ELSEVIER

0309-1740(94)00029-8

Meat Science 40 (1995) 193–202
Elsevier Science Limited
Printed in Great Britain
0309-1740/95/$9.50

Chilling Pig Carcasses: Effects on Temperature, Weight Loss and Ultimate Meat Quality

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(Received 9 February 1994; revised version received 15 June 1994; accepted 13 July 1994)

ABSTRACT

Effects of conventional (4°C, *air velocity* 0·5 m/s) *and forced chilling at* –5°C (120 *min*) or –30°C (30 *min*) *with air velocities of* 1, 2 or 4 m/s, *followed by conventional chilling till* 24 h post mortem *on temperatures, meat quality and weight losses, were studied. Experiments were carried out in six batches of six slaughter pigs each (crossbred gilts, weighing* 105–110 kg*).*

The subcutaneous temperature decreased very rapidly to values below 0°C *when 'ultra' rapid chilling* (–30°C) *at high air velocities* (4 m/s) *was used. Immediately after rapid chilling, when the carcasses were railed into a conventional chiller, the subcutaneous temperature increased above the air temperature, after which the decline in temperature was continued. Temperature inside the* biceps femoris *muscle decreased from the start of chilling rather slowly according to an asymptotic curve until ultimate values of* 4°C *were reached. Theoretically calculated temperatures during slaughter and chilling were comparable with the measured values; indicating that a finite-element calculation method in combination with a cylindrical model for heat transport can be used to predict muscle temperatures for various chilling regimes.*

Losses in carcass weight, 24 h *after conventional and forced chilling at* –5°C, *were about* 2%. *After 'ultra' rapid chilling* (–30°C) *the losses were reduced to* 1·3% *when air velocity was increased to* 4 m/s.

Meat quality of the longissimus lumborum *muscle was not significantly affected by the various chilling regimes except for the variables related to tenderness. The Warner–Bratzler shear forces were higher* ($P < 0{\cdot}05$) *together with shorter sarcomere lengths* ($P < 0{\cdot}10$) *after 'ultra' rapid chilling at a high* (4 m/s) *air velocity, indicating an increased risk of cold shortening.*

INTRODUCTION

Heat is withdrawn from carcasses during chilling procedures directly after scalding (van der Wal *et al.*, 1993). Furthermore, it is known that deep leg temperatures in pigs decrease faster with higher air velocities in the chiller (Brown & James, 1992). A lack of information, however, exists about the effects of moderate and various types of forced chilling processes following slaughter, on skin and muscle temperatures, weight loss and ultimate meat quality. Therefore, continuous temperature measurements and theoretical calculations were carried out together with determinations of ultimate pork quality and carcass weight losses caused by chilling. A theoretical model was developed which can be used to predict the effect of heating, followed by various chilling procedures, on the course of carcass temperatures. The predicted temperatures were compared with the experimental results.

MATERIALS AND METHODS

Chilling experiments were carried out in the autumn with six batches of six gilts each. The pigs, crossbreds weighing 105–110 kg, were stunned electrically (350 V, 1·5 s) without the use of a restrainer. The right hind leg was shackled after stunning, before exsanguination started. Scalding was performed at 60°C during 9 min in a scalding-dehairing combination (Nijhuis, Winterswijk, The Netherlands). Temperature measurements (Noronix Digital thermometer NTD 21C; sensor: 5 cm length, 2 mm outside diameter) were carried out in the *M. biceps femoris* (BF) and just below the rind at the same position of the ham, immediately after dehairing. Further measurements on both carcass sides were performed at 45 min *post mortem*. These comprised, additional to those already mentioned, temperatures of the *M. longissimus lumborum* (LL) between the 3rd and 4th lumbar vertebrae and of the *M. semimembranosus* (SM), pH (Schott-Geräte CG 818, D-6238 Hofheim a. Ts. Germany; Ingold Xerolyte pH electrode, type 14) of the LL and SM, and HGP-2 (Hennessy Grading Probe; Hennessy and Chong Ltd., Auckland, N.Z.) measurements for predicting the lean meat percentage, based on fat thickness, and the reflectance of light, in the *M. longissimus thoracis* at 6 cm from the dorsal midline between the 3rd-and-4th-from-last ribs of the left carcass side.

Next, the two halves of each carcass were weighed and transported to the chilling facilities. From each carcass, one randomly chosen side was subjected to a moderate, conventional, chilling regime (0–4°C; air velocity 0·5 m/s). This side was regarded as control. The other side was treated according to a forced chilling regime, which differed per batch. Each batch was subjected to a combination of rapid chilling (–5°C) during 2 h, or ultra rapid chilling (–30°C) during 30 min with an air velocity of 1, 2 or 4 m/s, as measured in the chiller (160 cm above the floor) where normally the carcasses are positioned. The air movement in the chiller was downward.

After forced chilling weight, temperature and pH of all carcass halves were determined, after which chilling (equalization chilling: 0–4°C, 0·5 m/s) was continued till 24 h *post mortem*.The pH and temperature determinations were repeated. Two 2·5 cm thick muscle samples were collected (LL) for further quality deter-

minations. For one of these samples measurements involved water-holding capacity with filter paper (Kauffman *et al.*, 1986), a colour analysis in triplicate (Hunter LS 5000, L^*, a^*, b^*, light source D65, observation angle 10°, opening 30 mm, blooming period 30 min), a six-point subjective quality evaluation (DFD–PSE) based on wetness, colour and texture (van der Wal *et al.*, 1988), marbling according to a 5-point scale (NPPC, 1991), colour with a set of standard models for pork colour (Nakai *et al.*, 1975) and sarcomere length (SL; μm) (Voyle, 1971). The other sample was used for the estimation of drip loss (%) after a 48 h storage period (4°C) on polystyrol foam trays, which were covered with oxygen permeable stretch foil. Cooking loss (%) was assessed by reweighing these loin samples after heating (75°C, 1 h) in polythene bags under vacuum and subsequent cooling. The cooked samples were also used for Warner–Bratzler (W–B) shear force (max. force: *N*) measurements on 10 cores (diameter 1·26 cm) with Adamel Lhomargy DY 20B equipment (speed 100 mm/min).

Per batch continuous temperature registrations of two complementary carcass halves were performed from the start of chilling [conventional (0–4°C) vs forced (–5°C or –30°C) plus equalization chilling] until the moment next day at which the experiment stopped. The temperatures of the two half carcasses were measured at both positions (BF and below the rind). For technical reasons it was impossible to weigh these half carcasses immediately after the short periods of the forced and the parallel running period of conventional chilling. Carcass weights could only be determined before and after the complete chilling process.

Actual temperature curves (data of the continuous registrations of the temperature) were compared with curves derived from a mathematical model.

Temperature calculations

A finite-element method was used to calculate the temperature profiles in the BF, during scalding, from scalding to chilling and during chilling. The thermophysical properties required for these calculations were calculated with the computer programme Costherm (Miles *et al.*, 1983). A cylinder model for heat transport was preferred instead of the model for a flat layer as used to calculate the temperature increase during scalding (van der Wal *et al.*, 1993). In the model the muscle is covered with a fat layer of 1 cm thickness. The radius of the cylinder was 10 cm for the calculations. The effects of evaporation were included in the effective heat transfer coefficients. The heat transfer coefficient and air temperature can be changed after each stage of the cooling procedure, in the calculation program. However, the model can also be used to calculate the heat flow in relation to cooling time and the cooling time to reduce the temperature at a certain place to the required end-point temperature.

Statistics

Variables were analysed separately with a mixed analysis of variance model, e.g. Searle *et al.* (1992). Experimental days and carcasses within days were included as random effects. Control and combinations of wind velocity and temperature were fixed effects in the model. Additionally, a main effect was introduced for systematic differences between left and right carcass halves and for time effects on the control halves for variables measured immediately after rapid chilling (i.e.

30 and 120 min, respectively). Components of variance were estimated by Restricted Maximum Likelihood (REML) (Patterson & Thompson, 1971) with the statistical package Genstat 5 (1987, 1990). Fixed effects were estimated by generalized least squares, employing the REML estimates for the components of variance to evaluate the statistical weights. Test results were based on the Wald test (Buist & Engel, 1992) assuming approximate normality.

In addition to the statistical procedures described above, in some cases (colour scale, visual quality evaluation and marbling) the data of control and treated half carcasses were compared within experiments using a matched pairs Student *t*-test (two-tailed test).

RESULTS AND DISCUSSION

The initial temperature of the right BF muscles appeared to be significantly higher in comparison to the left ones (Table 1), in contrast to the subcutaneous (skin) temperatures which were nearly equal. The differences in muscle (BF) temperature were maintained at the two levels till at least 45 min *post mortem*. Comparable observations were made for the SM muscle, in contrast to the LL, where similar results were found for both carcass sides at 45 min *p.m.* Together with the higher temperatures, the pH-values of the right SM were significantly lower. The differences in both parameters, temperature and pH of the BF and SM muscles can be explained as a consequence of shackling the carcasses on the right hind leg immediately following stunning. These observations agree with

TABLE 1

Mean Values (mean) and Standard Errors (s.e.) of Subcutaneous (just below the rind) Temperatures and Those in the *Biceps femoris* (BF), the *Semimembranosus* (SM) and the *Longissimus lumborum* (LL) Muscles of both Carcass Sides after Scalding and at 45 min *post mortem*, Together with the pH-values (45 min p.m.) of the LL and SM (n = 36)

Carcass side:	*Left*		*Right*		
	mean	*s.e.*	*mean*	*s.e.*	*P*
After scalding, temperature (°C):					
subcutaneous[1]	45·6	0·4	45·9	0·3	NS
BF	40·3	0·1	40·7	0·1	< 0·001
45 min *post mortem*, temperature (°C):					
subcutaneous	29·9	0·5	29·9	0·5	NS
BF	39·9	0·1	40·1	0·1	< 0·001
SM	40·0	0·1	40·1	0·1	< 0·05
LL	39·4	0·2	39·4	0·2	NS
45 min *post mortem*, pH:					
SM	6·50	0·06	6·33	0·06	< 0·001
LL	6·42	0·04	6·44	0·04	NS

[1]After scalding and dehairing only subcutaneous temperatures were measured of the top sides of the carcasses lying on the dehairing table; left: n = 17, right: n = 19).

other data given by Fischer & Augustini (1981) and justified the decision to subject randomly chosen carcass sides to the moderate conventional chilling procedure, which served as a control, while using the complementary half carcasses for the experiments with forced chilling regimes. This procedure enabled us to start the chilling experiments with carcasses at which effects on muscle temperature and pH, caused by shackling, were eliminated. According to the HGP measurements none of the batches scored outside the normal range for carcass composition (leanness). The HGP–PSE reflectance value, however, was somewhat higher in the fourth batch (–30°C, 30 min, 1 m/s), but with no noticeable effect on the quality measurements.

Forced chilling, at either –5°C over 120 min, or –30°C over 30 min, resulted in significant lower skin temperatures compared to conventional chilling (4°C) during corresponding chilling periods (Table 2). These findings for temperature measurements agreed with the continuous registrations depicted in Figs 1, 2 and 3. Subcutaneous temperatures surprisingly, in contrast to those in the muscular tissue, increased significantly when rapid chilling conditions ended and the half carcasses were railed into the conventional chilling chamber. The subcutaneous temperatures increased about 4–12°C, depending on the forced chilling regime, before they decreased further during chilling. This process lasted about 20–60 min. The phenomenon described is caused partly by condensation of moisture (producing heat), present in the conventional chiller (relative humidity 80–90%), on the much colder, rapidly chilled surfaces of those carcasses. On the other

TABLE 2

Mean Values and Standard Errors (s.e.) of Temperatures (°C), Measured Subcutaneously and in the BF, SM and LL Muscles Immediately after Forced (–5°C, 120 min and –30°C, 30 min; air velocity 1, 2 or 4 m/s) and Conventional Chilling (4°C, 0·5 m/s) during Corresponding Periods

	Conventional chilling				*Forced chilling*				
	120 min		*30 min*		*m/s*	*–5°C, 120 min*		*–30°C, 30 min*	
	mean	*s.e.*	*mean*	*s.e.*		*mean*	*s.e.*	*mean*	*s.e.*
Subcutaneous	16·0	0·4	20·4	0·4	1	7·2	0·7	13·0	0·7
					2	8·4	0·7	5·0	0·7
					4	6·2	0·7	4·8	0·7
BF	30·3	0·7	37·8	0·7	1	27·1	0·8	36·9	0·8
					2	26·9	0·8	36·7	0·8
					4	26·3	0·8	36·1	0·8
SM	28·7	0·4	36·8	0·4	1	25·0	0·6	35·6	0·6
					2	23·1	0·6	35·7	0·6
					4	22·0	0·6	34·9	0·6
LL	24·1	0·3	35·1	0·4	1	20·7	0·5	34·0	0·5
					2	15·3	0·5	32·9	0·5
					4	15·5	0·5	31·3	0·5

The differences between forced chilling and the corresponding control (conventional chilling) were highly significant ($P < 0{\cdot}001$) in all situations.

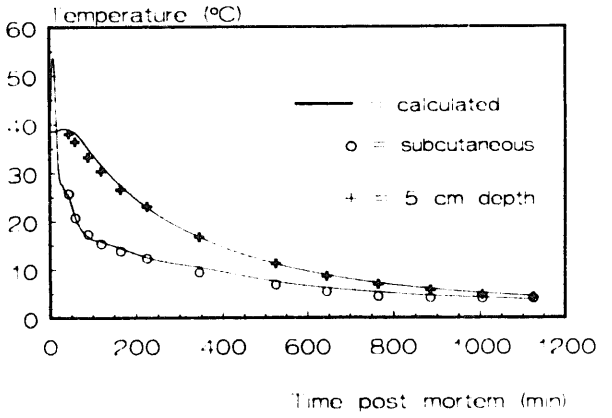

Fig. 1. Calculated (—) and measured (O, +) temperatures during conventional chilling (4°C, air velocity 0·5 m/s) of pig carcasses. The measurements were performed subcutaneously (between the rind and the underlying fat layer) and at a depth of 5 cm in the *M. biceps femoris* of the ham.

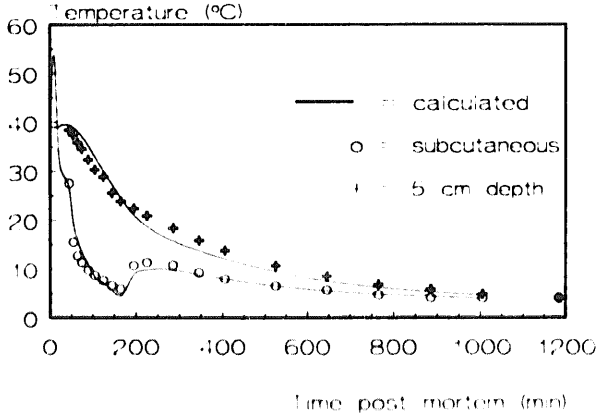

Fig. 2. Calculated (—) and measured (O, +) temperatures during 120 min forced chilling (-5°C, air velocity 2 m/s), followed by conventional chilling of pig carcasses. The measurements were performed subcutaneously (between the rind and the underlying fat layer) and at a depth of 5 cm in the *M. biceps femoris* of the ham.

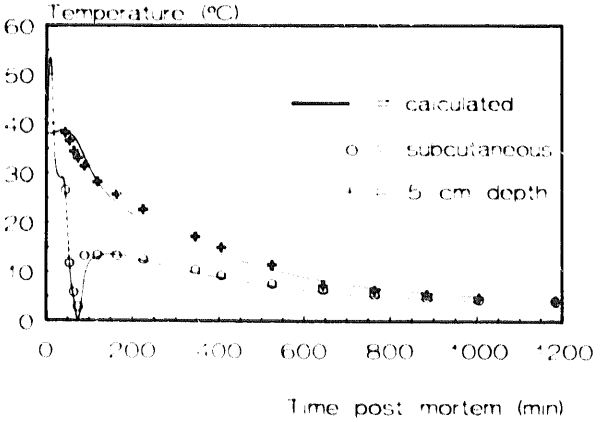

Fig. 3. Calculated (—) and measured (O, +) temperatures during 30 min forced chilling (-30°C, air velocity 1 m/s), followed by conventional chilling of pig carcasses. The measurements were performed subcutaneously (between the rind and the underlying fat layer) and at a depth of 5 cm in the *M. biceps femoris* of the ham.

hand, the steep temperature gradient in the product increased the heat transport to the surface.

The effect of air velocity on chilling efficiency could also be demonstrated by a higher level of significance at increasing air velocities. Furthermore, it has to be noted that freezing of the skin occurred with the higher air velocities at chilling temperatures of –30°C. The effect of forced chilling on muscle temperature was also significant ($P < 0{\cdot}001$) compared to the control carcass halves. Duration of the chilling procedure appeared to be important, as the internal muscle temperatures after prolonged (120 min) moderate (–5°C) chilling were significantly lower (Table 2) in comparison with forced chilling (–30°C) over a shorter period (30 min). An effect of air velocity on the decrease in temperature could only be demonstrated clearly in the LL and SM muscles, but not in the BF muscle. This might be a consequence of the fact that the BF is covered with a fat layer (10–12 mm), reducing the heat transport from the inner part of the muscle tissue to the surroundings. In the conventional chilling process the thickness of the fat layer above the BF appeared to be positively correlated ($r = 0{\cdot}70$) with the temperature in the underlying muscular tissue. The SM and LL muscles are at least partly lacking such a (protecting) fat layer, with a lower thermal conductivity [0·40 W/(m K)].

The average loss in carcass weight was 2% (about 0·9 kg/half carcass) till 20–24 h post slaughter, when conventional chilling (4°C, 0·5 m/s) was applied (Table 3). Comparable results were obtained when initially (120 min) moderate chilling regimes at –5°C were used, irrespective of air velocity (1, 2 or 4 m/s), followed by conventional chilling. After forced chilling (–30°C, 30 min), however, losses decreased with increasing air velocity from about 1·7%, via 1·5–1·3% compared with the control half carcasses ($P < 0{\cdot}001$). This agrees with results of James *et al.* (1983) who found that 'ultra' rapid chilling (–30°C, 4 m/s, 4 h) was advantageous above batch chilling (0°C, 0·5 m/s, 24 h) with a 1% profit.

The reduction in carcass weight loss at higher air velocities can only be obtained at the cost of a considerable increase in kinetic energy. This is because the demand for kinetic energy which is proportional to cubic air velocity, according to: $P_k = \frac{1}{2}QAv^3$, at which P_k: kinetic energy, Q: quantity, A: area, v: air velocity. The lowest weight losses at –30°C and a high air velocity can be

TABLE 3

Carcass Weight Loss (kg, %) after Conventional (4°C) and Forced Chilling at Various Air Velocities (1, 2 and 4 m/s) Either at –5°C (120 min) or at –30°C (30 min), Followed by Conventional Chilling until 24 h *post mortem*

Conventional chilling		*Forced chilling*				
4°C, 24 h			*–5°C, 120 min*		*–30°C, 30 min*	
kg	*%*	*m/s*	*kg*	*%*	*kg*	*%*
0·9	2·0	1	0·9	1·9*	0·7	1·7***
		2	0·9	1·9	0·6	1·5***
		4	0·9	2·0	0·6	1·3***

*$P < 0{\cdot}05$.
***$P < 0{\cdot}001$.

explained by a relatively high amount of water condensed on the cold (below 0°C) surface of the carcass at the start of equalization chilling period. It is known that wetting the carcasses with tap water, once or a few times during the initial period of conventional chilling can have a similar effect on weight loss (Jones & Robertson, 1988; Veerkamp, 1990). This is in line with other studies at which a reduction of the relative humidity in the chiller from 95 to 80% was accompanied by an 0·5% increase in weight loss (James & Bailey, 1986) as a consequence of an increased evaporation of water from the wet carcass' surface.

Only some of the ultimate meat quality characteristics, determined in the LL of the control half carcasses, were significantly different from those of the complementary half carcasses treated according to the experimental conditions. These differences concerned variables related to tenderness, i.e. Warner–Bratzler shear force and, less pronounced ($P < 0{\cdot}10$), sarcomere length and pH (Table 4). Differences for other parameters, e.g. water holding capacity, cooking loss, colour, quality (nearly all samples scored normal) and marbling (all scores for i.m. fat were 1–2, i.e. no or only small traces of fat visible) were negligible, and when significant they only occurred after forced chilling at the highest air velocity (4 m/s).

TABLE 4

Mean Values and Standard Errors (s.e.) of Instrumentally Determined Meat Quality Parameters of the *Longissimus lumborum* Muscle (LL) in Control (conventional; 4°C, 0·5 m/s) and Rapidly (forced) Chilled (−5°C, 120 min or −30°C, 30 min, 1, 2 or 4 m/s) Carcasses

	Control		*Forced chilling*				
	4°C, 0·5 m/s			*−5°C, 120 min*		*−30°C, 30 min*	
	mean	*s.e.*	*m/s*	*mean*	*s.e.*	*mean*	*s.e.*
pH	5·47	0·02	1	5·46	0·03	5·45	0·03
			2	5·51	0·03	5·51	0·03
			4	5·53	0·03*	5·53	0·03
drip	3·9	0·3	1	3·3	0·5	3·7	0·5
			2	3·3	0·5	3·7	0·5
			4	3·0	0·5*	3·5	0·5
cooking loss	30·3	0·2	1	30·4	0·3	30·2	0·4
			2	30·6	0·3	30·4	0·3
			4	30·4	0·3	30·2	0·3
FP (mg)	29·7	2·4	1	25·8	4·7	33·9	4·6
			2	23·7	4·8	28·0	4·6
			4	21·0	4·6	28·3	4·6
Hunter L^*	56·2	0·4	1	55·8	0·6	55·9	0·6
			2	55·9	0·6	56·0	0·6
			4	55·3	0·6	55·5	0·6
W–B shear f.	36·1	1·1	1	37·6	1·8	39·1	1·8
			2	34·0	1·8	35·5	1·8
			4	38·4	1·8	39·9	1·8*
SL	1·71	0·02	1	1·70	0·03	1·70	0·03
			2	1·70	0·03	1·67	0·03
			4	1·66	0·04	1·65	0·03

*$P < 0{\cdot}05$.

In general, the effect of forced chilling on meat quality was smaller than in previous studies (van der Wal & Eikelenboom, 1984). In the latter study muscle (LL) temperature was reduced to about 35°C immediately after slaughter. However, this does not exclude that in practice no negative effects of chilling for tenderness as a consequence of cold shortening can be expected.

The results of the continuous temperature registrations are comparable with the results of the theoretical model for calculating temperature profiles during the complete slaughter process. This means that it is possible to predict the effects on carcass temperatures of different chilling regimes without doing expensive, large scale experiments.

CONCLUSIONS

— Carcass weight losses are less after 'ultra' rapid chilling (–30°C, 30 min) compared to conventional (4°C), or moderate forced (–5°C, 120 min) chilling procedures.
— With the exception of higher Warner–Bratzler shear force values and shorter sarcomere lengths after 'ultra' rapid chilling at higher air velocities (4 m/s), there were no indications of negative effects on meat quality due to various forced chilling procedures.
— Negative effects of cold shortening are indicated by an increased W–B shear force after 'ultra' rapid chilling, especially at higher air velocities (4 m/s).
— With a theoretical model for calculating temperature profiles it is possible to predict the effects of various chilling regimes on temperatures in the muscle in relation to time and place.

ACKNOWLEDGEMENTS

The authors thank Mrs A. H. Hoving-Bolink, Mrs B. Hulsegge, Mr W. Buist, Mr T. C. van Dijk and Mr G. S. M. Merkus for their help during the experiments.

The research was financially supported by the Product Board for Livestock and Meat (PVV), Rijswijk, The Netherlands.

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