Tenderization of Meat by Pre-Rigor Pressurization

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Introduction

Tenderness of meat is variable but indispensible if meat is to be readily accepted by the consumers. It is thus increasingly important that meat sceintists elucidate causes of variation in tenderness and find a way to consistently maintain a desirable level.

Locker and Hagyard (1963) observed that cold shortening is responsible for post-rigor myofibrillar toughness. Their findings have lead to extensive research to solve this problem. Several tenderization techniques have been suggested (Busch et al., 1967; Smith et al., 1971; Carse, 1973; MacFarlane, 1973). Of these, electrical stimulation and pre-rigor pressurization emerge as very promising.

In the past eight years, electrical stimulation has been intensively researched (Carse, 1973; Chrystal and Hagyard, 1976; Bendall et al., 1976; Bouton et al., 1980; Savell et al., 1977; Elgasim et al., 1981). Pre-rigor pressurization research is in its early stages and is concentrated in Australia at the CSIRO Division of Food Research, Meat Research Laboratory, and at the Clark Meat Science Laboratory, Oregon State University, U.S.A.

History

MacFarlane of Australia in 1973 was the first to report research that indicated that pre-rigor pressurization significantly tenderized beef and sheep muscle. However, the concept of the effect of pressure on biological substance is not new. Early in the 50's, the discovery of organisms living at a depth of 6,000 meters at a hydrostatic pressure of 600 atmospheres has intrigued investigators and led to the study of the effect of pressure on biological activity. Several investigators have shown that pressure induces the development of tension in muscles (Johnson et al., 1954; Brown, 1957; Johnson and Erying, 1970). Both pressure alone (MacFarlane, 1973; Elgasim, 1977; Kennick et al., 1980) and in combination with heat (Bouton et al., 1977, 1978) have been shown to have a substantial and highly significant tenderizing effect on beef and sheep muscle.

MacFarlane (1973) reported the effect of treating pre-rigor muscle from beef and sheep with various combinations of pressure, temperature and time under pressure. He concluded that 103.5 MN/m² (15,000 lb/in²) at 30-35°C for two minutes was as effective as more extensive treatments. These are the treatments used for all work reported from our laboratory. MacFarlane's work was carried out on fairly small samples since the largest chamber used was 7.62 cm in diameter and 23.76 cm long.

We have confirmed MacFarlane's findings first using a chamber large enough (10.16 × 30.48 cm) to hold samples up to about two kilograms and are now working with a larger chamber (30.48 × 60.96 cm) capable of holding several large boneless cuts such as those produced in commercial practice.

Results and Discussion

Tenderness

Effect of pressure on tenderness was studied objectively, using Warner-Bratzler shear device, and subjectively (taste panel). The results are summarized in Table 1 and 2. The shear force values for all muscles treated (Table 1), whether from sheep or cattle, were substantially and significantly ($P < .01$) lower than for corresponding controls.

Table 1. Effect of pressure[a] on shear force value of sheep and beef muscle

Muscle & Species		*W-B, (kg/cm₂)* Control		Treated	
Longissimus dorsi	(sheep)	5.74	(.68)[b]	1.85	(.54)
Semimembranosus	(sheep)	6.26	(.89)	2.30	(.49)
Longissimus dorsi	(cattle)	8.39	(.37)	2.99	(.27)
Semitendinosus	(cattle)	6.17	(.25)	4.51	(.15)
Supraspinatus	(cattle)	7.13	(.69)	4.35	(.53)
Sternomandibularis	(cattle)	14.97	(.64)	5.80	(.89)

[a]Conditions of the treatment; pressure = 15,000 lb/sq in, temperature, 39°C, and duration = 2 min.
[b]Values in parenthesis are the standard deviations.

Cuts from 10 high Good and Choice cattle used in a consumer evaluation of 12 major retail cuts. The results of 226 consumer evaluations of various organoleptic properties are summarized in Table 2. Eight out of the 12 cuts were found to be significantly ($P < .05$) more tender than corresponding controls. The consumer panelists were unable to detect any significant ($P > .05$) differences in flavor. The juiciness ratings of the treated New York and top round were lower ($P < .05$) than for the control.

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Table 2. Summary of consumer evaluations indicating whether pressure treated (P)[a] or control (C) were rated significantly* higher for tenderness, juiciness, flavor and overall desirability

Cut	Tenderness	Juiciness	Flavor	Overall Desirability
Inside Chuck Roll	P	ns	ns	P
Tip Roast	P	ns	ns	ns
Arm Roast	P	ns	ns	ns
Top Sirloin	P	ns	ns	ns
Shoulder Clod	ns	ns	ns	ns
New York	P	C	ns	P
Jewish Tender	ns	ns	ns	ns
Ribeye	P	ns	ns	ns
Filet Mignon	ns	ns	ns	ns
Eye of Round	P	ns	ns	ns
Top Round	P	C	ns	ns
Bottom Round	ns	ns	ns	ns

* = significant ($P < .05$)
[a]Conditions of the treatment; pressure = 15,000 lb/sq in, duration = 2 min, and temperature, 39°C.
ns = not significant.

The reduced juiciness ratings reported by MacFarlane (1973) and observed in our work (Table 2) agree well with reduced water-holding capacities of pressure treated samples which were found in both studies. However, there is an anomalous situation in that both studies also reported reduced cooking losses in treated samples and MacFarlane (1973) reported higher moisture contents in cooked treated samples when compared to either standard control or cold-shortened samples. It is possible that muscle protein breakdown products resulting from pressure treatment bind water against heat loss in a way that physical forces do not measure.

Panelists were able to detect an improvement in overall desirability as a result of pressure treatment in New York and inside chuck roll cuts. Overall desirability ratings of the other 10 cuts were not significantly different from controls.

It is an interesting observation that pressurization has its greatest effect on tougher meat and very little effect on meat that is already tender.

From the subjective and objective results it is evident that tenderness of the pressure treated samples is superior to that of control samples. At this stage there are four tentative explanations for the tenderizing effect.

1. Breakdown of myofibrillar structure (MacFarlane, 1973)
2. Early release of lysosomal enzymes (Elgasim, 1977)
3. Creation of breaks in fiber structure as a result of massive contractions (Elgasim, 1977)
4. F-G transformation of action and/or myosin.

We are currently involved in a number of studies in an attempt to further elucidate the mechanisms by which pressure tenderizes meat.

Effect on pH

The effect of pressure on pH of ovine and bovine pre-rigor muscles is shown in Table 3. It is evident that pressure treatment caused a drastic change in the pattern of pH drop in all muscles studied. Significant differences between treated and control muscles were found at 1 hr ($P < .01$), 2 hr, 4 hr and 6 hr ($P < .05$) postmortem. At 24 hr postmortem both treated and control muscles exhibited similar pH values ($P > .05$). These results suggest that pressure treatment accelerates postmortem glycolysis and had no effect on the ultimate pH of muscles investigated.

Table 3. Effect of pressure on pH of longissimus dorsi, semimembranosus (from sheep) and semitendinosus (from cattle)

Muscle & Treatment		n	pH Hours postmortem 1**	2*	4*	6*	24
Sheep							
Longissimus dorsi	(C)	10	6.63	6.22	5.97	5.86	5.66
~ ~	(T)	10	5.82	5.76	5.70	5.67	5.65
Semimembranosus	(C)	10	6.48	6.16	5.92	5.84	5.69
~ ~	(T)	10	5.80	5.78	5.72	5.69	5.63
Cattle							
Semitendinosus	(C)	15	6.54	6.27	6.00	5.90	5.74
~ ~	(T)	15	5.81	5.75	5.73	5.73	5.64

*Significant at $P < .05$
**Significant at $P < .01$
C = control, T = treated
Conditions of treatment; pressure = 15,000 lb/sq in, duration = 2 min, and temperature, 39°C.
(Adapted from Kennick et al., 1980)

Protein Functionality

The results (some of which are preliminary) of these studies are summarized in Table 4. Immediately following the treatment WHC, protein solubility and emulsification capacity of protein extract and meat homogenate were all found to be

Table 4. Effect of pressure on protein functionality, protein quality, purge loss and cooking loss

Parameters	*Control*	*Treated*	*Observations*
Protein functionality			
WHC, %	40.2	35.4	*
Solubility, mg/ml	18.5	11.9	preliminary result
Emulsification capacity			
Protein extract[a]	66.9	61.1	preliminary result
Homogenate[b]	33.8	26.3	preliminary result
Protein quality			
PER[c]	2.6	2.5	ns
NPU[d], %	68.1	70.3	ns
BV[e], %	76.1	78.0	ns
Digestability, %	88.9	90.8	*
Purge loss, %	1.50	1.52	ns
Cooking loss, %	19.7	16.50	*

[a]Results expressed as ml oil emulsified/200 mg protein
[b]Results expressed as ml oil emulsified/0.375 g tissue
[c]PER = protein efficiency ratio
[d]NPU = net protein utilization
[e]BV = biological value
*Significant at $P < .05$
ns = non significant

lower than for control samples. At 24 to 168 hr postmortem, however, none of these parameters, were different from controls. Water-holding capacity of treated samples continued to be lower than that of control samples at all times measured.

Nutritional Value and Amino Acid Composition

Our study on the effect of pressure on nutritional quality of meat revealed that treatment did not significantly affect the apparent biological value (BV), net protein utilization (NPU) or protein efficiency ratio (PER) but did significantly improve protein digestability (Table 4). The total essential amino acid content of the control and treated samples were not different. Concentration of alanine, glycine and proline (non-essential amino acids), however, were increased by pressure treatment when compared to corresponding controls. Since these are the major amino acids of collagen it is likely that pressure treatment enhances degradation of collagen (Elgasim and Kennick, 1980).

Wholesale and Retail Yields

In order for the application of pressure treatment to be adapted commercially it was necessary to determine that it is effective on large muscle masses and that wholesale and retail yields are at least equal. The possibility that the massive contraction associated with treatment could cause large purge losses and extensive distortion of multi-muscled wholesale cuts was evaluated using 10 high Good and Choice cattle. One half of each carcass served as the hot-boned treated sample and the other as a cold-boned control.

There were no significant differences in purge loss for any of the 12 individual cuts and the overall mean purge loss (Table 4) was almost exactly equal.

There were no significant differences in yield of wholesale cuts, lean trim, fat or bone between the control and treated sides.

Wholesale cuts processed into roasts yielded essentially 100% and therefore did not differ in retail yield but this was not true for the wholesale cuts processed into steaks (Table 5). The treated tenderloin and top round had a slightly larger (0.68 and 1.91%, respectively) yield of retail cuts as a result of their shorter thicker conformation reducing end trim. The opposite was true for the ribeye and strip loin because the rounded ends required trimming causing a significant reduction in yield of 3.42 and 6.65%, respectively. The largest loss was in the boneless top sirloin where the major muscles contracted quite differently and resulted in a 16.41% lower yield from the treated sample. It is very possible that developing different techniques of packaging before pressurization and changed cutting techniques can reduce these losses.

Table 5. Effect of pre-rigor pressurization on processing yield of five major wholesale cuts process into steaks.[a]

	% mean yield		*Significance*	
Boneless Wholesale Cut	*Control*	*Treated*	*S.E.*[b]	*of difference*
Ribeye	99.41	95.99	.64	**
Strip loin	96.79	90.14	2.08	*
Tenderloin	94.97	97.65	1.37	ns
Top sirloin	95.26	78.85	2.56	**
Top round	90.87	92.78	1.06	ns

[a]n = 10
[b]S.E. = Standard error of the difference between 2 means
[c]Conditions of treatment; pressure = 15,000 lb/sq in, duration = 2 min, temperature, 39°C
*Significant ($P < .05$)
**Highly significant ($P < .01$)

Micro Structure

Comparison of control and treated samples shown in the scanning electron micrographs in Figure 1 shows extensive disruption of the endomyseal sheath of the pressure treated sample. This must have a substantial weakening effect on the structure of the muscle and could be one of the major causes of the observed tenderizing effect.

Figures 2 and 3 present a massive change in the ultra structure which we have not as yet explained. It is possible that the blurred appearance of the treated sample is the result of an F-G transformation.

Conclusion

Pre-rigor pressurization tenderizes meat from a wide variety of classes of both cattle and sheep and does not reduce the total yield of wholesale or retail cuts of beef.

There is a massive input of energy into the production of high quality beef, from man made fertilizers for grain crops through the chilling, handling and shipping of large portions of carcasses which are not used for human consumption. A method of assuring the eating quality of beef without exten-

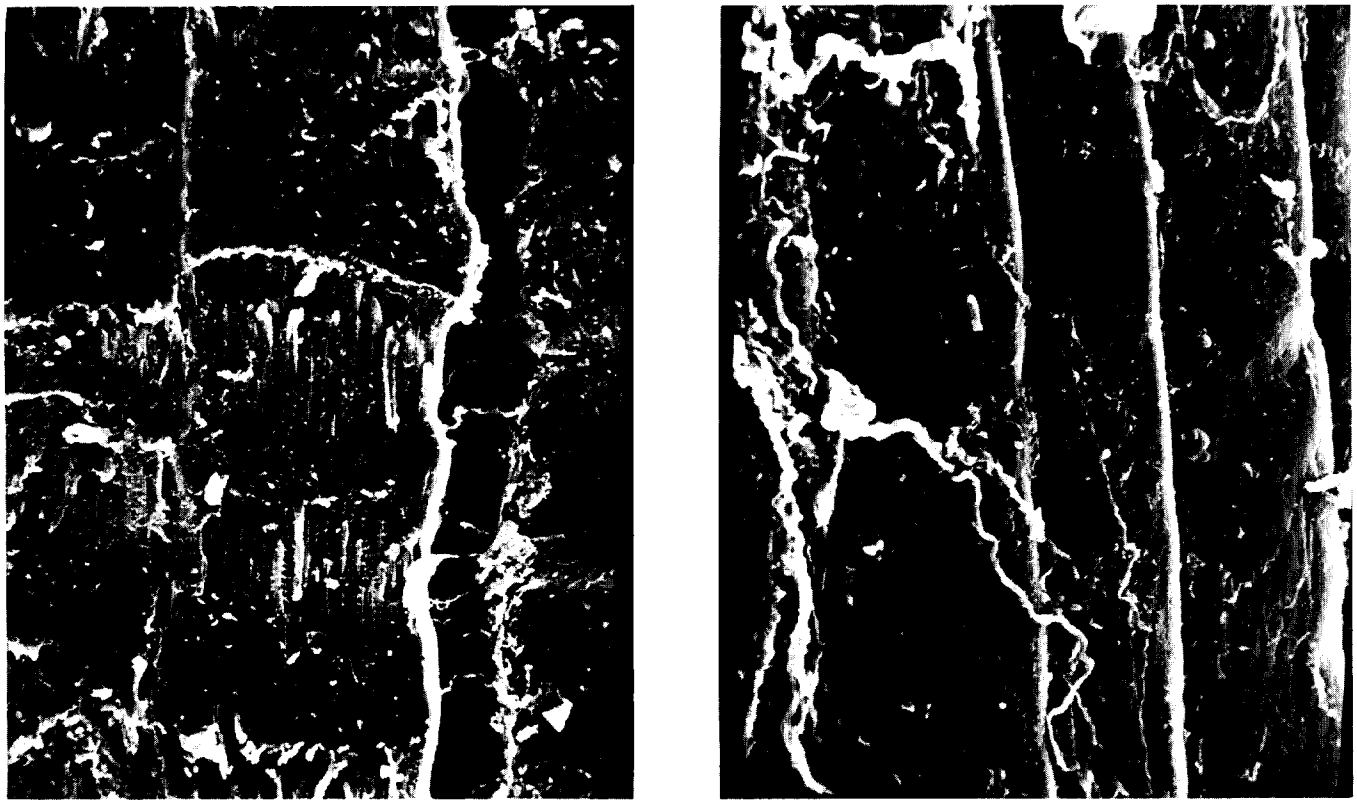

Figure 1. Scanning electron micrograph of (a) pressure treated (15,000 lb/sq in) and (b) control semitendinosus muscle (1000X). (Elgasim and Kennick, 1980)

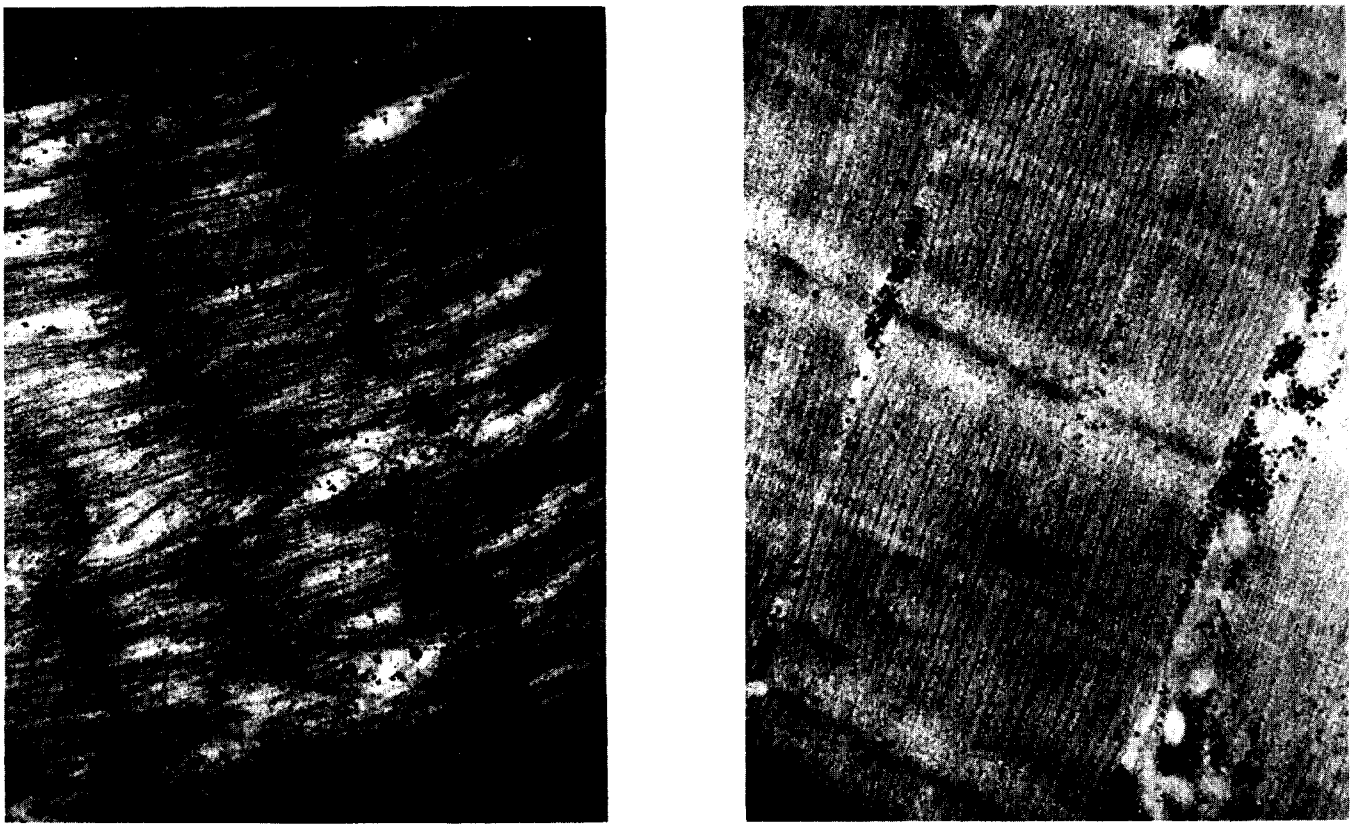

Figure 2. Transmission electron micrograph (longitudinal section) of (a) pressure treated (15,000 lb/sq in) and (b) control semitendinosus muscle.

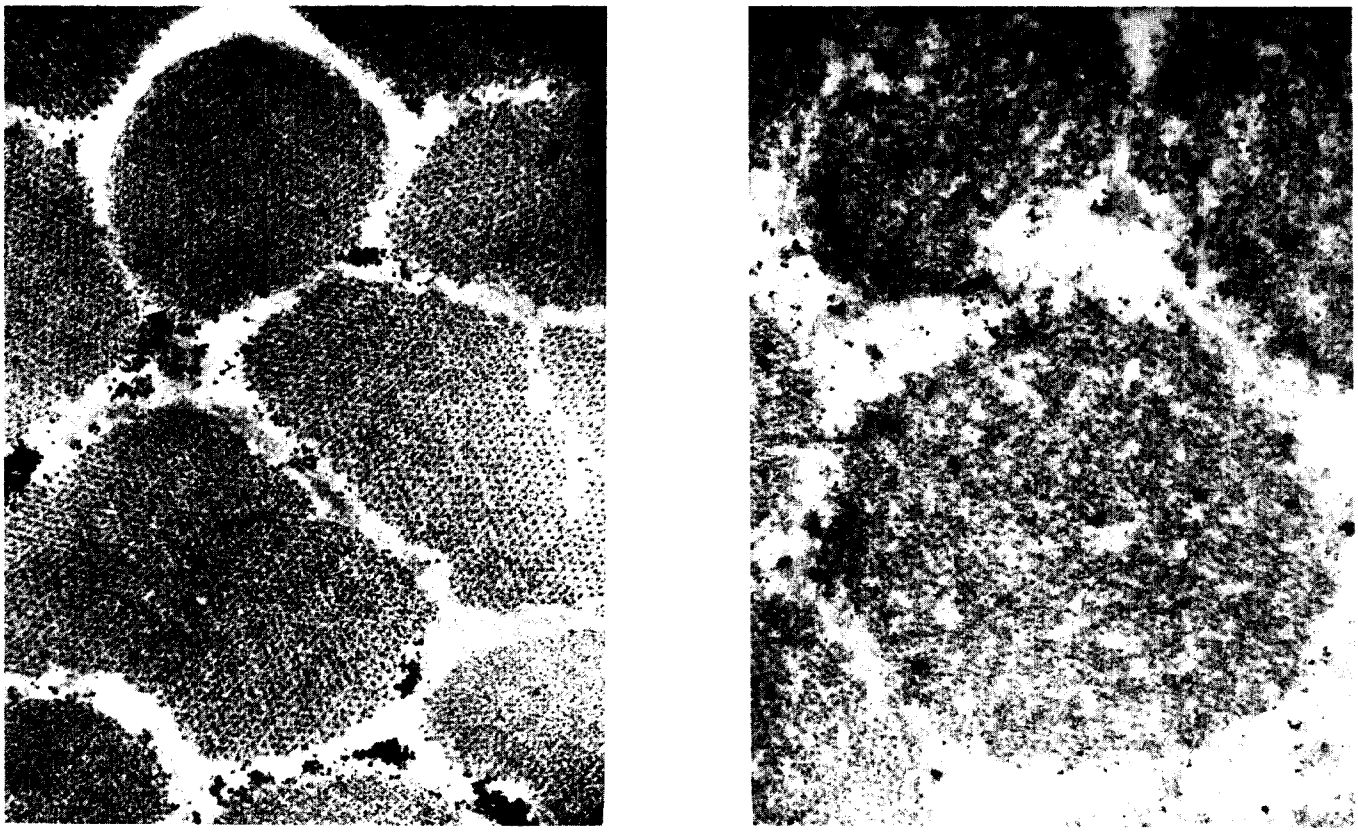

Figure 3. Transmission electron micrograph (cross section) of (a) pressure treated (15,000 lb/sq in) and (b) control semitendinosus muscle.

sive grain feeding would allow beef to be produced by the most biologically efficient method in any given area. Hot boning, an essential step in pre-rigor pressurization, would eliminate the chilling, re-heating for rendering and/or shipping of approximately 40% of the carcass which is trimmable fat and bone. The feasibility of a commercial application of pre-rigor pressurization after the determination of optimum treatment condition and appropriate engineering developments seems very great and broadly beneficial.

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