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EFFECTS OF ELEVATED STORAGE TEMPERATURE AND CHANGES IN METHOD OF CARCASS SUSPENSION ON BEEF TENDERNESS

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Introduction

The contraction or shortening of unrestrained muscles during the onset of rigor mortis is a well established phenomenon. The gradual shortening of sarcomeres which accompanies the change in muscle extensibility during onset of rigor (Locker, 1960) is associated with meat tenderness. Storage temperature during the onset of the death-stiffening process has been shown to affect the degree to which muscles shorten (Locker and Hagyard, 1963; Marsh and Leet, 1966; Marsh, Woodhams and Leet, 1968). Changes in carcass position during the onset of rigor mortis have been observed to produce pronounced effects on sarcomere length, muscle fiber diameter and tenderness (Eisenhut et al., 1965; Herring, Cassens and Briskey, 1965b; Hostetler et al., 1970). The experiments described here were designed to investigate methods for increasing the tenderness of the beef longissimus muscle. Changes in method of suspension, carcass or skeletal integrity and temperature during chilling were studied in relation to their effects in the prevention of muscle shortening and/or on the subsequent tenderness of beef.

Experimental Procedure

Twenty experiments involving 424 sides of beef have been conducted to determine the effects of changes in storage temperature, skeletal integrity and method of suspension on beef tenderness. Four experiments were conducted to determine the effects of vertebral severance, ligamentum nuchae severance and/or attachment of weights on tenderness. Nine experiments were conducted to evaluate elevated prerigor storage temperature, five experiments determined the effect of changes in method of carcass suspension and two trials were designed to evaluate the effect of combined severance, suspension and temperature treatments on the subsequent tenderness of beef muscle. The essential elements of the experimental design are included in the tabular material. The data in experiments 1, 2, 3, 5, 6, 7, 14, 15, 16, 17 and 19 have previously been reported (Hostetler et al., 1970; Smith, Arango and Carpenter, 1971; Hostetler et al., 1972).

Severance treatments. In experiments 1, 2, 3, 4 and 19, individual cuts were made between certain vertebrae which severed the intervertebral fibro-cartilages and the ventral and dorsal longitudinal ligaments. These cuts were made between the 6th and 7th cervical; 5th and 6th, 9th and 10th, 12th and 13th thoracic; and the 4th and 5th lumbar vertebrae. In experiments 1, 2, 4 and 19 the funicular part of the ligamentum nuchae was severed at the anterior end, posterior to the dorsal spinous process of the first cervical vertebra, and the lamellar portions were freed from their attachments to the cervical spines.

Weighted load treatments. In experiments 2, 3, 4 and 19, weight loads of 68 kg were attached to the neck (3rd to 6th cervical vertebrae) for 48 hr in an attempt to maintain carcass length during periods of subsequent storage at 2°C.

Body curvature and carcass suspension treatments. Individual sides in experiments 1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19 and 20 were suspended by the achilles tendon. Certain sides in experiments 3, 4, 15, 16, 17, 18, 19 and 20 were suspended by the obturator foramen in the manner described by Hostetler et al. (1970). One side of each carcass in experiment 14 was bent by use of two small hooks, one of which was attached to the achilles tendon and the other attached to either the anterior border of the sternum or the 4th cervical vertebra. Tension was achieved by connecting the two hooks with a wire to achieve lateral curvature along the vertebral column. In experiment 17, horizontally suspended sides were placed on a table, bone side down, with the limbs pulled into position perpendicular to the vertebral column; cervically suspended sides were suspended via the cervical vertebrae with the limbs tied together to bring the pelvic limb perpendicular to the vertebral column and certain of the sides were suspended from the obturator foramen with the limbs tied together to bring the thoracic limb perpendicular to the vertebral column.

Temperature treatments. Individual sides in experiments 5, 6, 7, 8, 9, 10, 11, 12, 13 and 20 were placed in a 16°C cooler for 8, 12, 16 or 20 hr. Following storage at the elevated temperature for the designated period, the sides were placed in the 2°C cooler for the remainder of the aging period.

Tenderness determinations. In experiments 1, 2, 3, 4, 5, 6, 7, 14, 15 and 19, frozen steaks (3.8 cm thick) were thawed at room temperature (23°C) and broiled at 177°C to an internal temperature of 75°C. In experiment 18, unfrozen steaks (3.8 cm thick) were broiled at 177°C to an internal temperature of 75°C. In experiments 8, 9, 10, 11, 12 and 13, frozen steaks (3.8 cm thick) were thawed at room temperature (23°C) and broiled at 165°C to an internal temperature of 70°C. In experiments 16, 17 and 20, 100 gram samples (7.5 x 5.0 x 2.5 cm thick) were broiled for 46 min to approximately 70°C in a 175°C oven. Trained sensory panels consisting of four members (experiments 1, 2, 3, 5, 6, 7, 14, 15 and 19), five members (experiment 16), six members (experiments 4, 17 and 20), seven members (experiment 18) or eight members (experiments 8, 9, 10, 11, 12 and 13) evaluated individual muscle samples on the basis of a 9-point scale (9 = very tender; 1 = very tough). Shear force determinations were made by use of 1.27 cm cores and the Warner-Bratzler apparatus.

Sarcomere length determinations. Unfixed samples of individual muscles were blended for 40 sec in cold (4°C) 0.25 M sucrose solution using a Virtis homogenizer. The suspension of muscle fibers was examined directly in a phase contrast microscope (10X ocular, 100X objective). Sarcomere length was determined by use of a filar micrometer and values are reported as the average length of 160 to 250 sarcomeres from each muscle.

Results and Discussion

Data regarding the effects of vertebral severance, ligamentum nuchae severance and/or attachment of weight loads on beef tenderness are presented in Table 1. Decreases in shear force requirement of 3% (P>.05) to 22% (P<.05) and increases in tenderness rating of 6% (P>.05) to 18% (P<.05) were associated with the use of severance and/or weight load treatments. The greatest proportionate effect on shear force requirements and tenderness ratings was achieved by use of both kinds of severance and a weight load when carcasses were suspended by the achilles tendon (experiment 2). Carcasses which were suspended by the obturator foramen were affected by severance and weighting to a lesser extent (6% and 9%, shear force and tenderness rating, respectively) than were carcasses suspended by the achilles tendon (18% and 12%, shear force and tenderness rating, respectively). These data suggest that vertebral severance, ligamentum nuchae severance and attachment of weights increase the tenderness of the longissimus muscle, and that the magnitude of increase in tenderness is greatest for carcasses suspended by the achilles tendon.

Data regarding the effect of elevated prerigor storage temperature on beef tenderness are presented in Table 2. Chilling of carcasses at 16°C rather than at 2°C immediately postmortem was associated with significant (P<.05) decreases in shear force requirement in 3 of 9 experiments and significant (P<.05) increases in tenderness rating in 5 of 9 experiments. These data suggest that periods of storage at 16°C of 16 hr or longer were associated with decreases in shear force requirement of 7% (P>.05) to 47% (P<.05) and with increases in tenderness rating of 9% (P>.05) to 40% (P<.05). The mechanism by which increases in tenderness are effected by elevated storage temperatures is not clear. Although Locker and Hagyard (1963) and Cassens and Newbold (1967) have demonstrated "cold shortening" in association with low chilling temperatures, it appears unlikely that the longissimus muscle would shorten in the intact carcass. Szent-Gyorgyi (1951) has postulated that the discontinuity in the enzymatic properties of myosin ATPase that occurs at 16°C may reflect a change in the shape of the active site on the myosin molecule which results in the formation of fewer actin to myosin bonds during the onset of rigor. Smith et al. (1971) suggested the possibility of increased cathepsin enzyme proteolysis during the 16 to 20 hr that the carcass is held at 16°C, but these workers did not provide direct evidence to support their hypothesis. Fields, Carpenter and Smith (1971) reported that the storage of beef carcasses at 16°C for 16 to 20 hr resulted in increased tenderness for treated vs. control sides after 2 days of storage but that this advantage diminished during subsequent aging at 2°C for 5 days. The data of the present study suggest that prerigor storage of beef carcasses at 16°C for 16 hr or more increases the tenderness of the *longissimus* muscle.

The effects of changes in method of carcass suspension are presented in Table 3. In experiment 14, body curvature was achieved by the use of tension applied upon a wire to effect lateral deformation of the vertebral column. No significant difference was observed in tenderness and the carcasses were irregular in form, undesirable in shape and unacceptable to the commercial trade. Carcasses suspended for 24 hr via the obturator foramen and subsequently resuspended by the achilles tendon (experiment 15) did not differ in tenderness from control carcasses and did not regain the shape characteristic of normally suspended carcasses.

All of the treatments employed in experiment 17 had a similar effect on the *longissimus* muscle. Bringing the pelvic limb forward increased the sarcomere length 0.4 to 0.6 microns, reduced shear force requirements by 1.1 kg or more and enhanced tenderness ratings by at least 1.2 units. With vertical suspension via the achilles tendon, the *longissimus* muscle is allowed to shorten due to the compression of the dorsal portions of the vertebrae. In all four of the treatments in experiment 17, the vertebrae are in straight alignment, with the weight of the carcass tending to pull them slightly apart. Suspension of the beef side from the obturator foramen (a natural opening in the pelvic bone) appears to be the most practical method for minimizing muscle shortening, increasing postrigor sarcomere lengths, enhancing tenderness ratings and decreasing shear force requirements. Suspension via the obturator foramen significantly (P<.05) decreased shear force requirements by 22, 18 and 21% and significantly (P<.05) increased tenderness ratings by 33, 30 and 24% in comparison to achilles suspension in experiments 16, 17 and 18, respectively. The postrigor conformation of obturator-suspended carcasses differs from that of achilles-suspended sides but minor modifications in cutting and fabrication procedure (Orts, Smith and Hostetler, 1971) facilitate rapid and efficient merchandising of the beef cuts.

Data regarding the combined effects of severance, suspension and temperature treatments on beef tenderness are presented in Table 4. In experiment 19, suspension via the obturator foramen, severance of the vertebral column and _ligamentum nuchae_, and attachment of weight loads to the neck was associated with a 27% decrease (P<.05) in shear force requirements and a 27% increase (P<.05) in tenderness ratings in comparison to control sides. Carcass length was increased 11.2% by the combination of treatments applied to treated sides. The treated sides exhibited some degree of _longissimus_ elongation (as evidenced by increased sarcomere length) and a concomitant increase in tenderness. The sarcomere length-tenderness relationship is in agreement with the previous reports of Herring _et al_. (1965a,b), Gillis and Henrickson (1967) and Hostetler _et al_. (1970).

Treatments involving achilles suspension-elevated temperature, obturator suspension-normal temperature, and obturator suspension-elevated temperature (Table 4) were associated with decreases (P<.05) in shear force requirements of 13, 24 and 30%, respectively, and with increases (P<.05) in tenderness ratings of 7, 18 and 24%, respectively, in comparison to control (achilles suspension-normal temperature) sides. These data suggest that suspension via the obturator foramen had the greatest effect on tenderness. Elevated temperature storage also improved tenderness. The combination of obturator suspension and elevated temperature storage produced the most tender beef but the difference between it and obturator suspension at normal temperature was small and not significant.

Summary

Twenty experiments involving 424 sides of beef have been conducted to determine the effects of changes in prerigor storage temperature, skeletal integrity and method of suspension on tenderness of the *longissimus* muscle. Vertebral severance, *ligamentum nuchae* severance and attachment of weight loads (68 kg) at the neck resulted in increased (P<.05) tenderness in 3 of 4 trials (as high as 22% increase, P<.05). Chilling of carcasses at 16°C for at least 16 hr immediately postmortem enhanced (P<.05) tenderness in 5 of 6 experiments (as high as 47% increase, P<.05). Suspension of the beef side by the obturator foramen for the entire chilling period increased (P<.05) tenderness in 3 of 3 trials (as high as 33% increase, P<.05). Obturator foramen suspension appears to be the most practical method for minimizing muscle shortening, increasing postrigor sarcomere lengths, enhancing tenderness ratings and decreasing shear force requirements. Treatments combining obturator suspension with skeletal severance and weight loads or obturator suspension with prerigor storage at 16°C produced minor improvements in tenderness, but the advantages in comparison to obturator suspension alone were small and not significant.

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TABLE 1. EFFECT OF VERTEBRAL SEVERANCE, *LIGAMENTUM NUCHAE* SEVERANCE AND/OR ATTACHMENT OF WEIGHTS ON TENDERNESS AND SARCOMERE LENGTH OF THE BEEF *LONGISSIMUS* MUSCLE

Exp.	N	Side	Method of suspension	Severance treatment[a]	Attachment of weight	Holding conditions Temp. (°C)	Holding conditions Time (hr)	Shear force (kilograms)[b]	Tenderness rating[bc]	Sarcomere length (microns)[d]
1	18	Control	Achilles	None	None	2	168	4.70[e]	5.54[e]	1.8
		Treated	Achilles	A, B	None	2	168	4.07[f]	5.88[e]	2.1
2	3	Control	Achilles	None	None	2	168	4.56[e]	5.71[f]	1.9
		Treated	Achilles	A, B	68 kg	2	168	3.54[f]	6.72[e]	2.0
3	4	Control	Obturator	None	None	2	168	3.91[e]	5.94[e]	2.3
		Treated	Obturator	A	68 kg	2	168	3.77[e]	6.38[e]	2.3
4	8	Control	Obturator	None	None	2	168	3.96[e]	6.02[f]	2.4
		Treated	Obturator	A, B	68 kg	2	168	3.64[e]	6.63[e]	2.5

[a] A = intervertebral severance between the 6th to 7th cervical; 5th to 6th, 9th to 10th, 12th to 13th thoracic; and 4th to 5th lumbar vertebrae. B = severance of the funicular and lamellar portions of *ligamentum nuchae*.

[b] Values determined from measurements of the *longissimus* muscle opposite the 6th cervical, 5th thoracic, 12th thoracic and 4th lumbar vertebrae regions in experiments 1, 2 and 4; values determined from measurements of the *longissimus* muscle opposite the 12th thoracic vertebra in experiment 3.

[c] Mean ratings based on a 9-point scale (9 = very tender; 1 = very tough).

[d] Measurements obtained from the *longissimus* muscle opposite the 12th thoracic vertebra.

[ef] Mean values within an experiment bearing different superscripts differ significantly ($P<.05$).

TABLE 2. EFFECT OF ELEVATED PRERIGOR STORAGE TEMPERATURE ON TENDERNESS AND SARCOMERE LENGTH OF THE BEEF LONGISSIMUS MUSCLE

Exp.	N	Side	Method of suspension	Holding conditions[a] Temp. (°C)	Time (hr)	Shear force (kilograms)[b]	Tenderness rating[bc]	Sarcomere length (microns)[b]
5	5	Control	Achilles	2	168	5.63[d]	5.95[d]	1.9
		Treated	Achilles	16(2)	8(160)	5.38[d]	5.80[d]	1.8
6	5	Control	Achilles	2	168	6.23[d]	4.10[e]	2.0
		Treated	Achilles	16(2)	16(152)	3.27[e]	5.75[d]	1.9
7	5	Control	Achilles	2	168	3.73[d]	4.73[d]	1.8
		Treated	Achilles	16(2)	20(148)	2.54[e]	6.06[d]	1.9
8	9	Control	Achilles	2	48	4.36[d]	5.84[d]	1.6
		Treated	Achilles	16(2)	12 (36)	4.34[d]	6.23[d]	1.8
9	9	Control	Achilles	2	48	4.74[d]	5.87[d]	1.7
		Treated	Achilles	16(2)	16 (32)	4.03[d]	6.43[d]	1.7
10	9	Control	Achilles	2	48	4.14[d]	6.03[e]	1.6
		Treated	Achilles	16(2)	20 (28)	3.83[d]	6.92[d]	1.7
11	7	Control	Achilles	2	48	5.80[d]	4.25[e]	1.5
		Treated	Achilles	16(2)	12 (36)	5.32[d]	5.21[d]	1.7
12	7	Control	Achilles	2	48	5.45[d]	3.97[e]	1.7
		Treated	Achilles	16(2)	16 (32)	4.70[d]	5.29[d]	1.7
13	7	Control	Achilles	2	48	7.08[d]	3.44[e]	1.6
		Treated	Achilles	16(2)	20 (28)	5.55[e]	4.44[d]	1.7

[a] Temperatures and times listed parenthetically are those for conditions used subsequent to initial chilling treatments.

[b] Measurements obtained from the longissimus muscle opposite the 12th thoracic vertebra.

[c] Mean ratings based on a 9-point scale (9 = very tender; 1 = very tough).

[de] Mean values within an experiment bearing different superscripts differ significantly ($P<.05$).

TABLE 3. EFFECT OF METHOD OF CARCASS SUSPENSION ON TENDERNESS AND SARCOMERE LENGTH OF THE BEEF *LONGISSIMUS* MUSCLE

Exp.	N	Side	Method of suspension	Body curvature[b]	Holding conditions Temp. (°C)	Holding conditions Time (hr)	Shear force (kilograms)[c]	Tenderness rating[cd]	Sarcomere length (microns)[c]
14	4	Control	Achilles	None	2	168	3.7^{e}	5.3^{e}	1.8
		Treated	Achilles	A	2	168	3.1^{e}	6.3^{e}	2.0
15	4	Control	Achilles	None	2	168	3.8^{e}	5.7^{e}	2.0
		Treated	Obturator[a]	None	2	168	3.2^{e}	6.6^{e}	2.1
16	8	Control	Achilles	None	2	168	6.3^{e}	4.0^{f}	1.9
		Treated	Obturator	None	2	168	4.9^{f}	5.3^{e}	2.4
17	40	Control	Achilles	None	2	168	6.0^{e}	3.8^{f}	1.9
		Treated	Horizontal	B	2	168	4.7^{f}	5.0^{e}	2.5
		Treated	Cervical	C	2	168	4.8^{f}	5.2^{e}	2.4
		Treated	Obturator	None	2	168	4.9^{f}	4.9^{e}	2.3
		Treated	Obturator	D	2	168	4.9^{f}	5.4^{e}	2.4
18	28	Control	Achilles	None	2	48	6.2^{e}	5.4^{f}	---
		Treated	Obturator	None	2	48	4.9^{f}	6.7^{e}	---

[a]During the first 24 hr the carcass was suspended by the obturator foramen; the carcass was resuspended via the achilles tendon for the remainder of the 168 hr storage period.

[b]A = body curvature was achieved by inducing tension on a wire attached from the achilles tendon to either the anterior border of the sternum or to the 4th cervical vertebra. B = the side was placed on a table, bone side down, with the limbs pulled into position perpendicular to the vertebral column. C = the side was suspended from the cervical vertebrae with the limbs tied together to bring the pelvic limb perpendicular to the vertebral column. D = the side was suspended from the obturator foraman with the limbs tied together to bring the thoracic limb perpendicular to the vertebral column.

[c]Measurements obtained from the *longissimus* muscle opposite the 12th thoracic vertebra.

[d]Mean ratings based on a 9-point scale (9 = very tender; 1 = very tough).

[ef]Mean values within an experiment bearing different superscripts differ significantly ($P<.05$).

TABLE 4. EFFECT OF COMBINED SEVERANCE, SUSPENSION AND TEMPERATURE TREATMENTS ON TENDERNESS AND SARCOMERE LENGTH OF THE BEEF LONGISSIMUS MUSCLE

Exp.	N	Side	Method of suspension	Severance treatment[a]	Attachment of weight	Holding conditions[b] Temp. (°C)	Time (hr)	Shear force (kilograms)[c]	Tenderness rating[cd]	Sarcomere length (microns)[e]
19	8	Control	Achilles	None	None	2	168	6.21[f]	4.21[g]	1.8
		Treated	Obturator	A, B	68 kg	2	168	4.53[g]	5.36[f]	2.2
20	24	Control	Achilles	None	None	2	168	8.03[f]	4.95[h]	1.8
		Treated	Achilles	None	None	16(2)	20(148)	6.98[g]	5.30[g]	1.8
		Treated	Obturator	None	None	2	168	6.07[h]	5.85[f]	2.2
		Treated	Obturator	None	None	16(2)	20(148)	5.60[h]	6.15[f]	2.3

[a] A = intervertebral severance between the 6th to 7th cervical; 5th to 6th, 9th to 10th, 12th to 13th thoracic; and 4th to 5th lumbar vertebrae. B = severance of the funicular and lamellar portions of ligamentum nuchae.

[b] Temperatures and times listed parenthetically are those for conditions used subsequent to initial chilling treatments.

[c] Measurements obtained from the longissimus muscle opposite the 6th cervical, 5th thoracic, 12th thoracic and 4th lumbar vertebrae regions in experiment 19; values determined from measurements of the longissimus muscle opposite the 12th thoracic vertebra in experiment 20.

[d] Mean ratings based on a 9-point scale (9 = very tender; 1 = very tough).

[e] Measurements obtained from the longissimus muscle opposite the 12th thoracic vertebra.

[fgh] Mean values within an experiment bearing different superscripts differ significantly (P<.05).

EFFECTS OF ELEVATED STORAGE TEMPERATURE ON CHANGES IN METHOD OF CARCASS SUSPENSION ON BEEF TENDERNESS

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Summary

Twenty experiments involving 424 sides of beef have been conducted to determine the effects of changes in prerigor storage temperature, skeletal integrity and method of suspension on tenderness of the longissimus muscle. Vertebral severance, ligamentum nuchae severance and attachment of weight loads (68 kg) at the neck resulted in increased ($P<.05$) tenderness in 3 of 4 trials (as high as 22% increase, $P<.05$). Chilling of carcasses at 16°C for at least 16 hr immediately postmortem enhanced ($P<.05$) tenderness in 5 of 6 experiments (as high as 47% increase, $P<.05$). Suspension of the beef side by the obturator foramen for the entire chilling period increased ($P<.05$) tenderness in 3 of 3 trials (as high as 33% increase, $P<.05$). Obturator foramen suspension appears to be the most practical method for minimizing muscle shortening, increasing postrigor sarcomere lengths, enhancing tenderness ratings and decreasing shear force requirements. Treatments combining obturator suspension with skeletal severance and weight loads or obturator suspension with prerigor storage at 16°C produced minor improvements in tenderness, but the advantages in comparison to obturator suspension alone were small and not significant.