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The Effects of Hot vs. Cold Boning on Eating Quality of New Zealand Grass Fed Beef

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Abstract: Sides of the 40 selected carcasses were alternately assigned to both conventional chilling and cold boning (CB) or hot boning (HB). Fabrication of CB sides took place after overnight chilling (20 h postmortem) and subsequent carcass grading, while fabrication of HB sides occurred on the day of slaughter within 60 min of exsanguination. Five muscles were removed, including the *longissimus lumborum* (LL), *longissimus thoracis* (LT), *psoas major* (PM), *gluteus medius* (GM), and *semimembranosus* (SM) for consumer evaluation, compositional analysis, and sarcomere length determination. Cold boning muscles had longer ($P < 0.05$) sarcomere lengths compared to HB muscles, expect for the GM and SM. Chilling treatment and postmortem aging (7, 21, or 35 d postmortem) had an impact on eating quality, but these results varied by muscle. Cold shortening could be responsible for the differences in sarcomere length and ultimately differences in tenderness between HB and CB muscles. Based on consumer evaluations, HB is not recommended for LT or PM due to the reduction ($P \leq 0.02$) of tenderness and overall liking scores for these subprimals; however, HB and early removal of muscles like the SM benefited ($P < 0.01$) from an eating quality standpoint for all palatability traits, and was neutral ($P \geq 0.21$) for tenderness, juiciness, flavor, and overall liking of the LL and GM. Postmortem aging did not affect ($P \geq 0.07$) eating quality of the GM and PM, but improved ($P < 0.01$) tenderness of LT and SM, as well as the tenderness, juiciness, flavor liking, and overall liking of the LL.

Introduction

Hot boning has the potential to save energy and refrigeration space in commercial abattoirs (Schmidt and Keman, 1974). Widespread implementation of this beef fabrication technique has yet to be seen, yet this process is more common in countries such as New Zealand and Australia. Cross and Tennent (1980) believed hot boning had not been implemented by many beef processors because carcasses could not be graded by current systems using this fabrication system. However, the risk of cold shortening could also prevent its implementation (Reagan, 1983), as Locker (1960) showed hot boning muscles pre-rig- or promoted contraction more than conventionally chilled muscles. Even so, Seideman et al. (1979) saw no difference in sarcomere lengths between electrically stimulated hot boned *longissimus* and conventionally chilled non-stimulated *longissimus*.

Multiple studies have shown that partial hot boning used in conjunction with electrical stimulation had no effect on trained sensory properties (Meade et al., 1992a; Seyfert et al., 2005). Moreover, Shaw and Powell (1995) found electrically stimulated hot boned beef was generally equivalent in tenderness and weep or purge compared to conventionally chilled beef. However, White et al. (2006) revealed non-electrically stimulated hot boned *longissimus dorsi* (LD) and *semimembranosus* (SM) had greater Warner-Bratzler shear force (WBSF) values and sarcomere lengths than cold-boned muscles, although

the use of electrical stimulation and slow chilling (chilling at 10 vs. 2°C) can have a positive effect on the tenderness of hot-boned muscles. However, wrapping (Devine et al., 1999; O'Sullivan et al., 2003) or stretching (Taylor et al., 2012) hot-boned muscles during rigor to provide artificial restraint can improve tenderness (Devine et al., 1999; O'Sullivan et al., 2003). Even so, these objective measures of tenderness nor even trained sensory evaluation cannot truly predict the consumer perception of hot vs. cold-boned beef, and which, if any, differences in tenderness are detectable by consumers.

Research was needed to compare conventionally chilled and completely hot boned beef in a commercial setting to determine if consumers can detect differences in beef eating quality, particularly in higher valued subprimals from the rib and loin. We believe eating quality may suffer when subprimals are removed from the carcass prior to rigor mortis due to the loss of tension provided by carcass suspension. Therefore, the objective of our study was to measure the effects that time and temperature of carcass fabrication (hot vs. cold) had on consumer palatability traits and sarcomere length for hot boned and conventionally chilled strip loin, cube roll, tenderloin, rump, and topside, and determine if hot vs. cold boned muscles reacted differently throughout the postmortem aging process.

Materials and Methods

Animal Care and Use Committee approval was not needed for this study because the meat samples were obtained from federally inspected slaughter facilities.

Carcass selection

Carcasses (*n* = 40) were selected initially at a commercial beef processing facility in New Zealand by Texas Tech personnel from all cattle (*n* = 325) harvested on June 29, 2015. Following carcass grading on d 1 postmortem, only 32 carcasses remained in the trial due to various exclusion characteristics detailed below.

All selected carcasses were grass fed steers. In New Zealand, all cattle are required under federal law to be electronically identified and all movements, starting at animal birth, between farms and to processing plants are recorded in the National Animal Identification and Tracing (NAIT) database. The Animal Status Declaration (ASD), as mandated under the Animal Products Act 1999, must be completed each time animals move between properties or are consigned for

processing as part of NAIT. One component of the ASD pertains to animal feeding, and producers must ensure animals have not been fed anything other than milk or pasture. To be considered pasture fed, animals must "have been raised under normal New Zealand farming conditions with year-round access to grass (e.g., hay, silage, lucerne, feed crops, or other grazed or conserved forages) and other supplementary feeds (including manufacturing feeds, provided that you have a statement from the manufacturer that the feed does not contain animal protein or animal fat, other than dairy). Where animals have been fed on a feed pad or feedlot other than for short term periods (e.g., only as supplementary feed immediately prior to slaughter) then they would not be 'pasture fed' because of not having year-round access to grass" (ASD, 2016).

After harvest, all cattle were electrically stimulated with 100 V, 15 Hz, 0.7 Amps., on a moving table for 45 to 48 s. To be eligible for selection, carcasses had to weigh between 250 and 350 kg and could not have more than 4 permanent incisors. After carcasses were split, sides from selected carcasses were alternately assigned to hot (HB) or cold boning (CB). One side remained in the chiller and the other was sent immediately to the fabrication room. Right and left chilling assignment switched between each carcass.

All 40 HB sides entered the fabrication room within 60 min of being harvested with boning taking place immediately. Subprimals were removed according to the AusMeat Handbook of Australian Meat (HAM; AUS-MEAT, 2005). The strip loin (HAM #2140; STR045), cube roll (HAM # 2244; CUB045), tenderloin (HAM #2150; TDR062), rump (HAM #2100; RMP131/231), and topside (HAM #2000; TOP073) were all removed and carcass primal identification tags were placed on each muscle. Prior to packaging, pH and temperature (d 0) were recorded for each muscle within 20 min using a handheld temperature-pH meter equipped with an intermediate junction pH sensor (TPS Model WP-90 with pH sensor part #111227, TPS Pty Ltd., Brendale, QLD, Australia). Following subprimal removal and data collection, subprimals were vacuum packaged and boxed as per standard procedures for the particular cut. Boxes were placed on racks, which entered a blast chiller. The chiller temperature was set as follows: 1 to 7 h at –10°C, 7 to 10 h at –5°C, and 10 to 24 h at –3°C. Chiller temperatures were dictated to achieve anaerobic Process Hygiene Index values below 2, so that the product would be eligible for export to the United States and to achieve a similar chilling curve as cold-boned subprimals. Due to the packaging state of each subprimal, individual subprimal temperature could not be monitored or obtained

throughout the initial chilling phase (first 24 h) of the trial once subprimals were vacuum packaged and boxed.

All CB sides were placed on the same rail within 1 chiller to facilitate efficient chiller loading and to minimize chilling effects including air flow, temperature, and spray chilling. Carcasses were in the chillers overnight. The chiller temperature was gradually reduced as follows: 1 to 4 h at 8°C, 4 to 8 h at 6°C, and 4°C for all remaining time in the chiller. Spray chilling was applied once every hour for 95 s a total of 10 times. When CB sides arrived in the chillers, pH and temperature (d 0) were recorded. Initial pH and temperature of HB and CB muscles was collected simultaneously in the fabrication room for HB sides and in the chiller for CB sides.

Following approximately 20 h chilling, the chilled side was graded by Texas Tech University personnel according to USDA standards (USDA, 1997) for marbling, lean and skeletal maturity. To remain eligible for the trial, carcasses had to have marbling scores between 200 and 400 based on USDA grading standards (200 = traces[00]; 400 = small[00]; USDA, 1997), could not have skeletal maturity above "A" maturity (USDA, 1997), had to have ultimate pH < 6.0 (i.e., no dark cutting), and could not have any bruising in major subprimals. Ultimate pH for cold boned sides were collected on Day 1 postmortem. In addition, certified Meat Standards Australia (MSA) graders collected MSA grade data. All carcasses were also required to have a fat thickness at the 12th rib between 3 and 10 mm. Eight carcasses were removed from the trial at this time because they did not meet the grading specifications, leaving 32 carcasses. After grading, the strip loin, cube roll, tenderloin, rump, and topside were all excised from the CB sides in a similar fashion as the HB sides.

Steak fabrication

On d 2 to 4 postmortem, subprimals were fabricated into steaks in accordance with MSA protocols (Watson et al., 2008). Subprimals that were previously fabricated on d 0 from the 8 HB sides removed from the trial were not fabricated into steaks. Before HB subprimals were processed, ultimate pH was collected (d 2 postmortem). All external fat and connective tissue was removed from subprimals prior to steak fabrication. In addition, the *gluteus medius* (GM) was removed from the strip loin leaving only the LL. The *multifidus dorsi*, *spinalis dorsi*, *complexus*, *serratus dorsalis*, *costarum*, and *intercostal* were all removed from the cube roll leaving the LT. The *psoas minor* and *ilacus* were removed from the tenderloin leaving only the *psoas major* (PM). The *biceps femoris*, *gluteus accessorius*, and the *glute-*

us profundus were removed from the rump leaving the GM only, which was further separated along the seam into 2 portions. The *adductor femoris* and *gracilis* were removed for the topside so that only the SM remained.

Subprimals were fabricated into 2.5-cm steaks and were further processed into smaller pieces measuring approximately 5 cm × 5 cm. Steak pieces were wrapped and vacuum packaged as sets of 5 based on position within the subprimal. Excess pieces from each subprimal were retained for proximate composition and sarcomere length analyses, vacuum packaged, held at 2– to 4°C, and frozen on d 7 postmortem.

All steaks were labeled with a unique ID code produced from MSA software prior to freezing for either 7, 21, or 35 d postmortem. After freezing, beef was shipped to the Texas Tech University Gordon W. Davis Meat Laboratory, located in Lubbock, TX. Frozen samples were sorted into a predetermined cook order. After sorting, steaks remained frozen until further analysis.

Proximate analysis

Samples were analyzed using an AOAC-approved (Anderson, 2007) near infrared spectrophotometer (FoodScan, FOSS NIRsystems, Inc., Laurel, MD) to determine the percentage of fat, moisture and protein. Frozen samples were thawed at 2 to 4°C for 24 h prior to analysis. All subcutaneous fat, intermuscular fat, and connective tissue were removed from each sample. Each sample was finely ground through a commercial food grinder (Krups 150 Watt Grinder item #402–70, Krups, Sheldon, CT) to obtain a 200-g sample.

Sarcomere length

Sarcomere lengths from each subprimal were measured on steak samples that were aged 7 d postmortem using a neon laser diffraction as described by Cross et al. (1981). A $3.0 \times 3.0 \times 2.0$ cm^2 sample was removed parallel to the muscle fiber and fixed in a glass vial with a 5% glutaraldehyde solution (Thermo Fisher Scientific, Fair Lawn, NJ) for 4 h at 4°C. After fixing, glutaraldehyde solution was removed and replaced with 0.2 M sucrose solution (Sigma Aldrich, St. Louis, MO) for overnight storage at 4°C. Muscle fibers were removed from each sample using tweezers and forceps and spread onto glass slides. Fibers were moistened with the 0.2 M sucrose solution before application of a cover slip to prevent movement of the fibers. A neon laser (Model 117A; SpectraPhysics Inc., Irvine, CA) operated at a wavelength of 632.8 nm was used to measure 6 different diffraction patterns per

sample. Of the 6 measurements, an average was calculated and the sarcomere length was determined.

Consumer panels

The Texas Tech University Institutional Review Board approved procedures for use of human subjects for consumer panel evaluation of sensory attributes.

Steak samples were thawed at 2 to 4°C for 24 h prior to consumer evaluation. All steaks were cooked on a Silex clamshell grill (Model S-143K, Silex Grills Australia Pty Ltd., Marrickville, Australia) with a temperature set at 225°C. The Silex grill was preheated 45 min prior to the start of the panels. Ten steak pieces (unrelated to trial) were prepared on the grill before consumer samples to commence the cooking cycle and stabilize temperatures throughout the heating elements. A strict and detailed time schedule was followed to ensure all steaks were prepared identically (Gee, 2006). Each cooking round consisted of 10 samples that were cooked at the same time on 1 grill. All steaks were cooked for 5 min and 45 s, followed by a 3-min rest period. After the rest period, each steak was cut in half into 2 equal size pieces and served to 2 separate predetermined consumer panelists.

Consumer panels were conducted in the Texas Tech University Animal and Food Sciences Building. Consumer panelists ($n = 1200$) were recruited from Lubbock, Texas and the surrounding local communities. Each consumer was monetarily compensated for being a participant and were only allowed to be participate 1 time. Each session consisted of 20 people with 3 sessions being conducted on a given night. Each session lasted approximately 60 min.

Each consumer evaluated 7 samples. Six test samples were served in a predetermined balanced order to equally represent both chilling treatments (hot and cold), 5 muscles [*longissimus lumborum* (LL), *longissimus thoracis* (LT), PM, GM, and SM], and 3 postmortem aging periods (7, 21, or 35 d). In addition, USDA Select strip loin steaks aged 7 d collected previously by TTU personnel from a commercial beef processor located in Omaha, NE were included in the cooking order as a warm-up sample for consumers and to provide linkage across all testing nights. The link samples were always served in the first position, followed by 6 test samples served in predetermined, balanced order.

Consumers rated tenderness, juiciness, liking of flavor, and overall liking on 100-mm line scales on a paper ballot. The zero anchors were labeled as not tender, not juicy, and dislike extremely of flavor and overall. The 100 anchors were labeled as very tender, very juicy, and like extremely of flavor and overall. Consumers were also asked to check 1 of 4 boxes to indicate if they considered each sample was unsatisfactory, good everyday quality, better than everyday quality, or premium quality.

Each panelist was seated at numbered booth and was provided with a ballot, plastic utensils, a toothpick, unsalted crackers, a napkin, an empty cup, a water cup, and a cup with diluted apple juice (10% apple juice and 90% water). Each ballot consisted of a demographic questionnaire, 7 sample ballots, and a post panel survey regarding beef purchasing habits. Before beginning each panel, consumers were given verbal instructions by Texas Tech personnel about the ballot and the process of testing samples. Panels were conducted in a large classroom under fluorescent lighting with tables that were divided into individual consumer booths.

Statistical analysis

Data were analyzed as a split plot design using SAS (version 9.3; SAS Inst. Inc., Cary, NC). Proximate composition and sarcomere length were analyzed using the GLIMMIX procedure of SAS, with chilling treatment (hot vs. cold) as the whole plot fixed effect and the muscle as the sub plot fixed effect. All future analyses were performed by muscle as opposed to including muscle as a fixed effect. The pH was analyzed using the GLIMMIX procedure, with chilling treatment as the whole plot fixed effect and the sampling time as the sub plot fixed effect. Consumer data were analyzed using the GLIMMIX procedure, with chilling treatment as the whole plot fixed effect and the post mortem aging (7, 21, 35 d) as the sub plot fixed effect. Carcass was included in the model as a random effect. Treatment least squares means were separated with the PDIFF option of SAS of a significance level of $P \leq 0.05$. The CORR procedure of SAS was used to generate Pearson correlation coefficients to determine the relationship between consumer responses, proximate composition, and sarcomere length across all samples at a significance level of $P \leq 0.05$.

Results and Discussion

Temperature and pH

As seen in Table 1, sampling time and chilling treatment affected pH and temperature of all 5 muscles. For each muscle, chilling treatment interacted with sampling time to impact pH readings ($P < 0.01$). Initial readings were greater ($P < 0.05$) than ultimate

Table 1. The effects of sampling time and chilling regime on pH and temperature (°C) of 5 beef muscles from New Zealand grass fed beef

| | HB | | CB | | P-value[1] | | | |
Trait	Initial	Ultimate	Initial	Ultimate	SEM[2]	Chill	Time	Chill × time
Longissimus thoracis								
pH	6.25[b]	5.63[c]	6.39[a]	5.46[d]	0.03	0.68	< 0.01	< 0.01
Temperature	34.50[a]	–1.17[d]	31.70[b]	5.09[c]	0.52	< 0.01	< 0.01	< 0.01
Gluteus medius								
pH	6.44[b]	5.61[c]	6.86[a]	5.46[d]	0.03	< 0.01	< 0.01	< 0.01
Temperature	35.55[a]	–1.13[d]	31.50[b]	6.77[c]	0.27	< 0.01	< 0.01	< 0.01
Longissimus lumborum								
pH	6.27[b]	5.59[c]	6.57[a]	5.42[d]	0.03	0.04	< 0.01	< 0.01
Temperature	33.25[a]	–1.11[c]	32.48[a]	5.28[b]	0.28	< 0.01	< 0.01	< 0.01
Psoas major								
pH	5.83[b]	5.53[c]	5.94[a]	5.43[d]	0.03	0.80	< 0.01	< 0.01
Temperature	34.52[a]	–0.58[d]	33.08[b]	6.18[c]	0.43	< 0.01	< 0.01	< 0.01
Semimembranosus								
pH	6.30[b]	5.49[c]	6.53[a]	5.42[d]	0.03	< 0.01	< 0.01	< 0.01
Temperature	36.20[a]	–1.22[d]	31.69[b]	7.43[c]	0.59	< 0.01	< 0.01	< 0.01

[a–d]Within a row, least squares means without a common superscript differ ($P < 0.05$) due chill × time interaction.

[1]Observed significance levels for main effects of chill, time of reading, and the chill × time interaction.

[2]Pooled (largest) SE of least squares means.

readings for all 5 muscles regardless of chilling treatment. Initial pH of all muscles from the conventionally chilled sides was greater ($P < 0.05$) compared to their HB counterparts. However, ultimate pH of conventionally chilled muscles was lower ($P < 0.05$) than HB counterparts. Even so, average ultimate pH for all muscles was between the acceptable range of 5.4 to 5.6 (Aberle et al., 2012).

Like pH, chilling treatment interacted with sampling time to impact temperature readings ($P < 0.01$) for all muscles. Except for the LL, initial temperature of all other HB muscles was greater ($P < 0.05$) than their chilled counterparts. The opposite was seen for ultimate temperature with muscles from the chilled sides being greater ($P < 0.05$) than the HB muscles.

In agreement with our work, Seideman et al. (1979) determined that chilling a carcass before boning resulted in lower pH values from the muscles within the carcass. Temperature is equally important because the rate at which temperature declines determines the rate at which pH will decline post mortem (Aberle et al., 2012). Within the exception of PM, all other HB muscles had average initial pH > 6.2, which is critical for the development of cold shortening (Smulders et al., 1986). According to Falk et al. (1975), a muscle does not have to reach its ultimate pH before subprimal removal to minimize muscle shortening, but the onset of rigor mortis should have commenced before the muscles are fabricated.

Sarcomere length and proximate analysis

The sarcomere length and proximate composition for all 5 muscles can be found in Table 2. Chilling treatment interacted with muscle to impact sarcomere length ($P < 0.01$). Chilled muscles had longer ($P < 0.05$) sarcomere lengths compared to HB muscles, expect for the GM and SM. The HB GM and SM had longer ($P < 0.05$) sarcomeres compared to CB, GM, and SM. Sarcomere length for CB PM were longer ($P < 0.05$) compared to HB PM. In fact, chilled PM had the longest ($P < 0.05$) sarcomere lengths of any muscle in the study, and were nearly 70% longer than HB PM. The CB, GM, and SM had shorter ($P < 0.05$) sarcomeres than all other muscles regardless of chilling treatment.

Cold shortening could be responsible for the differences in sarcomere length between HB and CB muscles. Cold shortening occurs when meat is chilled too rapidly if onset of rigor mortis has not set in (Savell, 2012). In the current study, all of the HB muscles, apart from the PM, had average initial pH > 6.2 at the time of removal from the carcass, which is critical for the development of cold shortening (Smulders et al., 1986). Falk et al. (1975), observed an 11% decrease in sarcomere length with hot boning compared to conventional chilling for the LD, SM, and the *semitendinosus*. However, Marsh and Leet (1966) indicated a decrease in sarcomere length no more than 20% would not greatly affect tenderness. Still, others

Table 2. The effects of chilling regime and muscle on the physicochemical traits of New Zealand beef (sarcomere length and proximate composition)[1]

| | CB | | | | | | HB | | | | | | | P-value[3] | | |
Trait	LT	LL	GM (heart)	GM (eye)	PM	SM	LT	LL	GM (heart)	GM (eye)	PM	SM	SEM[2]	Chill	Muscle	C×M
Sarcomere length, μm	1.79[bc]	1.80[b]	1.53[fg]	1.47[g]	3.07[a]	1.54[fg]	1.67[de]	1.71[cd]	1.61[ef]	1.68[de]	1.81[b]	1.69[de]	0.03	< 0.01	< 0.01	< 0.01
Fat, %	3.28[x]	3.96[x]	2.50[y]	2.79[y]	4.44[w]	1.96[z]	3.34[x]	3.76[x]	2.6[y]	2.79[y]	4.58[w]	1.99[z]	0.27	0.80	< 0.01	0.82
Moisture, %	73.23[y]	72.22[z]	73.35[y]	73.16[y]	72.94[yz]	73.86[x]	72.70[y]	72.59[z]	73.04[y]	72.68[y]	72.58[yz]	73.51[x]	0.25	0.05	< 0.01	0.46
Protein, %	22.56[wx]	22.59[w]	22.24[y]	22.47[xy]	21.49[z]	22.91[v]	22.24[wx]	22.49[w]	22.14[y]	22.10[xy]	21.65[z]	22.62[v]	0.10	< 0.01	< 0.01	0.08

[a–g]Within a row, least squares means without a common superscript differ ($P < 0.05$) due to muscle × chilling interaction.

[v–z]Within a row, least square means without a common superscript differ ($P < 0.05$) due to muscle.

[1]LT- *longissimus thoracis*; LL- *longissimus lumborum*; GM- *gluteus medius*; PM- *psoas major*; SM- *semimembranosus*.

[2]Pooled (largest) SE of least squares means.

[3]Observed significance levels for main effects of chilling, muscle, and the chilling x muscle interaction.

have observed that an increase in sarcomere length up to 2.0 μm was linked with an increase in tenderness (Bouton et al., 1973; Wheeler et al., 2000).

Some researchers have found that if HB beef was electrically stimulated while it was close to rigor or in rigor, cold shortening would be prevented (Bouton et al., 1980; Gilbert et al., 1977). However, applying electrical stimulation to the whole carcass does not have the same effect on all muscles (Olsson et al., 1994; Troy, 1999). This agrees with Seideman et al. (1979) who reported no difference in electrically stimulated HB or conventionally chilled non-stimulated *longissimus* sarcomere lengths. White et al. (2006) revealed non-electrically stimulated hot boned LD and SM had greater WBSF values and sarcomere lengths than cold-boned muscles, although the use of electrical stimulation and slow chilling (chilling at 10°C vs. 2°C) can have a positive effect on the tenderness of hot-boned muscles. However, Unruh et al. (1986) noted that low voltage electrical stimulation can negatively impact beef tenderness when combined with a slow chilling rate.

In agreement with our work on the chilled muscles, several researchers have reported PM have longer sarcomere lengths than other muscles including the LT, LL, GM, and SM (Carmack et al., 1995; Hunt and Hedrick 1977; Rhee et al., 2004). In support of the current results, Rhee et al. (2004) reported the GM had the shortest sarcomere lengths compared to the LT, PM, and SM, which agrees with our CB muscles except the GM and SM had similar values in the current study.

Results of proximate composition can also be found in Table 3. No interaction was observed between chilling treatment and muscle for proximate composition. However, each component was impacted by muscle ($P < 0.01$). Fat percent was highest ($P < 0.05$) in the PM

and lowest ($P < 0.05$) for SM, while both *longissimus* muscles had greater fat percentage than either portion of the GM. Chilling treatment had no impact on fat percentage ($P = 0.80$). Percent moisture was highest in SM ($P < 0.05$) and lowest ($P < 0.05$) in LL for both HB and CB muscles. Percent moisture was greater ($P < 0.05$) for chilled sides compared to their hot counterparts. Both chilling treatments and muscle affected ($P < 0.01$) percent protein. The PM had the lowest ($P < 0.05$) percent protein and the SM had the highest ($P < 0.05$) while HB muscles had lower protein than their conventionally chilled counterparts. However, the numerical difference in protein between HB and CB muscles was relatively minor (22.2 vs. 22.4%, respectively).

One possible explanation for greater moisture between HB and CB could be due to spray chilling. Hot boned sides were not exposed to any type of spray chilling as they were transferred directly to the boning room from the slaughter floor. However, CB sides were in a chiller for 20 h with spray chilling occurring throughout the chiller cycle. This is the only time any moisture was added to either treatment.

Consumer analysis

Table 3 shows the effects of chilling and postmortem aging for consumer evaluations of tenderness, juiciness, flavor liking, and overall liking. No 2-way interactions between chilling treatment and postmortem aging were observed for any eating quality traits of any muscles ($P > 0.05$). For the LT, chilling treatment and postmortem aging had an effect ($P < 0.01$) on consumer tenderness. Cold boned LT were rated more tender ($P < 0.01$) than their hot counterparts, regardless of postmortem aging. For postmortem aging, LT

Table 3. The main effects of chilling and postmortem aging on consumer reflections of tenderness, juiciness, flavor, and overall liking of 5 beef muscles from New Zealand grass fed beef[1,2]

Trait	Treatment				Aging				
	CB	HB	SEM	P-value[3]	7	21	35	SEM	P-value[3]
Tenderness									
LT	69.10	63.14	1.40	< 0.01	62.45[b]	66.67[a]	69.25[a]	1.67	< 0.01
GM	59.85	57.86	1.83	0.21	56.56[b]	58.83[ab]	61.17[a]	2.10	0.10
LL	65.28	66.12	1.63	0.47	60.89[c]	66.14[b]	70.06[a]	1.72	< 0.01
PM	81.15	71.88	1.21	< 0.01	74.94[a]	77.70[a]	76.91[a]	1.50	0.34
SM	34.54	39.25	1.18	< 0.01	31.96[b]	37.86[a]	40.86[a]	1.37	< 0.01
Juiciness									
LT	67.94	63.61	1.34	< 0.01	65.31[a]	64.59[a]	67.43[a]	1.65	0.36
GM	57.67	59.50	1.57	0.22	57.39[a]	57.54[a]	60.83[a]	1.84	0.17
LL	65.90	65.16	1.43	0.55	62.08[b]	64.96[b]	69.55[a]	1.56	< 0.01
PM	69.65	66.85	1.37	0.08	67.24[a]	68.62[a]	68.89[a]	1.69	0.69
SM	42.34	46.05	1.30	< 0.01	40.07[b]	45.69[a]	46.83[a]	1.47	< 0.01
Flavor									
LT	61.63	59.66	1.26	0.19	59.02[a]	60.27[a]	62.65[a]	1.56	0.19
GM	57.32	57.37	1.30	0.97	56.54[a]	56.28[a]	59.20[a]	1.61	0.30
LL	61.52	61.58	1.22	0.96	58.18[c]	61.41[b]	65.06[a]	1.35	< 0.01
PM	68.97	64.09	1.30	< 0.01	66.09[a]	66.99[a]	66.52[a]	1.61	0.91
SM	43.67	47.46	1.04	< 0.01	42.80[b]	46.98[a]	46.91[a]	1.20	< 0.01
Overall Liking									
LT	64.78	61.50	1.28	0.02	61.26[b]	62.52[ab]	65.63[a]	1.56	0.07
GM	57.50	57.40	1.73	0.95	55.97[b]	56.10[b]	60.29[a]	1.73	0.07
LL	62.64	63.56	1.31	0.44	59.41[c]	62.93[b]	66.96[a]	1.44	< 0.01
PM	72.39	66.69	1.37	< 0.01	69.35[a]	69.95[a]	69.32[a]	1.68	0.95
SM	40.81	45.09	1.17	< 0.01	38.72[b]	45.31[a]	44.83[a]	1.31	< 0.01
Satisfaction									
LT	3.53	3.43	0.05	0.07	3.36[b]	3.49[ab]	3.57[a]	0.06	0.01
GM	3.26	2.28	0.05	0.63	3.25	3.21	3.35	0.06	0.21
LL	3.45	3.48	0.05	0.47	3.33[b]	3.49[a]	3.58[a]	0.05	< 0.01
PM	3.90	3.64	0.05	< 0.01	3.76	3.79	3.76	0.07	0.94
SM	2.75	2.85	0.04	0.03	2.65	2.87	2.88	0.04	< 0.01

[a–c]Within a row, least squares means without a common superscript differ ($P < 0.05$) due to aging.

[1]LT- *longissimus thoracis*; GM- *gluteus medius*; LL- *longissimus lumborum*; PM- *psoas major*; SM- *semimembranosus*.

[2]Pooled (largest) SE of least squares means.

[3]Observed significance levels for main effects of chilling, aging and the chilling x aging interaction by muscle.

samples aged 7d scored lower ($P < 0.05$) than samples aged 21 and 35 d, which were similar. Neither chilling treatment nor postmortem aging had an effect ($P > 0.05$) on the tenderness of the GM. Postmortem aging influenced ($P < 0.01$) the LL as consumers scored samples aged 35 d most tender, 21 d intermediate, and 7 d least tender. Chilling treatment had no effect ($P > 0.05$) on consumer tenderness scores for the LL. Postmortem aging had no impact on the PM tenderness; however, chilling treatment influenced consumer tenderness evaluations with CB PM being rated more tender ($P < 0.01$) compared to HB PM, regardless of postmortem aging. Tenderness of the SM was affected by both chilling treatment and postmortem aging ($P < 0.01$). Consumers scored HB SM more tender ($P < 0.01$) than their chilled counterparts, regardless of postmortem aging. According to consumers, SM samples aged 7d were considered less tender ($P < 0.05$) than SM samples aged 21 d or 35 d which did not differ ($P > 0.05$), regardless of chilling treatment.

Consumer juiciness for the LT was affected by chilling treatment as consumers scored CB LT juicer ($P < 0.01$) than HB LT, regardless of postmortem aging. Neither chilling treatment nor postmortem aging had an effect ($P > 0.05$) on the juiciness of the GM or PM. Postmortem aging influenced ($P < 0.01$) the juiciness of

the LL as consumers scored samples aged 35 d juicier (P < 0.05) than samples aged 21 d or 7 d, which were similar. Lastly, both chilling treatment and postmortem aging had an effect (P < 0.01) on consumer juiciness for the SM. Consumers ranked juiciness for the HB SM greater (P < 0.01) than CB, regardless of aging. Plus, SM aged 21 d or 35 d were rated juicier (P < 0.05) compared to samples aged 7 d, regardless of chilling treatment.

Consumers did not indicate a difference (P > 0.05) in flavor liking for the LT or GM due to chilling treatment or postmortem aging. Postmortem aging influenced (P < 0.01) the flavor liking of the LL, as consumers scored samples aged 35 d the greatest (P < 0.05), 21 d intermediate (P < 0.05), and 7 d lowest (P < 0.05). Flavor liking of the PM was influenced by chilling treatment with consumers scoring the CB PM greater (P < 0.01) compared to HB, regardless of postmortem aging. Both chilling treatment and postmortem aging had an effect (P < 0.01) on consumer flavor liking of the SM. Consumers ranked the HB SM greater (P < 0.01) for flavor compared to CB, regardless of aging. Plus, SM aged 21 d or 35 d were greater (P < 0.05) for flavor compared to samples aged 7 d, regardless of chilling treatment.

Overall, consumers liked CB LT samples more (P = 0.02) compared to HB LT samples, regardless of aging. Neither chilling nor postmortem aging impacted overall liking of GM (P > 0.05). Postmortem aging influenced (P < 0.01) the overall liking for the LL as consumers most liked samples aged 35 d, 21 d samples were intermediate, and samples aged 7 d were least liked. Consumers preferred CB samples from the PM more (P < 0.01) than HB PM samples, regardless of aging periods. Both, chilling treatment and postmortem aging had an effect (P < 0.01) on overall liking of the SM. Consumers liked the HB SM more (P < 0.01) than CB SM. In addition, consumers preferred SM samples aged 21 d and 35 d compared to samples aged 7 d (P < 0.05), regardless of chilling treatment.

Satisfaction was affected (P = 0.01) by postmortem aging for the LT with consumers indicating they were less satisfied with samples aged 7 d than samples aged 21 d or 35 d. Neither chilling treatment nor postmortem aging had an effect (P > 0.05) on the satisfaction of the GM. Postmortem aging affected (P < 0.01) the satisfaction of the LL with samples aged 21 d or 35 d generating greater satisfaction (P < 0.05) compared to samples aged 7 d, regardless of chilling treatment. Chilling treatment influenced the satisfaction of the PM with consumers being more satisfied with CB than HB PM, regardless of postmortem aging. Postmortem aging also influenced satisfaction of the SM according

to consumers, where SM samples aged 7 d were less satisfying (P < 0.05) than SM samples aged 21 or 35 d which did not differ (P > 0.05). Unlike other muscles, HB SM received greater satisfaction among consumers compared to CB SM.

Schmidt and Keman (1974) compared sensory attributes of HB and CB beef, but employed different chilling and aging parameters than the current study. Hot boned wholesale cuts were chilled at 7°C for 4 h following fabrication, then at 1°C until 24 h, at which time they were vacuum packaged and stored with CB sides until 8 d postmortem when the fabrication of CB sides occurred. Unlike our results, Schmidt and Keman (1974) reported no difference between HB and CB steaks from the anterior LD (10th rib) and PM for flavor, juiciness, tenderness, overall acceptability, or WBSF, while also observing no difference for posterior LD (4th lumbar) and GM, which aligns with our results. They believe holding the HB cuts at higher temperatures for the first 4 h may have minimized the potential for cold shortening.

Dransfield et al. (1976) also compared sensory traits of HB and CB cuts, but again chilling and aging parameters varied from the current study. Cold boned sides were held at ambient temperature for 5 h before moving to a chilled room at 1°C. On the other hand, HB muscles were removed from the carcass and vacuum packaged within 3 h of stunning. Packaged muscles were stored at 10°C for 24 h before moving to colder storage (1°C) for another 6 to 10 d. Removal of HB muscles did not occur as rapidly as the current study, and pH was not reported, so it is hard to say if rigor mortis had set in. Like Schmidt and Keman (1974), by holding the muscles at higher temperatures for the first 24 h, Dransfield et al. (1976) could have also minimized the potential for cold shortening. In large part, Dransfield et al. (1976) did not observe differences in consumer eating quality between HB and CB muscles (including LL, GM, and SM), with the exception that CB PM were more tender than HB PM. It should be noted that only 1 carcass of the 6 in their trial was used for consumer testing, and testing was done in the home as part of the consumers' evening meal, not in a controlled testing environment as in the present study.

Seideman et al. (1979) also saw no difference in palatability traits, WBSF, or sarcomere length of LL and SM that were either HB or CB. However, HB sides were electrically stimulated, whereas CB sides were not. HB muscles were removed within 60 min after exsanguination, vacuum packaged and stored at 1°C. Following 24 h of chilling at 1°C, CB muscles were fabricated. Those muscles were packaged and stored in a similar fashion as HB muscles.

In contrast to our results, Meade et al. (1992b) reported there were no significant differences for trained sensory scores, including tenderness, juiciness, and flavor intensity of CB or HB LT steaks. However, Meade et al. (1992a) employed a partial hot boning system where the HB sides received high voltage electrical stimulation in addition to the low voltage electrical stimulation applied to the entire carcass, and second, the hot boning procedure did not commence until the longissimus muscle pH reached 5.8. All HB muscles, as well as the conventionally chilled sides, were chilled at 1°C. Previous work has shown that holding periods to allow muscle pH to reach 5.8 prior to carcass boning to remove subprimals can greatly minimize or eradicate tenderness problems associated with hot boning (Cross and Tennent, 1980; Gilbert and Davey, 1976).

It is generally accepted that tenderness should improve as postmortem aging increases, but this could vary by muscle. A study by Eilers et al. (1996) examined the use of postmortem aging and its effect on tenderness of the LD, GM, and SM. Tenderness increased for each muscle as length of aging extended, which aligns with our findings. The authors also noted an increase in tenderness of the GM until d 24. No increase was observed in tenderness of conventionally chilled GM from d 21 to 35 but a significant increase was seen from d 21 to 35 for the HB GM.

Correlations

To determine the extent that palatability traits, sarcomere lengths, and proximate components were related to overall liking, Pearson correlation coefficients between those traits were determined and reported in Table 4. The 3 palatability traits of tenderness, juiciness, and flavor liking were strongly related ($r \geq 0.87$) to overall liking. Neely et al. (1998) showed a strong and positive relationship between tenderness, juiciness, and flavor of the top loin, sirloin butt, and top round as well. The correlations reported for the palatability traits were also similar to those reported by Hunt et al. (2014). Flavor liking was more positively correlated to overall liking compared to tenderness but still both were strongly related. In addition, with an increase in sarcomere length, an increase in consumer tenderness scores was noticed ($P < 0.01$). The relationship between fat and overall liking was positively related ($P < 0.01$) while protein and moisture had a negative relationship ($P < 0.01$).

Conclusions

The results indicated that chilling treatment and postmortem aging had an impact on eating quality, but these results varied by muscle. Cold shortening could be responsible for the differences in sarcomere length and ultimately differences in tenderness between HB and CB muscles. Based on consumer evaluations of these 5 muscles, hot boning is not recommended for cube rolls or tenderloins due to the reduction of eating quality scores for these subprimals; however, hot boning and early removal of muscles like the SM benefited from an eating quality standpoint, and was neutral for the strip loin and rump. Based off our results, complete hot boning of all subprimals from a carcass minimized the ability to capture the best eating experience from a carcass. However, a partial hot boning system (removal of selected subprimals prior to rigor) could create an opportunity for processors to improve eating quality of those subprimals, but would also present new logistical challenges.

Table 4. Pearson's correlation coefficients for the relationships between sarcomere, proximate data, and consumer sensory scores for the five beef muscles from New Zealand grass fed beef

Trait	Overall liking	Tenderness	Juiciness	Flavor liking	Sarcomere	Fat	Protein
Tenderness	0.91*						
Juiciness	0.87*	0.85*					
Flavor Liking	0.96*	0.85*	0.82*				
Sarcomere	0.41*	0.47*	0.32*	0.38*			
Fat	0.45*	0.48*	0.49*	0.42*	0.30*		
Protein	−0.39*	−0.40*	−0.38*	−0.37*	−0.38*	−0.54*	
Moisture	−0.32*	−0.32*	0.36*	−0.31*	−0.07**	−0.75*	0.27*

*Correlation coefficients were significant ($P < 0.01$).

**Correlation coefficients were significant ($P < 0.05$).

Literature Cited

Aberle, E. D., J. C. Forrest, D. E. Gerrad, and E. W. Mills. 2012. Principles of Meat Science. 5th ed. Kendall Hunt Publishing Company, Dubuque, IA.

Anderson, S. 2007. Determination of fat, moisture, and protein in meat and meat products using the FOSS FoodScan near-infrared spectrophotometer with FOSS Artificial Neural Network Calibration Model and Associated Database: Collaborative study. J. AOAC Int. 90:1073–1083.

ASD. 2016. Animal Status Declaration. Ministry for Primary Industries of New Zealand. http://www.foodsafety.govt.nz/elibrary/industry/animal-status-declaration/asd-form-2016.pdf (accessed 21 July 2017).

AUS-MEAT. 2005. Handbook of Australian Meat. 7th ed. International Red Meat Manual. AUS-MEAT Limited, South Brisbane, QLD, Australia.

Bouton, P. E., P. V. Harris, W. R. Shorthose, and R. I. Baxter. 1973. A comparison of the effects of aging, conditioning and skeletal restraint on the tenderness of mutton. J. Food Sci. 38:932–937.

Bouton, P. E., A. L. Ford, P. V. Harris, and F. D. Shaw. 1980. Electrical stimulation of beef sides. Meat Sci. 4:145–155. doi:10.1016/0309-1740(80)90038-8

Carmack, C. F., C. L. Kastner, M. E. Dikeman, J. R. Schwenke, and C. G. Zepeda. 1995. Sensory evaluation of beef-flavor-intensity, tenderness, and juiciness among major muscles. Meat Sci. 39:143–147. doi:10.1016/0309-1740(95)80016-6

Cross, H. R., and I. Tennent. 1980. Accelerated processing systems for USDA Choice and Good beef carcasses. J. Food Sci. 45:765–768. doi:10.1111/j.1365-2621.1980.tb07444.x

Cross, H. R., R. L. West, and T. R. Dutson. 1981. Comparison of methods for measuring sarcomere length in beef semitendinosus muscle. Meat Sci. 5:261–266. doi:10.1016/0309-1740(81)90016-4

Devine, C. E., N. M. Wahlgren, and E. Tornberg. 1999. Effect of rigor temperature on muscle shortening and tenderisation of restrained and unrestrained beef M. longissimus thoracicus et lumborum. Meat Sci. 51:61–72. doi:10.1016/S0309-1740(98)00098-9

Dransfield, E., A. J. Brown, and D. N. Rhodes. 1976. Eating quality of hot deboned beef. J. Food Technol. 11:401–407. doi:10.1111/j.1365-2621.1976.tb00738.x

Eilers, J. D., J. D. Tatum, J. B. Morgan, and G. C. Smith. 1996. Modification of early-postmortem muscle pH and use of postmortem aging to improve beef tenderness. J. Anim. Sci. 74:790–798. doi:10.2527/1996.744790x

Falk, S. N., R. L. Henrickson, and R. D. Morrison. 1975. Effect of boning beef carcasses prior to chilling on meat tenderness. J. Food Sci. 40:1075–1079. doi:10.1111/j.1365-2621.1975.tb02271.x

Gee, A. 2006. Protocol Book 4: For the thawing preparation, cooking and serving of beef for MSA (Meat Standards Australia) pathway trials. North Sydney: Meat and Livestock Australia.

Gilbert, K. V., and C. L. Davey. 1976. Carcass electrical stimulation and early boning of beef. New Zeal. J. Agr. Res. 19:429–434. doi:10.1080/00288233.1976.10420971

Gilbert, K. V., C. L. Davey, and K. G. Newton. 1977. Electrical stimulation and the hot boning of beef. New Zeal. J. Agr. Res. 20:139–143. doi:10.1080/00288233.1977.10427317

Hunt, M. R., A. J. Garmyn, T. G. O'Quinn, C. H. Corbin, J. F. Legako, R. J. Rathmann, J. C. Brooks, and M. F. Miller. 2014. Consumer assessment of beef palatability from four beef muscles from USDA Choice and Select graded carcasses. Meat Sci. 98:1–8. doi:10.1016/j.meatsci.2014.04.004

Hunt, M. C., and H. B. Hedrick. 1977. Profile of fiber types and related properties of five bovine muscles. J. Food Sci. 42:513–517. doi:10.1111/j.1365-2621.1977.tb01535.x

Locker, R. H. 1960. Degree of muscular contraction as a factor in tenderness of beef. J. Food Sci. 25:304–307. doi:10.1111/j.1365-2621.1960.tb00335.x

Marsh, B. T., and N. G. Leet. 1966. Studies in meat tenderness. III. The effects of cold shortening on tenderness. J. Food Sci. 31:450–459. doi:10.1111/j.1365-2621.1966.tb00520.x

Meade, M. K., D. D. Johnson, and R. L. West. 1992a. Physical and sensory characteristics and microbiological quality of beef from a partial hot fabrication procedure. J. Food Sci. 57:1041–1044. doi:10.1111/j.1365-2621.1992.tb11257.x

Meade, M. K., D. D. Johnson, R. L. West, and M. O. Balaban. 1992b. Yield, USDA grade factors and time requirements for a beef partial hot fabrication procedure. J. Food Sci. 57:1038–1040, 1045. doi:10.1111/j.1365-2621.1992.tb11256.x

Neely, T. R., C. L. Lorenzen, R. K. Miller, J. D. Tatum, J. W. Wise, J. F. Taylor, M. J. Buyck, J. O. Reagan, and J. W. Savell. 1998. Beef customer satisfaction: Role of cut, USDA quality grade, and city on in-home consumer ratings. J. Anim. Sci. 76:1027–1033. doi:10.2527/1998.7641027x

Olsson, U., C. Hertzman, and E. Tornberg. 1994. The influence of low temperature, type of muscle and electrical stimulation on the course of rigor mortis, ageing and tenderness of beef muscles. Meat Sci. 37:115–131. doi:10.1016/0309-1740(94)90149-X

O'Sullivan, A., M. Korzeniowska, A. White, and D. J. Troy. 2003. Using a novel intervention technique to reduce the variability and improve tenderness of beef longissimus dorsi. Proceedings of the 49th International Congress of Meat Science and Technology, Sao Paulo, Brazil. p. 513–514.

Reagan, J. O. 1983. Hot processing of pork whole muscle cuts. In: 36th Recip. Meat Conf. Proc., Am. Meat Sci. Assoc., Champaign, IL. p. 71–73.

Rhee, M. S., T. L. Wheeler, S. D. Shackelford, and M. Koohmaraie. 2004. Variation in palatability and biochemical traits within and among eleven beef muscles. J. Anim. Sci. 82:534–550. doi:10.2527/2004.822534x

Savell, J. W. 2012. The beef checkoff. Beef carcass chilling: Current understanding, future challenges. Available at: Http://www.beef-research.org/CMDocs/BeefResearch/BeefCarcass Chilling%20 White%20Paper_final.pdf (Accessed 10 January 2016).

Schmidt, G. R., and S. Keman. 1974. Hot boning and vacuum packaging of eight major bovine muscles. J. Food Sci. 39:140–142. doi:10.1111/j.1365-2621.1974.tb01008.x

Seideman, S. C., G. C. Smith, T. R. Dutson, and Z. L. Carpenter. 1979. Physical, chemical and palatability traits of electrically stimulated, hot-boned, vacuum-packaged beef. J. Food Prot. 42:651–653. doi:10.4315/0362-028X-42.8.651

Seyfert, M., M. C. Hunt, R. A. Mancini, K. A. Hachmeister, D. H. Kropf, J.A. Unruh, and T. M. Loughin. 2005. Beef quadriceps hot boning and modified-atmosphere packaging influence properties of injection-enhanced beef round muscles. J. Anim. Sci. 83:686–693. doi:10.2527/2005.833686x

Shaw, F. D., and V. H. Powell. 1995. Meat quality aspects of hot boning. Proceedings of CSIRO Meat Industry Research Conference. 12B:1–4.

Smulders, F. J. M., G. Eikelenboom, and J. V. van Logtestijn. 1986. The effect of electrical stimulation on the quality of three bovine muscles. Meat Sci. 16:91–101. doi:10.1016/0309-1740(86)90068-9

Troy, D. J. 1999. Enhancing the tenderness of beef. Teagasc final report 11. The National Food Centre Research Report. No. 11. Teagasc, Dublin, Ireland. p. 3–4.

Taylor, J., E. S. Toohey, R. van de Ven, and D. L. Hopkins. 2012. SmartStretch^{TM} technology. IV. The impact on the meat quality of hot-boned beef rostbiff (*m. gluteus medius*). Meat Sci. 91:527–532. doi:10.1016/j.meatsci.2012.03.009

Unruh, J. A., C. L. Kastner, D. H. Kropf, M. E. Dikeman, and M. C. Hunt. 1986. Effects of low-voltage electrical stimulation during exsanguination on meat quality and display colour stability. Meat Sci. 18:281–293. doi:10.1016/0309-1740(86)90018-5

USDA. 1997. United States standards for grades of carcass beef. Livest. Seed Program, Agric. Market. Serv., Washington, DC.

Watson, R., A. Gee, R. Polkinghorne, and M. Porter. 2008. Consumer assessment of eating quality- Development of protocols for MSA testing. Aust. J. Exp. Agr. 48:1360–1367.

Wheeler, T. L., S. D. Shackelford, and M. Koohmaraie. 2000. Variation in proteolysis, sarcomere length, collagen content, and tenderness among major pork muscles. J. Anim. Sci. 78:958–965. doi:10.2527/2000.784958x

White, A., A. O'Sullivan, D. J. Troy, and E. E. O'Neill. 2006. Effects of electrical stimulation, chilling temperature and hot-boning on the tenderness of bovine muscles. Meat Sci. 73:196–203. doi:10.1016/j.meatsci.2005.11.020