period followed by an exponential decay. A similar lag period has been reported by Moerman (1972) for the deep muscle of conventionally chilled beef. This behaviour could be explained in terms of theoretical solutions for the centre of conduction-heat solids. The slight upward curvature of the exponentional portion of these curves suggests a moderate increase in the thermal diffusivity of meat and temperature.

Effect of infused fluid temperature on chilling rate

As shown in Table 2, increasing the infusion temperature from 1 to 10°C resulted in slightly higher LD muscle temperatures 45 minutes post-mortem but had no significant effect on deep SM muscle temperatures. Similarly, the LD muscles in carcasses infused at the lower temperature exhibited a moderately higher chilling rate in the cooler while there was no significant difference for the SM muscle (Figure 2). Considering the small effect of the infusion

temperature on chilling rate, it may be desirable to use the higher temperature (10°C) which is closer to the ideal pre-rigor temperature for prevention of cold-shortening.

Effect of infusion flow rate on carcass temperature

As shown in Table 3, the infusion flow rate had little effect on carcass temperature in either the LD or SM muscle. Similarly, post-infusion chilling curves in the cooler are essentially identical for carcasses that had been subjected to different flow rates as shown in Figure 3. However, since the total amount of infused water was the same (20%) regardless of the flow rate, higher flow rates resulted in proportionately shorter infusion times. From theoretical considerations, the effects of these two parameters can be expected to cancel out since the total amount of heat removed by vascular infusion is proportional to flow rate, and heat transfer rate as proportional to the 0.8 power of flow rate (i.e., as per turbulent flow inside tubes), the total heat removed is only proportional to the -0.2 power of flow rate. Therefore, higher flow rates should theoretically result in slightly less chilling, which agrees with Figure 3.

Effect of vascular infusion on weight changes of beef sides

As shown in Figure 4, water uptake by carcass sides depended on the total amount and temperature of infused water. Carcasses infused with 20% water gained approximately 4% weight compared to control carcasses. Higher infusion temperatures also resulted in increased carcass weights, although the increase was not highly significant. Likewise, the infusion flow rate had only a marginal effect on water uptake within the range tested.

Tracer dye experiments revealed that water gained by carcasses during vascular infusion was predominantly retained in capillaries and the peripheral venous system. This excess water was subsequently lost by evaporation in the chiller. Sides that had been infused with 20% water exhibited shrinkage values ranging from 1.68% during the first 24 hours to 3.7% after six days, as shown in Table 4. Although these values are comparable to evaporative losses of 1 to 2% encountered in ideally controlled chillers (Collet and Gigiel, 1986), net shrinkage was kept at negligible levels since evaporation losses in previously infused carcasses were balanced by the weight gained during infusion. This can have immense economic implications since the cost of evaporative weight losses in a typical beef chilling operation is considerably greater than the energy cost (Collet and Gigiel, 1986).

Vascular infusion proved far more effective at minimizing shrinkage than alternative technologies such as rapid chilling and water-spray chilling. Rapid chilling could only reduce 24-hour shrinkage by 0.3% (Aalhus et al., 1991) while water-spraying for four to 24 hours resulted in reductions of 0.48 and 0.89% respectively (Jones and Robertson, 1989). Neither rapid chilling nor water spraying had any effect on shrinkage after a six-day conditioning period.

CONCLUSION

Vascular infusion of intact beef carcasses immediately after slaughter can substantially reduce or eliminate carcass weight loss and increase cooler chilling rate. The total volume of water infused into carcasses can considerably influence water uptake by muscle while infusion temperature and flow rate have only a marginal effect on water uptake. Vascular infusion can substantially increase the chilling rate of LD muscle but has little effect on deep SM muscle. Although infusion flow rate has little effect on chilling rate due to reduced contact at higher flow rates, high flow rates can increase circulation in the hind limb and have the potential to improve temperature distribution in the carcass side if a suitable infusion time is selected.

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Table 1. Effect of total volume of infused water on carcass temperature (45 minutes after slaughter).

Total infused water at 1°C (%live weight)	Carcass weight (kg)	LD muscle temperature (°C)	SM muscle temperature (°C)
0	596.9 ± 78.0	39.1 ± 0.8	40.2 ± 0.4
10	570.5 ± 13.8	37.3 ± 0.8	39.7 ± 0.6
20	579.3 ± 12.7	35.0 ± 0.5	38.6 ± 0.6

Table 2. Effect of infused medium temperature on carcass temperature (45 minutes after slaughter).

Water temp. (°C) (20%live weight)	Carcass weight (kg)	LD muscle temperature (°C)	SM muscle temperature (°C)
1	579.3 ± 12.7	35.0 ± 0.5	38.6 ± 0.6
10	565.5 ± 13.5	35.7 ± 0.4	38.8 ± 0.8

Table 3. Effect of infusion flow rate on carcass temperature (45 minutes after slaughter).

Water temp (°C) 20%livewt)	Medium flow rate (L/min)	Carcass wt (kg)	LD muscle temp. (°C)	SM muscle temp. (°C)
1	12.0	563.3±20.7	36.3±0.4	39.1±1.0
	14.8	534.6±16.4	34.9±0.8	38.7±0.2
	16.8	560.6±10.4	35.8±0.7	38.5±0.3
10	12.0	535.9±10.0	35.0±0.3	38.9±0.4
	14.8	535.3±11.6	35.8±0.8	39.6±0.2
	16.8	579.0±12.7	35.2±0.5	38.8±0.4

Table 4. Carcass weight loss in the chiller.

Total infused water (%live wt)	Carcass side wt (kg)	24 hours shrinkage (%)	six day shrinkage (%)
20	180.0 ± 10.3	1.68 ± 0.18	3.70 ± 0.31