A simple, on-line processing method for improving beef tenderness

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Aalhus, J. L., Best, D. R., Costello, F. and Jeremiah, L. E. 1999. **A simple, on-line processing method for improving beef tenderness.** Can. J. Anim. Sci. **79**: 27–34. Traditional beef carcass suspension by the Achilles tendon allows considerable rigor shortening and decreased tenderness in some of the major muscles of the back and hindlimb. To reduce this effect, 60 market-weight (480 ± 42 kg) Hereford Angus cross cattle (30 steers and 30 heifers) of an estimated Canada 1 yield grade were used to compare the effects on meat quality of an on-line altered suspension (OLAS) under CC (2°C for 24 h) and BC (–20°C for 3 h with wind speed of 2.32 m s^{-1}) conditions. Regardless of the rate of chilling, OLAS resulted in significant improvements in shear force in the longissimus thoracis et lumborum and inside round (decreases ranged from 1.13 kg to 2.38 kg in the muscles studied). Longissimus thoracis et lumborum steaks from OLAS sides were rated significantly higher by a laboratory panel for initial tenderness, amount of connective tissue, overall tenderness and overall palatability ($P \leq 0.01$). In addition, compared with conventional suspension, OLAS reduced ($P \leq 0.01$) the proportion of unacceptable scores for initial tenderness (28.3 to 7.5%), overall tenderness (19.2 to 2.5%) and overall palatability (17.5 to 3.3%). Hence OLAS appears to have considerable potential to improve tenderness in the major muscles of the back and hip without compromising the quality of the smaller, contralateral muscles.

Key words: Altered suspension, beef tenderness, blast chilling

Aalhus, J. L., Best, D. R., Costello, F. et Jeremiah, L. E. 1999. **Modification simple de l'accrochage sur la chaîne d'abattage pour améliorer la tendreté de la viande bovine**. Can. J. Anim. Sci. **79**: 27–34. L'accrochage classique des carcasses de boeuf par le tendon d'Achilles a pour effet d'accentuer le raccourcissement des fibres musculaires durant l'état de rigidité et, par là, de diminuer la tendreté de certains des muscles principaux du dos et du quartier arrière. Pour atténuer cet effet, 60 bovins croisés Hereford × Angus (30 bouvillons et 30 génisses) de poids marchand, soit 480 ± 42 kg, de catégorie estimative Canada nº 1, ont été utilisés pour comparer les effets sur la qualité de la viande d'une modification de l'accrochage sur la chaîne (AMC) en conditions de ressuage classique (24 h à 2°C) ou par soufflage (3 h à –20°C sous vitesse du jet d'air de 2,32 m s^{-1}). Quel que soit le taux de ressuage, l'accrochage modifié apportait des améliorations significatives de la force de cisaillement du longissimus thoracis et lumborum (LTL) et de l'intérieur de ronde, soit des diminutions de 1,13 à 2,38 kg dans les muscles étudiés. Les steaks de LTL des demi-carcasses AMC étaient classées significativement plus haut par un jury en laboratoire pour la tendreté initiale, pour la quantité de tissu conjonctif et pour la tendreté et l'appétibilité globales ($P \leq 0{,}01$). En outre, par rapport à l'accrochage ordinaire, la méthode AM diminuait ($P \leq 0{,}01$) la proportion de notations inacceptables pour la tendreté initiale (28,3 à 7,5 %), pour la tendreté globale (19,2 à 2,5 %) et pour l'appétibilité globale (17,5 à 3,3 %). L'accrochage modifié, en anglais OLAS, semble donc offrir de grandes possibilités pour améliorer la tendreté des muscles principaux du dos et de la hanche, sans compromettre la qualité des muscles contralatéraux plus petits.

Mots clés: Accrochage modifié, tendreté de la viande bovine, ressuage par air soufflé

Traditionally, beef carcass sides have been suspended by the Achilles tendon during post-mortem chilling. However, it has been clearly demonstrated that this method of carcass suspension allows considerable rigor shortening and results in a decrease in tenderness in some of the major muscles of the back and hindlimb in beef carcasses (Herring et al. 1965; Hostetler et al. 1972; Jeremiah et al. 1984). Various methods of altered carcass suspension have been attempted (Hostetler et al. 1972; Fapohunda and Okubanjo 1987) and most reports indicate suspending carcasses by the aitch-bone (hip-free suspension) results in longer sarcomeres and improved tenderness in the LTL and hamstring muscles (semimembranosus, semitendinosus) of the hindlimb. However, at the same time, aitch-bone hanging permits increased rigor shortening, which results in increased shear values in the tenderloin (Hostetler et al. 1972).

Despite documented benefits of aitch-bone suspension for improving tenderness, it is not widely used due to the abattoir modifications required to implement aitch-bone suspension and objections to the altered shape of the carcass, which influences the appearance of retail cuts. However, Claus et al. (1993), Wang et al. (1994) and Ludwig et al. (1997) detailed a method of altered suspension (Tendercut™), which consisted of a prerigor cut through the bone and connective tissues at the round/loin junction and through the

Abbreviations: **ALTL**, anterior longissimus thoracis et lumborum; **BC**, blast chilling; **CC**, conventional chilling; **CS**, conventional suspension; **LTL**, longissimus thoracis et lumborum; **OLAS**, on-line altered suspension; **PM**, psoas major; **PLTL**, posterior longissimus thoracis et lumborum; **RF**, rectus femoris; **SM**, semimembranosus

vertebrae and associated connective tissue at the 12th/13th thoracic vertebrae. Severing these tissues permitted the major muscles of the hip and back to assume support for the full weight of the carcass, thereby restricting rigor-related shortening. Based on a limited number of observations, these studies demonstrated improved tenderness through both objective (decreased shear force) and subjective (improved sensory panel ratings) means.

Canada 1 yield grade carcasses comprised 69.1% of the carcasses that were yield graded in 1996 (Agriculture and Agri-Food Canada 1996). These carcasses are lean (fat thickness at the grade site ranging from 4 to 11 mm) and subsequently may be sensitive to cold induced toughening post-mortem. Altered suspension may be able to reduce cold induced toughening in lean carcasses. Therefore, the present study was conducted to investigate the efficacy of a simple on-line altered suspension system to improve tenderness under conventional and rapid chilling regimes.

MATERIALS AND METHODS

Slaughter

The animals used in this study were raised and slaughtered in accordance with the principles and guidelines set out by the Canadian Council on Animal Care (1993). Sixty market-weight (480 ± 42 kg) Hereford Angus cross cattle (30 steers and 30 heifers) of a subjectively estimated Canada 1 yield grade were slaughtered and dressed in the normal commercial manner. After splitting the carcass into sides, we attempted, on the basis of limited descriptive information (Claus et al. 1993), to duplicate the Tendercut™ procedure. Alternate sides of the carcass were used such that one side served as the control (traditional carcass suspension) and one side as the treated side (alternative suspension). A cut was made with a knife to separate the vertebrae (including connective tissue and overlying muscles) between the 12th and 13th thoracic vertebrae such that only the LTL was left to support the weight of the carcass. As well, the pelvic bone was severed with a bone saw, at the narrowest part of the body of the ilium. Since this cut differed from the cut through the body of the ischium of the pelvic bone, described in a later publications by Marriott and Claus (1994) and Claus et al. (1997), we termed our procedure on-line, altered suspension (OLAS) to distinguish it from the Tendercut™ procedure. Thirty of the carcasses (15 steer and 15 heifer carcasses) were conventionally chilled at 2°C for 24 h and the remaining 30 (15 steer and 15 heifer carcasses) were blast chilled (–20°C with a wind speed of 2.32 m s^{-1}) for 3 h prior to chilling at 2°C for the remainder of the 24 h.

Meat Quality

Five muscles were chosen to investigate the extent of the effects of OLAS on the carcass. The ALTL (5th to the 12th thoracic; rib-eye portion) and PLTL (12th thoracic to 4th lumbar vertebrae; loin portion) were chosen to determine whether the effects of OLAS were consistent along the length of the LTL. The PM (tenderloin) was chosen as the contralateral muscle to the ALTL and PLTL. The SM (inside round) and RF (sirloin tip) were chosen as contralateral muscles of the hip, representing the hamstring and quadriceps groups, respectively. Contralateral muscles were selected because changes to the carcass that increase tension in the musculature on one side of the bone are likely to decrease tension in the musculature on the opposite side of the bone. At 45 min and 4 h post-mortem, pH and temperature were measured in the five muscles in both sides of the carcass using a Fisher Scientific Accumet 1002 pH meter equipped with an Ingold electrode (Urdorf, Switzerland). At 24 h post-mortem, carcass side weights were recorded to determine cooler shrink losses and, after grading, pH and temperature values were measured in both the right and left ALTL, PLTL, SM, PM, and RF muscles. The muscles were then dissected from both sides of the carcass. Once removed from the carcass, a steak was cut from each muscle. Objective color measurements were obtained on the freshly cut muscle surfaces after a 20-min bloom time. Three meat color measurements (CIE L* [brightness], a* [red-green axis] and b* [yellow-blue axis] values; [Commission Internationale de l'Éclairage 1978]) were made on all samples using a Chroma-Meter II (Minolta Canada Inc., Mississauga, ON). Small samples (2 g) were removed from consistent locations in the ALTL, PLTL and PM for determination of sarcomere length and fiber diameter. The remainder of each muscle was trimmed of external fat and stored in a polyethylene bag at 2°C for subsequent quality assessment.

At 6 d post-mortem, steaks from the ALTL, PLTL, SM, PM, and RF were removed, weighed onto a polystyrene tray, over-wrapped with oxygen permeable film (8000 mL m^{-2} 24 h^{-1}; Vitafilm Choice Wrap, Goodyear Canada Inc., Toronto, ON) and stored for 4 d at 2°C to determine drip loss. Steaks were also removed from the ALTL and PLTL, vacuum packaged and frozen (–35°C) for subsequent taste panel analysis. An additional steak was removed from all muscles for ultimate pH, temperature, and objective color as described previously. After these measurements were obtained each steak was cut into three equal pieces (approx. 5 cm × 5 cm × 2.5 cm) and placed in beakers containing 100 mL of a 0.9% saline solution. Samples were cooked to an internal temperature of 72°C (monitored with a Fisher Scientific digital thermometer) in an 80°C water bath (Blue M Electric Company, Blue Island, IL) similar to water-bath cookery methods described by Møller (1980–1981) and Weber et al. (1988). Cooked samples were cooled on ice, transferred to sealed containers and stored overnight at 2°C. A single round core, 19 mm in diameter, was removed parallel to the muscle grain from the center of each sample. Individual peak shear force values were determined on each core (perpendicular to the muscle grain) with an Instron 4301 Material Testing System (Burlington, ON) equipped with a Warner-Bratzler cell. Crosshead speed was set at 200 mm min^{-1}.

Sarcomere Length

Two grams of fresh muscle were hand-minced with a surgical blade, avoiding connective tissue and large fat deposits. The rough-minced sample was added to 10 mL of a suspension solution (0.25 M sucrose, 0.02 M EDTA, 0.1 mM sodium azide) and scissor-minced. An additional 10 mL of

Table 1. The effect of OLAS on quality traits of individual muscles

	ALTL		PLTL		PM		SM		RF			Probability	
	CS	OLAS	CS	OLAS	CS	OLAS	CS	OLAS	CS	OLAS	SEM	SUSP	SUSP × MUSC
pH													
45 min	6.68	6.68	6.64	6.63	6.24	6.25	6.58	6.60	6.66	6.66	0.023	–	–
4 h	6.22*b*	6.40*a*	6.26	6.29	5.88	5.87	6.09	6.08	5.94	5.97	0.023	***	***
24 h	5.60	5.63	5.57	5.57	5.59	5.60	5.50	5.49	5.62	5.61	0.012	–	–
6 d	5.52	5.55	5.51	5.51	5.60	5.62	5.50	5.48	5.63	5.61	0.012	–	–
Temp (°C)													
45 min	38.9	38.7	38.8	38.8	39.0*b*	39.5*a*	39.5	39.6	38.9	38.7	0.098	–	***
4 h	16.0*a*	9.4*b*	14.6	15.2	12.4*b*	13.8*a*	19.0	18.4	21.6	21.2	0.408	***	***
24 h	3.7	3.3	4.4	4.2	4.6	4.1	5.6	5.4	7.1	6.4	0.103	***	*
6 d	4.1	3.7	3.8	3.7	4.9	4.8	4.0	3.9	4.3	4.1	0.11	***	–
Minolta (24 h)													
L*	36.1	35.8	37.0	37.1	37.1	36.4	35.9	36.5	43.2*a*	42.2*b*	0.251	–	***
Hue angle (°)	21.0	21.1	22.3	22.5	21.3	21.0	24.5	24.6	24.7	24.1	0.213	–	–
Chroma	18.1*b*	18.8*a*	18.9*b*	19.6*a*	20.2	20.2	20.4	21.0	22.3	21.8	0.218	**	**
Minolta (6 d)													
L*	37.9	37.8	37.8	38.3	38.7	37.0	38.6	38.7	41.7	42.0	0.245	–	–
Hue angle (°)	24.7	24.6	24.6	24.9	24.3	23.8	27.4	27.4	25.3	25.7	0.193	–	–
Chroma	21.7	22.3	20.8	21.7	22.2	22.1	25.1	25.0	23.1	23.3	0.216	**	*
Drip loss (g 100 g^{-1})	4.54	4.50	5.47	5.28	7.13	6.61	5.58	5.47	5.54	5.41	0.114	***	–
Sarcomere length (μm)	1.69	1.76	1.62	1.66	1.73	1.81	–	–	–	–	0.029	***	–
Sarcomere diameter (μm)	61.5	62.0	64.4	63.1	52.0*b*	55.9*a*	–	–	–	–	0.73	*	***

a,b Values within the same muscle and row bearing different letters are significantly different ($P \leq 0.05$).
***, **, * $P \leq 0.01$, $P \leq 0.05$ and $P \leq 0.10$, respectively.

solution was added, and the mixture was homogenized (10 s, 5000 rpm, Brinkman Polytron PT 10/35, using a 12-mm × 160-mm saw-tooth generator). Two drops (approx. 100 μL) of homogenized sample were mounted on a microscope slide and sarcomere lengths and fiber diameters were determined on a Zeiss Axioskop microscope at 1250× magnification using an American Optical micrometer eyepiece. Twenty sarcomere lengths and 10 fiber diameters were recorded for each sample.

Sensory Evaluation

Previously cut and individually vacuum-packaged ALTL and PLTL steaks were removed from the freezer, weighed and placed in a refrigerator to thaw for 24 h. Fifteen minutes prior to grilling, the steaks were removed from the refrigerator and weighed to determine thaw losses and raw muscle weights. Temperature probes were inserted horizontally to the mid-point along the long axis of the steak. Steaks were placed on a commercial electric grill (average surface temperature 130°C) and heated to an internal temperature of 40°C. Steaks were turned and cooked to a final internal temperature of 72°C. After cooling for 10 min, cooking losses were determined by weight difference. Each steak was cut into 1.3-cm cubes, avoiding connective tissue and large areas of fat. Six cubes from each sample were randomly assigned to a six-member trained sensory panel, screened according to established guidelines (American Meat Science Association 1995). Samples were placed in glass jars in a circulating water bath and allowed to equilibrate to 70°C prior to evaluation. Each sample was evaluated for initial and overall tenderness, amount of perceptible connective tissue, juiciness, and flavor intensity, using nine-point descriptive scales (9 = extremely tender, no perceptible connective tissue, extremely juicy, and extremely intense beef flavor; 1 = extremely tough, abundant connective tissue, extremely dry, and extremely bland beef flavor). In addition, each sample was evaluated for flavor desirability and overall palatability using a nine-point hedonic scale (9 = extremely desirable, 1 = extremely undesirable). All panel evaluations were conducted in well-ventilated, partitioned

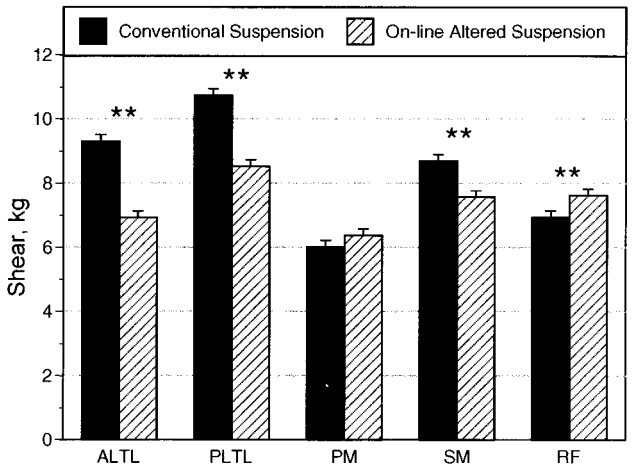

Fig. 1. Changes to shear force under different suspension conditions in the ALTL, PLTL, PM, SM and RF. ** indicates a significant difference ($P \leq 0.05$) between suspension treatments within a muscle.

Table 2. Least-squares means for cooking and palatability properties[z] of LTL steaks subjected to different suspension conditions

	CS	OLAS	SEM	*P*
Initial tenderness	5.13	5.78	0.069	<0.001
Juiciness	5.75	5.78	0.050	0.776
Flavour desirability	6.04	6.10	0.036	0.341
Flavour intensity	5.94	5.91	0.030	0.474
Amount of connective tissue	6.77	7.13	0.036	<0.001
Overall tenderness	5.38	6.09	0.063	<0.001
Overall palatability	5.35	5.83	0.050	<0.001
Cook loss, (g 100 g^{-1})	26.80	26.36	0.314	0.279
Drip loss, (g 100 g^{-1})	4.33	3.86	0.075	0.004
Cook time, (min g^{-1})	0.103	0.097	0.0021	0.056

[z]Evaluations for initial and overall tenderness, amount of perceptible connective tissue, juiciness, and flavour intensity, used 9-point descriptive scales (9 = extremely tender, no perceptible connective tissue, extremely juicy, and extremely intense beef flavor; 1 = extremely tough, abundant connective tissue, extremely dry, and extremely bland beef flavor). Evaluations for flavor desirability and overall palatability used a nine-point hedonic scale (9 = extremely desirable, 1 = extremely undesirable).

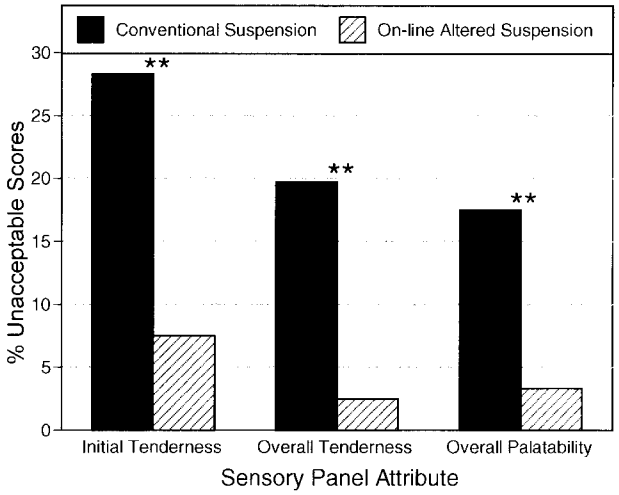

Fig. 2. Proportion of unacceptable initial tenderness, overall tenderness and overall palatability sensory panel scores (≤4.5) under different suspension conditions. ** indicates a significant difference ($P \leq 0.05$) between suspension treatments.

booths, under 882 lx of incandescent and fluorescent white light. Distilled water and unsalted soda crackers were provided to purge the palate of residual flavor notes between samples (Larmond 1977).

Statistical Analysis

Prior to analysis, meat color a* and b* measurements were converted to hue (H_{ab} = arctan[b*/a*]) and chroma (C_{ab} = $[a^{*2} + b^{*2}]^{0.5}$). All quality and taste panel data were analyzed using the multiple linear regression subset of the General Linear Model computer algorithm of the SAS Institute, Inc. (1990) using the following model:

$$Y = \mu + \text{CHILL} + \text{CARC(CHILL)} + \text{SUSP} + \text{SUSP} \times \text{CHILL} + \text{SUSP} \times \text{CHILL(CARC)} + \text{MUSC} + \text{MUSC} \times \text{CHILL} + \text{MUSC} \times \text{SUSP} + \text{MUSC} \times \text{CHILL} \times \text{SUSP} + \varepsilon$$

where CHILL = blast or conventional; SUSP = on-line altered suspension or conventional; MUSC = ALTL, PLTL, PM, SM or RF for quality data; ALTL, PLTL or PM for sarcomere length and fibber diameter data; ALTL or PLTL for sensory panel data; CARC = individual carcasses.

Linear contrasts with one degree of freedom were used for means separation ($P \leq 0.05$). As well for the sensory panel data, a secondary analysis was performed to assess the frequency of unacceptable ratings for the LTL steaks. The frequency of unacceptable ratings for steaks (panel scores ≤4.5) were analyzed using chi-square tests to determine their probability of being influenced by suspension conditions and chilling regimes.

RESULTS AND DISCUSSION

The Effect of On-line Altered Suspension

There were no significant chill-by-suspension interactions; however, as expected, the influence of OLAS varied depending on the muscle sampled (Table 1). The subtle changes in carcass configuration as a result of OLAS resulted in a decrease in ALTL temperature and a slight increase in PM temperature at 4 h post-mortem. Only the decrease in temperature in the ALTL resulted in elevated pH (0.18 units). Although these temperature and pH changes were significant ($P \leq 0.01$), it is unlikely they made a major contribution to the large differences in shear force observed in certain muscles. Similar to the results of the Tendercut™ procedure reported by Ludwig et al. (1997), OLAS significantly reduced shear force in the ALTL and PLTL in the present study (Fig. 1). In addition, OLAS also significantly reduced shear force in the SM. However, OLAS resulted in a significant increase in shear force in the RF (contralateral muscle to the SM), in contrast to the results of the Tendercut™ procedure described by Marriott and Claus (1994) and Claus et al. (1997). The different location of the cut in the pubis bone between the two studies likely caused these differences.

The improvements in shear force in the back (ALTL and PLTL) and inside round (SM) muscles were large, ranging from a 1.13-kg decrease in the SM to a 2.38-kg decrease in the ALTL. In contrast, the contralateral muscles increased in shear force by only 0.35 kg in the PM and 0.68 kg in the RF. Using the present methodology, a difference of 1 kg of shear force is on the borderline for consumer detection (Jeremiah, unpublished data). Therefore, the decreases in shear force in the ALTL and PLTL should be easily detectable and the increased shear in the PM and RF would likely be undetectable. In fact, when assessed by the sensory panel, steaks from OLAS sides (over both ALTL and PLTL locations) were rated significantly higher for initial tenderness, amount of connective tissue, overall tenderness and overall palatability ($P \leq 0.01$; Table 2). More importantly, the proportion of unacceptable scores for initial tenderness, overall tenderness and overall palatability were significantly reduced in OLAS steaks (Fig. 2). Unacceptable initial tenderness scores decreased from 28.3 to 7.5%, unacceptable overall tenderness scores decreased from 19.2 to 2.5% and

Table 3. The effect of BC on quality traits of individual muscles

	ALTL		PLTL		PM		SM		RF			Probability	
	CC	BC	CC	BC	CC	BC	CC	BC	CC	BC	SEM	CHILL	CHILL × MUSC
pH													
45 min	6.62	6.73	6.60	6.68	6.17	6.33	6.58	6.61	6.60	6.72	0.023	***	*
4 h	6.17*b*	6.45*a*	6.19*b*	6.35*a*	5.80*b*	5.95*a*	6.04*b*	6.13*a*	5.88*b*	6.03*a*	0.023	***	***
24 h	5.61	5.62	5.54*b*	5.60*a*	5.63*a*	5.56*b*	5.48*b*	5.51*a*	5.66*a*	5.57*b*	0.012	–	***
6 d	5.55	5.53	5.50	5.52	5.66*a*	5.56*b*	5.49	5.49	5.66*a*	5.58*b*	0.012	***	***
Temp (°C)													
45 min	38.8	38.8	38.8	38.8	39.4*a*	39.0*b*	39.8*a*	39.3*b*	39.0*a*	38.6*b*	0.098	***	***
4 h	17.6*a*	7.71*b*	18.9*a*	10.8*b*	18.6*a*	7.5*b*	22.4*a*	15.0*b*	25.1*a*	17.7*b*	0.408	***	***
24 h	3.6	3.5	4.6*a*	4.1*b*	4.5	4.2	5.7*a*	5.2*b*	7.5*a*	6.0*b*	0.103	***	***
6 d	4.1*a*	3.7*b*	3.9	3.6	4.8	4.9	4.0	4.0	4.1	4.3	0.11	–	**
Minolta (24 h)													
L*	36.1	35.9	37.3	36.7	36.7	36.8	36.6	35.9	43.0	42.4	0.251	***	–
Chroma	18.9*a*	18.0*b*	19.9*a*	18.5*b*	20.6*a*	19.9*b*	21.5*a*	19.9*b*	22.3	21.9	0.218	***	**
Hue angle (°)	21.9*a*	20.3*b*	23.2*a*	21.6*b*	21.4	20.9	25.3*a*	23.8*b*	24.8*a*	24.1*b*	0.213	***	**
Minolta (6 d)													
L*	37.9	37.9	38.2	37.9	37.2	37.6	39.4*a*	37.9*b*	42.7*a*	41.0*b*	0.245	***	***
Chroma	22.2	21.8	21.7*a*	20.9*b*	22.6*a*	21.6*b*	26.0*a*	24.1*b*	23.7*a*	22.7*b*	0.216	***	**
Hue angle (°)	24.5	24.8	24.6	25.0	23.5*b*	24.7*a*	27.6	27.2	25.4	25.6	0.193	***	***
Drip loss (g 100 g^{-1})	4.58	4.45	5.57	5.18	7.26	6.47	5.72	5.27	5.65	5.30	0.114	***	*
Sarcomere length (μm)	1.78*a*	1.67*b*	1.61	1.67	1.76	1.78	–	–	–	–	0.029	–	***
Sarcomere diameter (μm)	61.0	62.4	65.7*a*	61.8*b*	54.6	53.3	–	–	–	–	0.73	**	***

a,b Values within the same muscle and row bearing different letters are significantly different ($P \leq 0.05$).
***, **, * $P \leq 0.01$, $P \leq 0.05$ and $P \leq 0.10$, respectively.

unacceptable overall palatability scores decreased from 17.5 to 3.3% ($P \leq 0.01$). Therefore, OLAS appears to have the potential to improve tenderness in the major muscles of the back and hip (the major "steak" muscles) without noticeably compromising the quality of the smaller, contralateral muscles.

The large improvements in tenderness in the back and inside round muscles that accompanied the OLAS procedure most likely result from a decrease in rigor-related muscle fiber shortening. In the muscles measured (ALTL, PLTL and PM), sarcomere lengths were significantly longer in OLAS- than CS-treated carcasses (1.74 vs. 1.68 μm; $P \leq 0.05$). As post-mortem glycolysis progresses, there is a gradual depletion of ATP, a decrease in pH and a decrease in muscle temperature. The integrity of the membranes of the sarcoplasmic reticulum and mitochondria is gradually lost, resulting in a release of calcium. The combination of free calcium (which binds to troponin and alters the spatial location of tropomyosin) and ATP (which activates the myosin heads and provides the energy required for movement) results in muscular contraction and shortening of the sarcomeres. When ATP is completely depleted, activation of the myosin heads is no longer possible and the myosin heads become locked to actin. The muscle becomes almost inextensible and is set in rigor mortis (Swatland 1984). However, when a load of sufficient magnitude (such as the weight of the carcass when carcass suspension is altered) is applied to a muscle during the post-mortem period, the muscle is unable to shorten and an isometric contraction occurs, resulting in the sarcomere length remaining the same, or increasing. Longer sarcomeres result in improved tenderness, probably as a result of fewer actomyosin crossbridges. Recent research suggests actomyosin crossbridges may not be permanent and may be subject to post-mortem changes in configuration and energy states as a result of osmotic and/or proteolytic changes (Takahashi et al. 1995; Taylor et al. 1995). Previously, much of the resolution of rigor was attributed to proteolytic breakdown at the Z-line. One other area that has received very little attention, and which may contribute to the relatively large changes in tenderness that were observed under altered suspension conditions, is the spatial configuration of the connective tissue framework surrounding the individual myofibers. Under conditions of increased tension, the number of endomysial fibers per unit area is reduced and the endomysial fibers may then be more susceptible to shear forces (Swatland 1984).

Although OLAS resulted in some statistically significant changes to meat color (L* was significantly lower in the RF and chroma [saturation] was significantly lower in the ALTL and PLTL at 24 h; Table 1), these changes were small and well within the acceptable range of normal meat color. Consequently they are unlikely to be visually discriminated against. In addition, over all muscles, OLAS significantly reduced the amount of drip loss from 56.5 mg g^{-1} for CS steaks to 54.5 mg g^{-1} for OLAS steaks ($P \leq 0.01$), which was probably a direct result of longer sarcomeres and an associated higher water-holding capacity (Offer et al. 1989).

Many other types of altered suspension, including aitch-bone suspension, have been attempted, with resulting improvements in the tenderness of muscles experiencing increased tension during the rigor process (Hostetler et al. 1970, 1972; Fapohunda and Okubanjo 1987). However, to

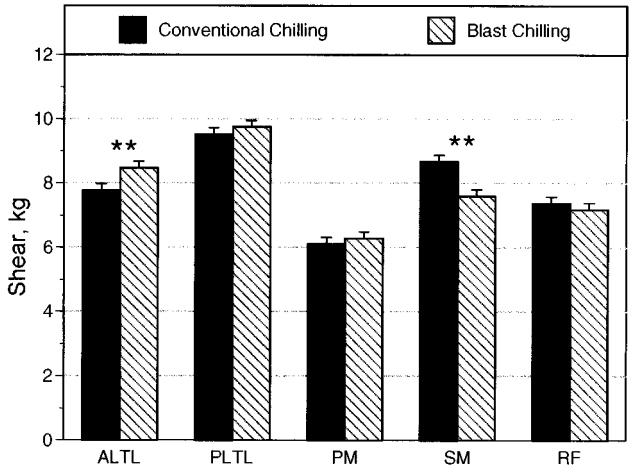

Fig. 3. Changes to shear force under different chilling regimes in the ALTL, PLTL, PM, SM and RF. ** indicates a significant difference ($P \leq 0.05$) between chilling treatments within a muscle.

Table 4. Least-squares means for cooking and palatability properties[z] of LTL steaks subjected to different chilling regimes

	CC	BC	SEM	*P*
Initial tenderness	5.62	5.29	0.107	<0.001
Juiciness	5.86	5.67	0.082	0.024
Flavour desirability	6.14	6.00	0.066	0.016
Flavour intensity	5.96	5.90	0.042	0.159
Amount of connective tissue	7.07	6.83	0.055	<0.001
Overall tenderness	5.95	5.52	0.104	<0.001
Overall palatability	5.78	5.40	0.090	<0.001
Cook loss, (g 100 g^{-1})	26.44	26.72	0.369	0.501
Drip loss, (g 100 g^{-1})	3.69	4.50	0.180	<0.001
Cook time, (min g^{-1})	0.101	0.098	0.0029	0.369

[z]Evaluations for initial and overall tenderness, amount of perceptible connective tissue, juiciness, and flavor intensity, used nine-point descriptive scales (9 = extremely tender, no perceptible connective tissue, extremely juicy, and extremely intense beef flavor; 1 = extremely tough, abundant connective tissue, extremely dry, and extremely bland beef flavor). Evaluations for flavor desirability and overall palatability used a nine-point hedonic scale (9 = extremely desirable, 1 = extremely undesirable).

date, none of these procedures has been adapted in a commercial abattoir because of the modifications required. On-line altered suspension appears to hold promise, since its implementation as an on-line procedure does not require expensive changes to the slaughter floor or coolers. Moreover, even though the muscles were removed from the carcass at 24 h post-mortem in the present study, the effect on tenderness persisted until 6 d post-mortem when the steaks were cooked for shear determination. Therefore, the OLAS procedure should work in a commercial setting where carcasses are routinely cut-out at 24 h post-mortem.

The Effect of Blast Chill

Blast chilling increased the rate of temperature decline and decreased the rate of pH decline in the muscles evaluated. On average, at 4 h post-mortem BC muscles were 8.8°C colder and had pH values 0.16 units higher than CC muscles (Table 3). Resulting shear values were significantly higher in the ALTL and significantly lower in the SM ($P \leq 0.01$; Fig. 3).

The ALTL location chilled very rapidly in BC carcasses, reaching a temperature of 3.9°C in OLAS carcasses and 11.5°C in CONV carcasses within 4 h post-mortem. The general rule for preventing cold shortening in beef is to delay the carcass musculature from cooling below 10°C before 10 h post-mortem (Bendall 1972) or before pH has fallen below a value of 6 (Davey and Gilbert 1974). In a previous study, moderate blast chill conditions (–20°C) did not result in significant cold shortening (Aalhus et al. 1991). However, in the present study, significantly shorter sarcomere lengths were observed in the ALTL of BC carcasses, indicating cold shortening. The extreme rate of chilling in the ALTL of OLAS carcasses produced by direct exposure of a portion of the LTL to chiller temperatures likely had an over-riding influence on sarcomere lengths. In our previous study (Aalhus et al. 1991) the LTL was always shielded from the BC conditions by a continuous layer of subcutaneous fat. The increase in shear force as a result of cold shortening was perceived by the sensory taste panel (Table 4). Significantly lower ($P \leq 0.01$) panel ratings were observed for initial tenderness, amount of connective tissue, overall tenderness and overall palatability in BC steaks (over both the ALTL and PLTL locations). As well, BC steaks had a significantly higher proportion of unacceptable initial tenderness scores than CC steaks (24.2 vs. 11. 7, respectively, $P \leq 0.01$; Fig. 4).

In contrast, the increased rate of chilling in the hip as a result of BC reduced the muscle temperature to 15°C by 4 h post-mortem (compared with 22.4°C in CC). Under CC conditions, the SM muscle appears to experience heat shortening with an associated toughening (Locker and Hagyard 1963; Marsh et al. 1987). Under BC conditions, the rate of chilling in the SM was more optimal, reducing heat shortening and improving tenderness. These data reflect the difficulties in chilling meat in a carcass form, since chilling facilities are designed to chill "on average" rather than being specifically designed to optimize chilling in certain anatomical regions.

In addition to changes in tenderness, most muscles from BC carcasses tended to have slightly darker meat color than their counterparts from CC carcasses after 24 h. Hue angle (color) and chroma were significantly lower in muscles from BC carcasses compared with muscles from CC carcasses indicating a more purple–red, less saturated color (Table 3). Rapid chilling has previously been reported to result in a slightly darker meat color (Bowling et al. 1987). Differences in rate of pH decline are thought to affect rate of protein denaturation and, thereby, water-binding ability of the proteins. The amount of free water influences light reflectance and color quality of meat (Offer et al. 1989). In most cases, differences in meat color between BC and CC muscles persisted to 6 d post-mortem. As well, averaged over all muscles, drip loss was significantly higher in muscles from CC than in muscles from BC carcasses (57.7 vs. 53.4 mg g^{-1}; $P = 0.01$.). Other researchers have also reported decreased drip loss associated with BC (Woltersdorf 1988).

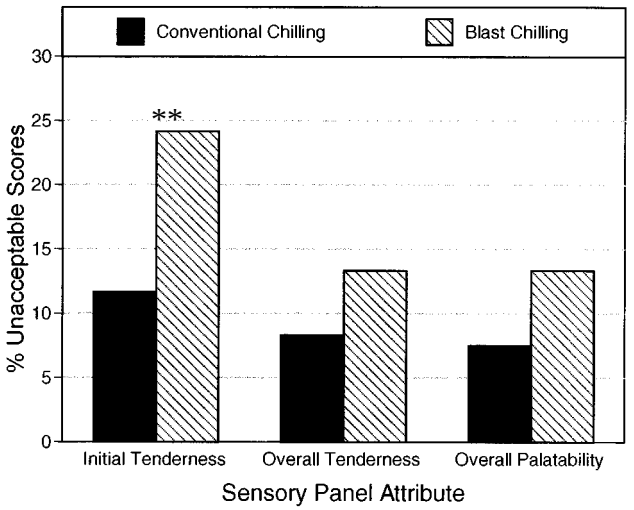

Fig. 4. Proportion of unacceptable initial tenderness, overall tenderness and overall palatability sensory panel scores (≤4.5) under different chilling regimes. ** indicates a significant difference ($P \leq 0.05$) between chilling regimes.

CONCLUSION

Regardless of the chilling regime, OLAS reduced shear force by 1.13, 2.21 and 2.38 kg in the SM, PLTL and ALTL muscles, respectively. In the contralateral muscles, shear force was increased by 0.35 kg in the PM and 0.68 kg in the RF. Sensory panel evaluation supported the reduced shear values in the LTL muscle. The panel rated these steaks significantly higher for initial tenderness, amount of connective tissue, overall tenderness and overall palatability. The proportion of unacceptable panel scores decreased significantly from 28.3 to 7.5% for initial tenderness, from 19.2 to 2.5% for overall tenderness and from 17.5% to 3.3% for overall palatability. Therefore, OLAS holds promise for improving tenderness and consumer acceptability of the major steak muscles from beef carcasses. OLAS can easily be implemented on existing slaughter floors, and does not increase the amount of time muscles must remain on the carcass. However, the effect of OLAS on Canadian yield and quality grades must be investigated prior to recommendation of the procedure to industry.

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