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Use of Electrical Stimulation for Hot Boning of Meat

H. R. Cross¹ and S. C. Seideman²

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With ever-increasing processing costs, the meat industry is being forced to look into new and innovative processing methods. The efficiency of marketing meat and moving it to the consumer must be increased. The meat industry must face these new challenges and demands in order to survive.

Over the past two decades, the meat industry has dramatically shifted its manner of distributing meat, from shipping beef to retail stores in carcass form to shipping beef to retail stores in the form of vacuum packaged primal and subprimal cuts (Table 5.1). This manner of distribution has introduced a concept identified as the "boxed beef" distribution system. This system entails the process of prefabricating carcasses into primal or subprimal cuts and vacuum packaging them at locations that are near the areas of livestock production. Processing meat at a centralized location in areas that are in the general proximity to areas of consumption is a concept that is termed "centralized breaking-point". At present, 65–70% of beef distributed to retail stores is distributed in the form of vacuum packaged primal cuts. Advantages attributed to the centralized breaking-point system include more efficient use of labor and meat by-products,

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of hot boning are: (1) hot boning after conditioning or chilling the carcass for a specified time postslaughter; (2) hot boning, vacuum packaging, and holding the primal cuts at an elevated temperature for a specified period of time; and (3) electrically stimulating the carcass followed by hot boning at various times poststimulation. Each method can produce differences in the ultimate quality of the meat. The objectives of this chapter are to discuss the history of hot boning, the storage parameters and sensory properties of hot-boned meat, the present industry status and economic implications of hot boning in the United States, and the use of postmortem electrical stimulation in conjunction with hot boning.

HISTORY OF HOT BONING RESEARCH

The removal of meat from the carcass of an animal soon after slaughter is not new. The first humans to eat meat almost certainly would have torn the flesh from the carcass soon after it was killed. Even today, in underdeveloped countries and in large areas of South America, Asia, and the Middle East, people still practice hot boning. Why has hot boning gained international interest during the past decade? The answer lies in economics. Renewed interest has been fostered by the economic advantages, including savings in energy, space, labor, materials, and product weight loss as well as improved functional properties. The advantages of hot boning are many, but before this system can be adopted by industry, industry must be assured of being able to maintain a safe and high quality product. In addition, many technical questions have not been answered and will not be until hot boning is commercially applied under a variety of conditions.

The history of hot boning research can be traced back to research reports by Lowe and Stewart (1946), Ramsbottom and Strandine (1949), and Paul *et al.* (1952), who found that meat cooked prerigor was more tender than meat cooked after rigor mortis. Weidemann *et al.* (1967) and Cia and Marsh (1976) found similar results and reported that the immediate cooking of prerigor muscle eliminated the occurrence of rigor mortis and its detrimental effects on tenderness.

Researchers such as Lowe and Stewart (1946), Ramsbottom and Strandine (1949), Locker (1960), and Herring *et al.* (1965, 1967) performed much of the muscle biology research that ultimately led to more applied hot boning research. They generally found that muscles excised soon after slaughter and permitted to contract freely were less tender than those muscles restrained during the development of rigor mortis or excised postrigor. The extra contraction of muscles induced under these conditions is referred to as "cold shortening." There is a great amount of scientific evidence indicating that the greater the degree of shortening the tougher the meat on subsequent cooking. Hot boning requires that muscles be removed before glycolysis is complete. In this regard, research by Marsh

FIG. 5.1. Optimal hot-processing systems for beefsteak and roast items.

Adapted from Kastner (1983). Reprinted from *Food Technology*. 1983. (May):96-104. Copyright © by Institute of Food Technologists.

(1954), Marsh and Thompson (1958), Bendall (1960), Marsh and Leet (1966), Cook and Langsworth (1966), and Cassens and Newbold (1967) found that the rate of glycolysis as measured by pH decline was dependent upon the temperature of the muscle. In conventional meat processing, the negative effects of cold shortening are partially reduced by high temperature aging or slow cooling of the carcass while rigor mortis is proceeding. During this period, the muscle glycogen stores are being broken down to lactic acid. With this lactic acid production, the pH of the muscle is falling toward its ultimate value of 5.4 to 5.6. When the pH of the muscle has fallen to approximately 6.0, cold shortening will no longer occur to the extent where there is significant toughening, and hot boning can proceed.

Research on the hot boning of pork began in the mid to late 1960s. Marsh *et al.* (1972) excised pork muscles prerigor and subjected them to a temperature environment of 0°C for 24 hr. The pork muscle became significantly less tender. The relative toughening of pork due to cold shortening is much smaller when compared with beef—30% increase in pork toughness *versus* 200% increase in beef toughness (Marsh and Leet 1966; McCrae *et al.* 1971; Behnke and Fennema 1973). Because lower microbial

counts were found on hot-boned ham, it was hypothesized that the rapid processing of hot-boned hams offered less opportunity for postslaughter microbial contamination and growth (Barbe *et al.* 1966; Barbe and Henrickson 1967). Mandigo and Henrickson (1966) found hot-boned hams to be equal or superior to conventionally processed hams in yield, tenderness, juiciness, flavor, and moisture content. Trautman (1964) found that hot-boned pork had greater emulsifying capacity and more salt-soluble proteins than postrigor muscle. Because of these early studies on pork, some commercial processors are now hot boning pork.

Actual hot boning research as related to applied technology began in the early 1970s. Much of the early research on beef hot boning relied on carcass and muscle conditioning at elevated temperatures or the conventional aging of hot-boned muscles or primals to prevent or minimize any effects of cold shortening. Schmidt and Gilbert (1970) excised beef longissimus, semitendinosus, and semimembranosus muscles at 2 hr postmortem and allowed them to age for 24 or 48 hr (Fig. 5.1, System A). When compared with controls excised from opposite sides and chilled at 9°C until 24 hr postmortem, the hot-boned samples were equal or superior to con-

trols in tenderness. Schmidt and Keman (1974) hot boned muscles from one side of six beef carcasses at 1 hr postmortem (Fig. 5.1, System B). The hot-boned muscles were stored at 7°C for 4 hr, then were placed in a 1°C cooler overnight. The muscles were vacuum packaged at 24 hr postmortem and held at 1°C for 8 days. The controls from the opposite sides were removed from the carcass at 8 days postmortem. Differences between sensory panel tenderness and shear force were not significant.

Kastner *et al.* (1973) boned bovine muscles at 2, 5, 8, and 48 hr postmortem and found 2 and 5 hr periods to produce slightly less tender meat than that which had been boned at 8 and 48 hr postmortem. The differences between the two treatments were not statistically significant. Will and Henrickson (1976) compared hot-boned beef boned at 3, 5, or 7 hr and then delay-chilled (16°C) for 48 hr with cold-boned (1°C) beef (Fig. 5.1, System D). They concluded that hot boning beef as early as 3 hr postmortem followed by a delayed chill resulted in satisfactory tenderness ratings. The approaches to hot boning outlined in Fig. 5.1 were designed to produce acceptable steak and roast cuts by preventing or alleviating the potential problems of cold shortening. Generally, these systems have been shown not only to ensure a product that is equal or superior in sensory traits to their control counterparts but also to produce a desirable product from an appearance and shelf-life standpoint (Cross 1980; Kastner 1981). However, these methods of hot boning may not facilitate the continuous flow of product required by the industry due to the need for carcass or muscle conditioning.

ELECTRICAL STIMULATION AND HOT BONING

Harsham and Deatherage (1951) reported that the application of electrical current to unchilled beef carcasses resulted in a more tender cooked product. Even though this research was the subject of a patent, industry elected not to pursue this approach, primarily because the negative effects of cold shortening were not recognized until the mid- to late-1950s. In addition, the efficiency of the meat industry's chillers was such that the effects of rapid temperature decline were not evident. The degree of fatness in U.S. beef prevented rapid postmortem temperature decline in muscle. The concept of electrical stimulation to reduce the effects of cold shortening was first realized in New Zealand since scientists there were seeking a means to overcome toughening problems in frozen lamb.

The New Zealand research defined the role of electrical stimulation in accelerating the onset and development of rigor mortis. A practical procedure for using electrical current to condition lamb carcasses with a subsequent reduction in the toughening during freezing was devised and reported by Chrystall and Hagyard (1976). These studies stimulated interest in other countries, especially in the United States, England, and Australia, where the aim has been to study the use of electrical stimula-

tion of beef rather than lamb. Published data to date have shown that a wide range of applied voltages will achieve acceleration of glycolysis in beef. In England, workers use 600 to 700 V DC (Bendall *et al.* 1976); in New Zealand (Gilbert and Davey 1976), workers use 3600 V AC; and in the United States, workers use 200 to 600 V AC (Berry and Kotula 1982; West and Oblinger 1979).

Electrically stimulating carcasses soon after slaughter can accelerate the onset of rigor mortis, thereby eliminating or minimizing tenderness problems associated with cold shortening. Therefore, carcass or cut conditioning periods (Fig. 5.1) used to avoid potential tenderness problems associated with rapid chilling prerigor can be eliminated or reduced by using electrical stimulation. Also, postmortem electrical stimulation may enhance tenderness by other mechanisms (Dutson *et al.* 1980). For these reasons, electrical stimulation has been incorporated into much of the recent hot boning research.

A number of electrical stimulation/hot boning systems are outlined in Fig. 5.2. Gilbert and Davey (1976) used electrical stimulation to accelerate the onset of rigor mortis to allow early boning of beef muscles (Fig. 5.2, System A). Rigor developed in 3–4 hr in stimulated carcasses; thus, they could be boned at 5 hr postmortem as compared with 24 hr for controls. Electrically stimulated muscles had all reached a pH of less than 6.0 at 5 hr postmortem. The authors reported that “stimulated carcasses had achieved rigor in 5 hr and it should be possible to bone them without the risk of cold-shortening despite subsequent rapid chilling or freezing.” Tenderness of unaged cuts transferred immediately to the freezer is the palatability characteristic most likely to be affected by processing treatment. Cuts from the stimulated sides had a moderate to high degree of tenderness. Gilbert and Davey (1976) concluded “that stimulation reduced the need for conventional chilling to achieve carcass setting, overcame cold and thaw shortening and still permitted additional tenderizing from aging.” They further concluded that the quality of the cuts from electrically stimulated/hot-boned beef sides were as acceptable as unstimulated/cold-boned (24 hr) ones and were further improved by aging.

Gilbert *et al.* (1976) hot boned/stimulated beef muscles at 1 hr and conventionally boned at 24 hr (Fig. 5.2, System B). Except for the fillet, the unstimulated, unaged cuts were all tougher and less uniform than their stimulated counterparts. Stimulation greatly reduced vulnerability of the cuts to shortening despite very early boning and rapid freezing. Gilbert *et al.* (1976) concluded “that hot-boned cuts from stimulated carcasses aged before freezing attained a high and uniform degree of tenderness. The major potential of carcass stimulation followed by hot-boning lies in reducing the chilling and aging period to two days from the 10–20 days often used commercially.” Pierce (1977) found that hot-boned beef that had been previously electrically stimulated was significantly more tender than unstimulated, hot-boned beef.

Cross and Tennent (1980) compared the effects of electrical stimulation

FIG. 5.2. Optimal electrical stimulation and hot-processing systems for beefsteak and roast items.

Adapted from Kastner (1983). Reprinted from *Food Technology*. 1983. (May):96-104. Copyright © by Institute of Food Technologists.

on USDA Choice and Good beef carcasses boned at 1, 4, and 48 hr postmortem (Table 5.3). Electrically stimulated carcasses were more tender than nonstimulated carcasses at all postmortem excision times. They also found that electrical stimulation tended to offset the negative effects of early boning time on tenderness and that, with electrical stimulation, muscles can be frozen after 24 hr. Numerous additional studies have been reported that vary the electrical stimulation treatment and boning times (Table 5.4). The interrelationships among stimulation method, current

distribution, time postmortem for current application, muscle excision time poststimulation, and rate of chill are complicated and have not been thoroughly studied. Considerable work is needed in this area before optimal systems can be developed.

It appears from the literature that some carcasses can be hot boned within 1 hr postmortem without affecting tenderness whereas others cannot. Electrical stimulation may be a useful tool in allowing these in the latter group to be hot boned at 1 hr also.

TABLE 5.3. Effect of Postmortem Boning Time and Electrical Stimulation on Palatability and Shear Force of the Beef Longissimus

Trait	Postmortem boning time (hr) ^a					
	1		4		48	
	ES ^b	NS ^b	ES ^b	NS ^b	ES ^b	NS ^b
Tenderness ^c	5.6 ^a	5.4 ^{ab}	5.5 ^a	5.1 ^b	6.0 ^a	5.6 ^a
Connective tissue ^c	6.5 ^{bc}	6.8 ^{ab}	6.6 ^{abc}	6.3 ^c	6.8 ^{ab}	7.0 ^a
Juiciness ^c	5.3 ^a	5.2 ^a	5.1 ^a	5.2 ^a	5.2 ^a	5.5 ^a
Flavor intensity ^c	5.1 ^a	5.0 ^a	4.9 ^a	4.8 ^a	5.0 ^a	5.1 ^a
Shear force (kg)	7.3 ^a	7.9 ^a	6.5 ^{ab}	6.8 ^{ab}	5.1 ^c	5.6 ^{bc}

Source: Adapted from Cross and Tennent (1980).

^a Means in the same row with different letters are significantly different ($P < 0.05$).

^b ES = electrically stimulated. NS = nonstimulated.

^c Tenderness: 8 = extremely tender and 1 = extremely tough. Connective tissue: 8 = none and 1 = abundant. Juiciness: 8 = extremely juice and 1 = extremely dry. Flavor intensity: 8 = extremely intense and 1 = extremely bland.

WATER HOLDING CAPACITY

Carcass shrinkage values are usually about 2% in the first 24 hr. Falk (1974) reported that hot-boned beef had a lower shrinkage value at 3, 5, and 7 hr holding periods as compared with 48 hr control sides. Taylor *et al.* (1980) also reported that hot boning reduced overall evaporative losses by more than 1%.

The capacity of primal cuts to retain their unbound water during storage has been measured by practical manifestations of this property such as purge (fluid) loss during vacuum-packaged storage, loss during retail display, and thaw and cooking losses.

Table 5.5 outlines comparisons of water holding capacity between hot and cold boning treatments without electrical stimulation. Kastner *et al.* (1973) conditioned muscles at 16°C for 2, 5, and 8 hr prior to boning. Hot-boned cuts removed after 8 hr at 16°C had a lower water holding capacity (WHC) than did comparable controls, but the differences were not large enough to be of practical importance. Follett *et al.* (1974) evaluated different conditioning temperatures for cuts removed at 1 hr postmortem. Differences in percentages for purge loss indicated that cuts conditioned at 5°, 10°, or 15°C for 24 hr lost less weight during storage than did cold-boned cuts. During retail display, cuts conditioned at 15°C had higher weight losses than cold-boned cuts. Cooking losses were greater for cuts conditioned at 5° and 10°C as compared with the controls.

Several studies that utilized electrical stimulation prior to hot boning are summarized in Table 5.6. Cross and Tennent (1979A) studied the effect of electrical stimulation and hot boning at 1 hr postmortem on purge loss differences of 10 primal cuts. Overall, the hot-boned treatment resulted in

TABLE 5.4. Variations in Electrical Stimulation (ES) and Boning Conditions

Authors	Product	Voltage	Current	Pulses (duration)	ES application time (PM)	Boning time (PM)
Berry and Kotula (1982)	Beef	250–400	1.5	40 (1 s)	60 min	2 hr
Butler <i>et al.</i> (1981)	Beef	500	5.0	16 (1.8 s)	Immediately	2 hr
Gill (1980)	Lamb	1130	1.8	858 (10 min)	905/30 min	30 min
Kotula and Emswiler-Rose (1981)	Beef	250–400	1.5	12 (10 s)	60 min	Immediately
Mrigadat <i>et al.</i> (1980)	Beef, lamb, pork	550	5.0	16 (1.8 s)	30–45 min	Immediately
	Rabbit	220	5.0	20 (2)	20 min	Immediately
Raccach and Henrickson (1978)	Beef	300	1.6–1.8	400 (0.5 min)	15/30 min	1.5 hr
Stern (1980)	Lamb	250–400	1.5	30 (1 s)	60 min	Immediately
West and Oblinger (1979)	Beef	500	1.5–2.0	60 (1 s)	30 min	45 min

Source: Adapted from Oblinger (1983). Reprinted from Food Technology, 1983, 37:86. Copyright © by Institute of Food Technologists.

TABLE 5.5. Difference Comparison of Water Holding Capacity Measures Between Cold- and Hot-boned Cuts as Related to Carcass or Cut Conditioning Treatment

Reference	Treatments ^a	Muscle or cut ^b	Storage time	Measures (difference, %) ^b		
				Purge	Retail	Cooking
Kastner <i>et al.</i> (1973)	CB—48 hr, 2°–3°C ^c	4 muscles	48 hr			(13.8 to 18.2%) ^d 0.4
	HB—2 hr, at 16°C, then 2°–3°C					
	HB—5 hr at 16°C, then 2°–3°C					
	HB—8 hr at 16°C, then 2°–3°C					
Follett <i>et al.</i> (1974)	CB—36 hr at 2°–3°C	Top round	7 days			(20.0 to 28.0%) ^d 0.3
	HB—1 hr, conditioned at: 15°C for 24 hr, then 0°–1°C			50.0	–25.0	
	10°C for 24 hr, then 0°–1°C			80.0	5.0	
	5°C for 24 hr, then 0°–1°C			75.0	20.0	
Taylor <i>et al.</i> (1980)	–5°C for 12 hr, then 0°–1°C	15 primals	5 days	–40.0	5.0	3.9
	CB—15°C for 7 hr, then 0°–1°C, 48 hr			(0.11%) ^d		
	HB—1–2 hr, 9 hr at 10°C, then 1°C			0		
	ES (50 min) + HB at 1–2 hr, –1°C for 24 hr			36.4		
	CB		21 days			(0.37%) ^d 56.8 29.7
	HB					
	ES + HB					

Source: Adapted from West (1983). Reprinted from Food Technology, 1983, 37:57. Copyright © by Institute of Food Technologists.

^a CB = cold-boned. HB = hot-boned. ES = electrical stimulation.

^b Difference values calculated as follows: Difference (%) = (CB value – HB value ÷ CB value) × 100.

^c Paired control sides were conditioned at appropriate times prior to chilling.

^d Actual values for cold-boned controls.

TABLE 5.6. Difference Comparison of Water Holding Capacity Measures Between Cold- and Hot-boned Cuts as Related to Electrical Stimulation and Chilling Treatments

Reference	Treatments ^a	Muscle or cut	Storage time (days)	Measures (difference, %) ^b		
				Purge	Cooking	Juiciness ^c
Cross and Tennent (1979A)	CB—48 hr, 2°–3°C	10 primals	20	(1.02%) ^d		
	ES + HB—1 hr, 2°–3°C			71.6		
Seideman <i>et al.</i> (1979)	CB—24 hr, 1°–3°C	Loin	14	(0.69%) ^d	(28.12%) ^d	HB < CB
	ES (30–40 min) + HB (45–60 min) 1°–3°C			17.9	–3.1	
	CB	Eye of round	14	(1.97%) ^d	(29.82%) ^d	ND
	ES + HB			97.5	–21.0	
Cross and Tennent (1980) ^e	NES + CB (48 hr)	Loin	—	(1.7%) ^d	(34.3%) ^d	ND /
	ES + CB (48 hr)			–29.4	–2.0	
	NES + HB (1 hr)			0	3.2	
	ES + HB (1 hr)			5.9	7.9	
	NES + HB (4 hr)			–47.1	–2.3	
	ES + HB (4 hr)			17.6	0.9	
	NES + CB (48 hr, 2°C)	Loin	7 and 14	(0.33%) ^d		
Berry and Kotula (1982)	ES + CB (48 hr, 2°C)			–45.5		
	ES + HB (2 hr, 2°C)			–236.4		
	NES + HB (2 hr, 2°C)			–93.9		
	NES + CB	Eye of round	7 and 14	(0.64%) ^d		
	ES + CB			–81.3		
	ES + HB			–71.9		
	NES + HB			–3.1		

Source: Adapted from West (1983). Reprinted from Food Technology. 1983. 37:57. Copyright © by Institute of Food Technologists.

^a CB = cold-boned. ES = electrical stimulation. HB = hot-boned. NES = nonstimulated.

^b Difference values calculated as follows: Difference (%) = (CB value – HB value ÷ CB value) × 100.

^c ND = no difference at probability level used in reference.

^d Actual value of CB control.

^e Used three storage treatments involving (1) immediate freezing; (2) freezing after 24 hr chill; and (3) chilling for 20 days then freezing.

71.6% less purge than did cold boning at 48 hr. Seideman *et al.* (1979) reported comparable findings for eye of round cuts but detected no differences in the purge loss of loin cuts. The eye of round cuts that were hot boned had a higher cooking loss than cold-boned cuts, suggesting a compensatory loss. In contrast, Berry and Kotula (1982) presented results suggesting that both electrical stimulation and hot boning lowered the ability of loin and eye of round cuts to hold moisture during vacuum-packaged storage.

Cross and Tennent (1980) evaluated various combinations of hot boning, electrical stimulation, cold boning, and storage methods on purge and cooking losses. When the combined effects of boning times and stimulation treatments were compared, stimulation of carcasses prior to cold boning was found to cause higher purge and cooking losses than did the control (nonstimulated) group. Boning at 1 hr resulted in loins with losses similar to the controls. Boning at 4 hr resulted in purge and cooking losses greater than the control group.

The majority of the literature indicates that if a treatment is used to promote a rapid pH decline prior to boning, water holding capacity (WHC) of hot-boned cuts is similar to that of cold-boned cuts. The losses at the various stages in the product flow may be compensatory. Advantages may be evident at initial stages (purge losses) but not later (cooking losses). Detrimental losses of WHC in hot-boned cuts do not appear to be a problem unless chilling of the cuts is too slow. One could expect more uniformity of WHC characteristics within hot-boned muscles since chilling is more uniform (Tarrant 1977; Tarrant and Mothersill 1977).

APPEARANCE PROPERTIES

Hot-boned beef cuts packaged in oxygen-permeable film have often been reported to be darker in color than cold-boned cuts, but the color was not considered unacceptable (Kastner *et al.* 1973; Kastner and Russell 1975; Hunt *et al.* 1980). Electrical stimulation coupled with hot boning tended to minimize the color differences between hot- and cold-boned cuts. Color uniformity of hot-boned muscle has been observed to be superior to cold-boned controls. This was due to the uniform pH decline of the muscle (electrical stimulation and/or uniform rate of temperature decline).

Cross and Tennent (1979A) reported that after 20 days of vacuum-packaged storage at 2°–3°C, hot-boned (1 hr postmortem) and conventionally processed (48 hr postmortem) primal cuts did not significantly differ in lean color; however, hot-boned cuts had significantly whiter fat. Conventionally processed cuts were rated more normal in shape and had greater weight losses (as purge) during storage as compared with hot-boned cuts (Cross and Tennent 1979A).

Buchter (1980) reported that hot-boned beef aged 1 week in an 80% O₂ + 20% CO₂ controlled atmosphere was slightly superior in retaining color and sensory traits as compared with conventionally processed beef aged in the same atmosphere.

MICROBIOLOGY

As is the case with any form of new technology, it is critical to examine all aspects of the process as well as the product that results from such a system. Few researchers have studied the microbiological aspects of hot boning. Whether one is dealing with conventional slaughter and chilling operations or innovative systems, such as hot boning, it is important that product integrity be maintained throughout the process. A vital portion of this integrity deals with the microbiology of the processing system from the natural microflora of the live animal to the microflora that develop during processing, storage, and distribution.

A major consideration of hot boning is the significant increase in exposed surface area available for cross-contamination as compared with conventional cold-boned meat. Hot-boned meat is meat still close to body temperature, with an initial microflora that reflects its environment. After packaging, the differences in handling begin to affect the microflora. With conventional cold boning, the heterogeneous population begins to change quickly as the carcass is chilled. There are combined effects of reduced temperature and surface desiccation. These conditions tend to favor the development of psychrotrophic microorganisms. With hot-boned meat, there is no comparable chilling period; hot meat is placed directly into bags and/or boxes within 3 to 4 hr postmortem. The hot meat is placed in a cooler or freezer; thus, there is no 24–48 hr of cold-temperature selection and desiccation.

In evaluating the effects of hot boning systems on the microflora, one must consider the effects of electrical stimulation, the packaging system, size of cut, and the temperature profile. Kotula (1981) reviewed the available research on the effects of electrical stimulation and growth of microorganisms and concluded that there was little or no influence of electrical stimulation on resident microflora.

Falk and Henrickson (1974) compared hot-boned ground beef with conventionally processed ground beef and found hot-boned ground beef to have slightly higher bacterial counts than conventionally processed beef but concluded the differences were not large enough for hot boning to be detrimental to shelf-life. Schmidt and Gilbert (1970) reported that conventionally processed wholesale cuts had a surface bacteria count of less than 10³/cm², whereas hot-boned wholesale cuts had a surface bacteria count of 10²/cm² to 10⁵/cm². They concluded that acceptable meat (as evaluated by

a sensory panel) having satisfactory microbiological standards could be produced when primal cuts were hot boned, vacuum packaged, and conditioned for 48 hr at 15°C.

Fung *et al.* (1980) reported that mesophilic and psychrotrophic bacterial counts of hot-boned and conventionally processed beef were low ($\log 0.2/\text{cm}^2$) at 0 time, but after 14 days of vacuum packaged storage at 2.2°C, hot-boned cuts had higher microbial counts than conventionally processed cuts. Mesophilic and psychrotrophic counts of hot-boned cuts were $\log 5.26/\text{cm}^2$ and $\log 5.15/\text{cm}^2$, respectively, and $\log 4.64/\text{cm}^2$ and $\log 4.43/\text{cm}^2$, respectively, for conventionally processed cuts (Fung *et al.* 1980). In the study by Fung *et al.* (1980), hot-boned cuts were vacuum packaged and boxed prior to chilling. This resulted in a slower chilling rate for hot-boned cuts which could have contributed to higher microbial loads and subsequently increased growth of bacteria in cold storage (Fung *et al.* 1980). Emswiler and Kotula (1979) reported that aerobic plate counts (APC) of ground beef made from hot-boned beef (2 hr postmortem) were either significantly lower or not significantly different from APC of ground beef made from conventionally processed beef. No significant differences in Most Probable Numbers (MPN) of coliforms and *Escherichia coli* were found between ground beef made from hot-boned and conventionally processed beef (Emswiler and Kotula 1979). They concluded that bacterial quality of ground beef made from hot-boned carcasses does not limit and might enhance the feasibility of boning carcasses before chilling.

Temperature Control

A major barrier to the adoption of hot boning is the uncertainty regarding the cooling procedures necessary to maintain the microbiological integrity of hot-boned meat. Herbert and Smith (1980) reported on the refrigeration requirements to meet the microbial demands of hot-boned meat. These workers sought to define temperature and microbiological parameters that would enable processors to chill and freeze beef while avoiding excessive bacterial growth. Herbert and Smith (1980) based much of their work on the observation of Meynall (1958) that rapid cooling to below 8°C of blended meat samples on which bacteria are growing results in a substantial decline in numbers. This work led Herbert and Smith (1980) to recommend that hot-boned meat be cooled to 8°C or below within 4 hr of boning when the initial temperature of the boned meat is 40°C. Their recommendation was 6 hr when initial temperature was 30°C and 9.5 hr for 20°C.

It can be concluded, based on the presently available data, that the practice of hot boning with or without electrical stimulation does not alter the microbiological quality of the resultant products. The major concern to processors and merchandisers is the temperature profile or history of products that originate as hot-boned meat.

COOKING PRERIGOR MUSCLE

The precooking of hot-boned muscle can result in considerable energy savings, particularly if little or no heating is required before serving (Berry *et al.* 1980). Cooked prerigor meat has been found to be more tender than cooked postrigor meat (Ramsbottom and Strandine 1949; Paul *et al.* 1952; Pearson 1971). Weidemann *et al.* (1967) and Cia and Marsh (1976) found similar results and reported that the immediate cooking of prerigor muscle eliminated the occurrence of rigor mortis and its detrimental effects on tenderness.

Cia and Marsh (1976) cooked sternomandibularis muscle at various stages of rigor mortis and concluded that although prerigor muscles shortened considerably more than postrigor muscle, cooking losses for prerigor muscle were lower and tenderness ratings were higher, particularly if cooked within 3 hr of slaughter.

Weidemann *et al.* (1967) found that after broiling and oven roasting, prerigor muscle became more tender product and postulated that the production of supercontraction clots disrupted the protein filaments and produced the resulting tenderization. Streitel *et al.* (1977) found microwave cookery to tenderize prerigor beef by as much as 50% when compared with the microwave cookery of postrigor beef. The speed of heat application of microwave cookery could, perhaps, produce even better tenderization results than conventional methods of cookery (Streitel *et al.* 1977). They also observed the clots of coagulated proteins in cooked prerigor beef as observed by Weidemann *et al.* (1967) and suggested that these clots were an indication of a disruption of the muscle's internal structure.

Berry *et al.* (1980) reported that cooked prerigor semimembranosus and semitendinosus roasts when served as cubes had significantly higher shear force values, higher amounts of sensory panel detectable connective tissue, and lower tenderness and juiciness scores than postrigor cooked roasts. However, no significant differences in sensory characteristics were found between prerigor and postrigor semitendinosus roasts when they were evaluated in a thinly sliced form (Berry *et al.* 1980).

Ray *et al.* (1981A,B) compared hot-boned (1 hr postmortem) semitendinosus (ST) and semimembranosus (SM) muscles with their conventionally processed (7 days postmortem) counterparts. Prerigor-cooked roasts from SM and ST muscles exhibited greater shortening (27 vs 18%) than those of postrigor muscles, whereas the width of the roasts from the prerigor ST was greater than roasts from postrigor muscles (+2 vs -7%). Roasts from prerigor muscles were deeper in width (23 vs 6.5%) than those from postrigor muscles, suggesting cooked roasts from prerigor muscles were than their counterparts. Prerigor roasts from ST and SM muscles had higher cooking yields, 84 vs 78% and 86 vs 79%, respectively, than postrigor roasts. Meat from postrigor-cooked roasts was significantly more tender than prerigor meat (3.6 vs 7.4 kg/1.27 cm). Prerigor roasts required

significantly less (22%) cooking time (93.2 vs 119.9 min/kg) than chilled postrigor roasts (Ray *et al.* 1981A,B).

UTILIZATION OF HOT BONING MEAT FOR THE PRODUCTION OF GROUND BEEF

Ground beef is a very important commodity in the United States. If advantages in functional properties, particularly water holding capacity (WHC) of prerigor meat, could be maintained by hot boning, tremendous savings could accrue. However, trimmings for the production of ground beef may have originated from carcasses from which primal cuts were hot boned and, therefore, may have undergone treatments to prevent cold shortening.

Table 5.7 illustrates the effects of these postmortem treatments on cooking loss and juiciness ratings. Most studies used carbon dioxide (CO₂) in some form to chill the hot trimmings and stored the finished product in the frozen state.

Jacobs and Sebranek (1980) compared ground beef patties made from hot-boned beef with those from conventionally processed beef. They concluded that ground beef patties made from hot-boned beef had a higher pH value, sustained less cooking loss, and were preferred by a consumer panel ($n > 100$) for tenderness, juiciness, and overall acceptability as compared with ground beef patties made from conventionally processed meat. Cross *et al.* (1979) concluded that ground beef made from hot-boned beef was

TABLE 5.7. Comparison of Cooking Loss and Juiciness Values of Ground Beef Prepared from Cold- and Hot-boned Meat

Reference	Treatments ^a	Storage	Comparison ^b	
			Cooking loss	Juiciness
Lester (1979)	CB (48 hr); HB (45 min); ES + HB; HTC (5 hr at 16°C) + HB; CO ₂	Fresh	ND	ND
Cross and Tennent (1979B)	CB (48 hr); HB (3 hr), CO ₂	Frozen (-10°C)	HB < CB	HB > CB
Jacobs and Sebranek (1980)	CB; HB (1-3 hr), CO ₂	Frozen (CO ₂)	HB < CB	HB > CB
Cross and Tennent (1980)	CB (24 hr), ES, HB (1 and 3 hr); CO ₂	Frozen (-10°C)	HB < CB	HB > CB
Contreras <i>et al.</i> (1981)	CB (48 hr), ES + HB (2 hr), 3°C for 24 hr	Frozen (-26°C)	HB > CB	HB < CB

Source: Adapted from West (1983). Reprinted from Food Technology. 1983. 37:57. Copyright © by Institute of Food Technologists.

^a CB = cold-boned. HB = hot-boned. ES = electrical stimulation. HTC = conditioning prior to boning. CO₂ = use of CO₂ snow for initial chilling.

^b ND = no difference.

superior to ground beef made from conventionally processed beef in palatability, cooking properties, and shelf-life. Cross *et al.* (1979) reported that ground beef patties made from hot-boned beef were significantly more tender and juicy and lost less water during cooking than patties prepared from chilled beef. In addition, patties made from hot-boned beef had significantly less change in configuration during cooking (diameter change was less in patties made from hot-boned beef) than patties made from chilled beef (Cross *et al.* 1979).

Thus, preparation of ground beef from hot-boned beef appears to offer many advantages with few problems. For the maintenance of the prerigor advantages in hot-boned ground beef, rapid fabrication and freezing of the product appear necessary. Hot boning, with or without electrical stimulation, does not appear to cause detrimental changes in the physical or sensory properties of ground beef.

WHY HASN'T INDUSTRY ACCEPTED HOT BONING?

Although hot boning may have numerous economic advantages and produce meat of equal or superior quality, several problems exist that prohibit the utilization of hot boning. A decade or so ago, hot boning was found to produce beef that was less tender than conventionally processed beef, but the advent of electrical stimulation and postmortem high temperature conditioning virtually eliminated any problems in this regard. However, some commercial processors have indicated that the hot-boned primal cuts, when vacuum packaged hot, undergo a distortion in shape; Cross and Tennent (1979B), however, did not find this to be a problem.

One large problem with hot boning centers around the chilling of hot-boned vacuum-packaged cuts. If several hot-boned, vacuum-packaged primal cuts are boxed, the temperature within the box may be too high for too long a period of time. This high temperature may lead to the proliferation of spoilage bacteria or, worse yet, food poisoning microorganisms such as *Clostridium botulinum* and *Staphylococcus* sp., among others. Very little research is available on chilling methods for large volumes of boxed, hot-boned primal cuts; however, this potential problem acts as a disincentive for industry acceptance of hot boning. Some small meat processors have tried vacuum packaging of hot-boned meat and placed the vacuum packages on shelves for a period prior to boxing. This practice was considered to be very laborious, used a substantial amount of cooler space, and offered no great advantage because of energy (refrigeration) input.

Another somewhat related problem is that most conventional meat processing plants within the United States would have difficulty in introducing hot boning into their existing plants due to their original design. Major renovations in plant design would be necessary to situate boning lines

nearer to the abattoir, and major changes would be necessary in refrigeration systems to accommodate boxes of hot-boned meat.

Another problem with hot boning that has limited its industrial acceptance is the inability to grade the unchilled carcass. The lack of a mechanism to quality- and yield-grade beef carcasses is perhaps the greatest single factor in preventing the U.S. industry from moving toward hot boning. The U.S. livestock and meat industry relies heavily on USDA grades as a marketing tool as do many other countries. Many feel that they cannot market their product effectively without grades.

Another problem that must be overcome in connection with hot boning concerns the dark-cutting (DFD) condition in some carcasses. If an animal prior to slaughter has been stressed sufficiently to deplete its muscle glycogen, the meat is likely to be dark and coarse textured. The lack postmortem of a sufficient quantity of muscle glycogen will result in a relatively high ultimate pH (6.0 or higher). This high pH will allow increased microbial growth, and thus reduced shelf-life. Thus, it is critical that DFD carcasses be identified prior to vacuum packaging so that the primal cuts can be marketed separately. This identification is not a problem in conventionally chilled carcasses, but potentially DFD prerigor muscle at 1–3 hr postmortem is difficult to segregate from normal muscle. Research is needed in this area to develop a means to identify these DFD carcasses at the time of hot boning.

Although the hot boning of beef has numerous industry problems regarding its acceptance, such has not been the case with pork. Pork carcasses are generally not quality graded in the United States, so that is not a problem. Hot-boned pork has been found to have exceptional emulsifying, binding, and water holding properties. Since a large proportion of pork is used in processed meat items, numerous pork processing plants utilize hot boning. One such example is breakfast sausage. Hogs can be hot boned, and the meat ground, formulated, stuffed into tubes, and rapidly chilled in a propylene glycol or supercooled solution, thereby preventing any microbial proliferation.

ECONOMIC IMPLICATIONS OF HOT BONING

Rosoff (1975) claimed that the meat industry accounts for 9% of the energy used by the entire food industry. Unger (1975) estimated that food and kindred products ranked sixth in energy use and first in labor use among all industries. The U.S. Department of Commerce (U.S. Dep. Commer. 1977) reported that within the food and kindred product group, meat packing and processing was the fifth highest user of energy. A Kansas State University study on the economics of hot boning (Erickson *et al.* 1980) reported that the high use of resources in meat processing basically reflects the large quantity of products involved, meat's highly perishable

nature, and the comparatively long transport distances between production and consumption areas.

Kastner (1981) reported that when compared with conventional processing practices, it has been estimated that hot boning could: (1) require 40–50% less refrigeration input; (2) result in a 50–55% reduction in cooler space; (3) eliminate the need for shrouding, neckpinning, scribing, and the operations needed to support these functions; (4) reduce labor used in fabrication operations by as much as 25%; (5) decrease cooler shrinkage up to 2%; and (6) reduce product in-plant residence time. Therefore, significant savings in energy, yield, materials and supplies, labor, and interest on fixed capital and inventory may be accrued due to hot boning (Kastner 1977; Dvorak 1979; Nason 1979; Cross and Tennent 1980; Erickson *et al.* 1980).

Because hot boning requires the chilling of only edible meat and not excess fat and bone, a distinct savings in cooling energy should result. Erickson *et al.* (1980) compared conventional processing (72 hr postmortem) with hot boning (within 8 hr postmortem) and with hot boning preceded by electrical stimulation. The meat that was hot boned reduced energy usage by 32%, and hot boning coupled with electrical stimulation reduced energy usage by 42%. Henrickson and McQuiston (1977) reported that the chilling of a 270 kg carcass would require 31,500 BTUs of energy transfer to reduce it from 40° to 0°C. The edible portion of the same carcass (420 lb) would require only 22,050 BTUs to lower the same edible product to a temperature of 0°C, which is nearly a 30% reduction in energy requirement. In addition to the reduced energy requirement, hot-boned meat can move more rapidly through the packing plant's inventory. Hot boning lends itself to boning on the rail. Brasington and Hammons (1971) indicated that on-the-rail boning resulted in a higher yield of meat than did normal table cutting.

Historically, beef has been distributed in the carcass form. Due to recent changes in methods of distribution, 65 to 70% of the beef in the United States is currently distributed in the form of vacuum-packaged primal cuts. This change in the method of distribution has resulted in a decrease in transportation costs due to a reduction in space requirements and the removal of excess fat and bone prior to shipment. Henrickson *et al.* (1974) reported that there could be a 30 to 35% reduction in the amount of required chilling space if beef is hot boned and chilled rather than handled in the conventional manner. Henrickson (1975) reported that hot boning could reduce refrigeration costs by 78% by the removal of excess bone and fat. Henrickson and Ferguson (1977) claimed that there could be a 65% savings in transportation space if carcasses were hot boned before shipping rather than shipped as carcasses. In this regard, truckers could haul much larger quantities of product and reduce the number of trips. Electrical stimulation has a cost of operation figure of approximately 3¢ per carcass. This figure does not include the wages for the operator, cost of the stimulator, sanitation, and the space required for stimulation.

CONCLUSIONS

Hot boning yields a quality product under a variety of processing conditions, and it offers a number of processing advantages. Even so, not all the questions about hot boning have been answered. More complete evaluations of integrated systems that incorporate the presently available knowledge are needed. Combined efforts between research and commercial application personnel are needed to determine which system is best suited for today and the future.

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