Effects of zilpaterol hydrochloride with or without an estrogen-trenbolone acetate terminal implant on carcass traits, retail cutout, tenderness, and muscle fiber diameter in finishing steers[1]

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ABSTRACT: Our objective was to determine the effects of feeding zilpaterol hydrochloride (ZH), a β-agonist, for the final 30 d of the feeding period, with or without a terminal estrogen + trenbolone acetate (TBA) implant (Revalor-S; 24 mg of estradiol-17β and 120 mg of TBA; REV) on meat tenderness and carcass cutout yields. Crossbred steers (n = 2,279) were divided into 6 BW blocks and 24 pens. Within each block, pens were assigned randomly to 1 of 4 treatments: 1) no terminal implant (control); 2) a terminal REV given 91 d before slaughter; 3) no terminal implant plus ZH; and 4) a terminal REV implant plus ZH (REV+ZH). All cattle received Component TE-IS (16 mg of estradiol and 80 mg of TBA) on d 61 of the feeding period. Zilpaterol hydrochloride was added to the diets at a concentration of 8.38 mg/kg (DM basis) during the final 30 d of the feeding period, followed by a 3-d period before slaughter in which ZH was withdrawn from the diet. Carcasses (n = 30/treatment) were selected from the 2,279 cattle and fabricated into subprimal cuts as per Institutional Meat Purchase Specifications. Strip loins were collected, cut into 2.54-cm steaks, and aged 7, 14, and 21 d, after which Warner-Bratzler shear force (WBSF), collagen content, desmin degradation, and muscle fiber diameter measurements were determined. Feeding ZH increased ($P < 0.05$) yield of the #112A ribeye roll, #116B chuck mock tender, #167A peeled knuckle, #169 top inside round, #171B outside round, #171C eye of round, #180 strip loin, #184 top sirloin butt, and #189A full tenderloin for ZH treatment. Longissimus muscle WBSF at 7, 14, and 21 d postmortem was increased ($P < 0.001$) with ZH supplementation. Desmin degradation at 7, 14, and 21 d postmortem was not affected with REV or ZH supplementation compared with controls. Zilpaterol hydrochloride had an additive effect with REV on increasing LM fiber diameter ($P < 0.001$). When fed to cattle that received a terminal implant of REV, ZH potentially increased LM WBSF as a result of induced muscle hypertrophy. During the 21-d aging period, WBSF decreased with aging, suggesting that carcasses from cattle supplemented with ZH might require longer aging time to ensure that acceptable levels of tenderness are reached.

Key words: β-adrenergic receptor agonist, cattle, estrogen + trenbolone acetate implant, tenderness, zilpaterol hydrochloride

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INTRODUCTION

Consumer preference for beef with more lean and less fat has continued to increase over the past several years (Platter et al., 2001). β-Adrenergic agonists are repartitioning agents that redirect absorbed nutrients away from adipose tissue, favoring protein accretion (Ricks et al., 1984). Feeding β-adrenergic agonists to pigs, sheep, and cattle increases protein accretion in skeletal muscle and decreases total body fat content (Miller et al., 1989; Yang and McElligott, 1989; Rikhardsson et al., 1991). Increasing efficiency of protein deposition and enhancing overall production efficiency are of great importance to all livestock industries. Most β-agonists used in livestock stimulate increased lipolysis, decreased lipogenesis, or stimulate protein disposition by binding to the β_1- or β_2-adrenergic receptors (Mersmann, 1998). Zilpaterol hydrochloride (**ZH**; Intervet/Schering-Plough Animal Health, DeSoto, KS), a β-agonist that was recently approved for use in feedlot cattle,

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increases ADG, G:F, and HCW when fed for 20 to 40 d before slaughter (Vasconcelos et al., 2008); however, effects of ZH on retail cut yields and beef tenderness have not been reported.

Steroidal implants, such as Revalor-S (**REV**; Intervet/Schering-Plough Animal Health), which contains trenbolone acetate (**TBA**) and estradiol 17β, have been used in the beef industry for many years. Implanting cattle with such compounds has been shown to increase Warner-Bratzler shear force (**WBSF**; Platter et al., 2001; Barham et al., 2003). Some studies have found no effects of implants on marbling scores (Gerken et al., 1995), whereas others have reported more advanced skeletal maturities and decreased carcass quality grades in implanted cattle (Belk, 1992). Given that ZH and REV could have effects on carcass cutability and WBSF, our objective was to evaluate the effects of ZH on tenderness and yield characteristics of cattle with or without a terminal implant of REV.

MATERIALS AND METHODS

All procedures involving live animals were conducted within the guidelines of and approved by the Texas Tech University Animal Care and Use Committee.

Cattle

A feedlot experiment was conducted using 2,279 English × Continental steers to evaluate the effects of feeding ZH in combination with and without the terminal implant REV on carcass characteristics. Cattle were weighed on arrival at the feedlot, and real-time ultrasound was used to determine empty body fat so that cattle could be blocked into 6 blocks as described in Baxa (2008). Cattle were fed a ground corn-based diet 3 times daily as described in Baxa (2008). All cattle received Component TE-IS (16 mg of estradiol and 80 mg of TBA; Vetlife Inc., West Des Moines, IA) on d 61 of the feeding period. Within each block, cattle were assigned randomly to 1 of 4 treatments (24 total pens; 6 pens/treatment) arranged as a 2 (ZH vs. no ZH) × 2 (REV vs. no REV) factorial arrangement. Thus, the 4 treatments consisted of 1) an initial implant only (control); 2) an initial implant plus a terminal REV implant (REV); 3) an initial implant only plus feeding of ZH; and 4) an initial implant and a terminal REV implant plus feeding of ZH (REV+ZH). The ZH was included in the diet at a concentration of 8.38 mg/kg (DM basis) for the final 30 d of the feeding period followed by a 3-d withdrawal period before slaughter, and the terminal implant of REV (24 mg of estradiol and 120 mg of TBA) was given 91 d before slaughter. Additional details of cattle management are provided by Baxa (2008).

Cattle Slaughter

Cattle were slaughtered on 6 different days representing each of the 6 blocks. One pen of cattle receiving each treatment within each block was slaughtered on each of the slaughter dates. Hot carcass weight was collected, and carcasses were spray-chilled for 36 h postmortem. After chilling, carcasses were ribbed at the 12th rib, and USDA quality and yield grade traits were measured (USDA, 1997). Carcass traits measured included preliminary yield grade, adjusted preliminary yield grade, LM area, KPH, skeletal and lean maturity scores, marbling score, carcass defects, and stamped USDA yield and quality grades.

Carcass Selection

Carcasses obtained for fabrication were selected from slaughter d 1, 2, 5, and 6 (representing 4 of the 6 blocks used in the study). From each of the 4 pens/treatment, carcasses (7 or 8/pen) were selected for fabrication, resulting in a total of 30 carcasses per treatment to be fabricated (n = 120). Selected carcasses were free of bruises, major trim loss, or other slaughter dressing defects. Carcasses selected from each pen were within ± 22.7 kg of the average HCW of the pen. Carcasses within the 22.7-kg weight range were then selected based on USDA quality and yield grade. Emphasis for selection was first based on yield grade, followed by quality grade. Selection of carcasses within the described grid was conducted to decrease the effects of treatment differences in carcass factors on cutability. The right side of selected carcasses was shipped to the Gordon W. Davis Texas Tech Meat Laboratory, Lubbock for fabrication into subprimal cuts. In addition, the left side of each carcass was followed through plant fabrication procedures, and the strip loin, Institutional Meat Purchase Specifications (**IMPS**) #180 was vacuum sealed, shipped to the Meat Laboratory, and stored at 2°C until further analyses.

Carcass Cutability

After shipment, the right sides of selected carcasses for fabrication were sorted into treatment groups. Each production day, balances (model CW-11, Ohaus Corp., Pine Brook, NJ) were calibrated by placing standard weights on the scales to ensure accuracy. Carcasses were fabricated in sets of 4 to represent 1 carcass from each treatment. Carcasses from each treatment were selected randomly within each set of 4 to decrease any possible confounding effect of fabrication order on cutability traits. Carcass sides were weighed entering the production floor to achieve a cold carcass weight. Subprimals collected from each fabricated carcass were fabricated as per IMPS as described by NAMP (1997) and trimmed to meet standard packer fat trim levels commonly found with boxed beef (approximately 7 mm). The subprimals collected were the shoulder clod (IMPS #114), chuck roll (IMPS #116A), chuck tender (IMPS #116B), brisket (IMPS #120), boneless short ribs (IMPS #130A), blade meat (IMPS #109B), ribeye roll (IMPS #112A), outside skirt steak (IMPS #121C),

inside skirt steak (IMPS #121D), back ribs (IMPS #124), knuckle, peeled (IMPS #167A), top inside round (IMPS #169), bottom round (IMPS #171B), eye of the round (IMPS #171C), strip loin, short-cut boneless (IMPS #180), top sirloin butt (IMPS #184), bottom sirloin flap (IMPS #185A), bottom sirloin ball tip (IMPS #185B), bottom sirloin tri-tip (IMPS #185C), full tenderloin, defatted (IMPS #189A), flank (IMPS #193), deep pectoral, pastrami, rose meat (elephant ear), round shank meat, heel meat, fat, bone, kidney knob fat, 90/10, 80/20, and 50/50 trimmings. Each subprimal was weighed and expressed as a percentage of the cold carcass weight. To verify accuracy of subprimal weights, all weights were added together and calculated as a percent cutout yield. Acceptable measures ranged from 99 to 100.5%. After fabrication, 3 cores of the LM were taken parallel to the muscle fibers and frozen in liquid nitrogen for fiber diameter analysis.

Purge and WBSF

For each corresponding left side of the carcass that was fabricated, the strip loin (IMPS #180) was collected, vacuum sealed, shipped to the Meat Laboratory, and stored at 2°C until 7 d postmortem. At d 7 postmortem, packaged strip loins were weighed, and each vacuum bag was identified with the corresponding strip loin. Strip loins were removed from the vacuum bag and blotted dry with a towel. The strip loins were then reweighed to determine the actual strip loin weight. Vacuum bags were dried in a 32°C oven (Alkar Inc., Dallas, TX) for 2 h. Once dried, the bags were weighed, and percent purge for each strip loin was calculated.

Strip loins were cut into 2.54-cm-thick steaks, placed in vacuum bags, and aged at 2°C. Steaks were allotted randomly to an aging treatment of 7, 14, or 21 d for WBSF analysis. After the allotted aging period, steaks were frozen and stored at −20°C.

Warner-Bratzler shear force determinations were conducted in accordance to AMSA (1995) guidelines. Steaks for WBSF were thawed for 24 h at 2°C and cooked on a George Foreman Grill (model GRP 99, Westmont, NJ) to an internal temperature of 71°C. Individual steaks were weighed before and after cooking to determine cooking loss. After cooking, steaks were placed on plastic trays, covered with polyvinyl chloride film, and chilled for 24 h at 2°C. Six round cores were removed from each LM parallel to the muscle fiber orientation, and sheared with a WBSF machine (Warner-Bratzler Meat Shear, G-R Manufacturing Co., Manhattan, KS). Individual core readings were monitored by a digital force gauge (model BFG500N, Mecmesin Corp., Sterling, VA). The average of the cores was then computed for statistical analyses.

Chemical Analyses

Trim from the fabricated carcasses (90/10, 80/20, and 50/50) was placed into a mixer/grinder (model 4400, Holymatic, Chicago, IL). The tissue was mixed for 5 min and ground through a 9.5-mm plate to achieve a coarse grind. The coarsely ground tissue was then placed back into the mixer and mixed for an additional 5-min period; the soft tissue was then ground through a 4.7-mm plate, and 6 random samples were taken for further analyses. Soft tissue moisture, protein, and fat were determined in triplicate according to AOAC (1990) techniques. Tissue moisture was determined using a 4-g sample and drying samples at 100°C for at least 16 h in a convection oven (ThermoScientific, Waltham, MA). Tissue protein was estimated on 1-g samples using a Leco N analyzer (model FP-2000, St. Joseph, MO), and tissue fat was determined using a 4-g sample using ether extraction.

Fiber Diameter

Muscle fiber samples (6 cores/carcass) were collected from the LM after the fabrication of a carcass. The samples were submerged in glycerol, frozen in liquid N, and stored at −80°C. Embedding medium was used to secure the samples upright on a piece of square corkboard. Using a cryostat (Leica CM 1800, Bonnockburn, IL), 10-μm-thick sections (3 sections/core) were cut and mounted on slides for microscopy for a total of 18 sections per carcass. The samples were allowed to thaw for 15 min to ensure adhesion to the slides. Slides were then submerged in hematoxylin for 5 min; rinsed twice with distilled, deionized water; placed in eosin for 15 s; rinsed twice with distilled, deionized water; and dehydrated with 80% (vol/vol) ethanol for 2 min, 90% (vol/vol) ethanol for 5 min, and 100% ethanol for 5 min. One drop of glycerol gelatin was placed on the section, covered with a coverslip, and viewed under a microscope (Diagnostic Instruments Model 1.4.0, Sterling Heights, MI) for fiber diameter determination. For each carcass, a minimum of 300 fibers were measured for statistical analysis. Fiber diameters were measured in micrometers and averaged for each sample for statistical analyses.

Protein Degradation

Protein extraction, electrophoresis, Western blotting, and quantification of desmin were determined using the 6 cores used in WBSF determinations as described by Wheeler and Koohmaraie (1999) and Wheeler et al. (2002). The cooked ends of each core were removed. At-death standard reference samples were obtained from the LM of 16 carcasses (4/treatment) within 1 h postmortem. Percent desmin was calculated using the following formula: (protein image density value/mean of pooled 0-h standard image density value) × 100. As a result of animal-to-animal variation in the amount of muscle desmin, some samples contained more desmin at 7 and 14 d than the reference samples. To adjust for this, the least negative value within a Western blot was set to 0 and all other values within the blot were

adjusted proportionally. This process was done for all 3 aging periods on each steak within each treatment.

Collagen Content

Total collagen concentration was determined on 7-d aged LM steaks by calculating hydroxyproline from HPLC measurements as described by Wheeler et al. (2000).

Statistical Analyses

Data for carcass grade, carcass cutability, and strip loin purge loss were analyzed as a 2 × 2 factorial arrangement of treatments as a randomized block design (4 blocks; 1 block on each slaughter day) with individual carcasses as the experimental unit. Least squares means were calculated using the MIXED models procedure (SAS Inst. Inc., Cary, NC) with slaughter day and slaughter day × treatment as random effects and marbling score as a covariate. When a ZH × REV interaction was significant ($P \leq 0.05$), differences among treatment means were determined using the pdiff option of SAS for the least squares means. Mean separations were conducted with a predetermined α level of 0.05.

For WBSF and protein degradation, a split-plot arrangement was used. The main plot was as described previously (randomized block with a 2 × 2 factorial arrangement of treatments and carcass as the experimental unit), whereas the subplot consisted of aging treatment and interactions of aging treatment with main-plot effects slaughter day and slaughter day × treatment. Categorical data (percentage of carcasses in USDA quality grade categories) were analyzed using the CATMOD procedure of SAS using the generalized logit function. Pearson correlation coefficients within each aging time were computed to evaluate relationships among WBSF, desmin degradation, collagen, and LM fiber diameter.

RESULTS AND DISCUSSION

Carcass Traits

Data were collected on carcasses that were selected for fabrication to determine overall USDA quality and yield grades. Results are presented in Table 1. No ZH × REV interactions ($P \geq 0.05$) existed for any of the carcass traits measured. Revalor-S decreased 12th-rib fat thickness ($P < 0.05$), whereas ZH had no effect on 12th-rib fat ($P \geq 0.05$). These findings agree with those of Plascencia et al. (1999), who reported that ZH-treated cattle showed no difference in carcass 12th-rib fat compared with controls; however, Casey et al. (1997a,b) reported ZH decreased ($P < 0.05$) carcass 12th-rib fat. Other studies have shown a trend ($P = 0.06$) for ZH-treated steers to have less 12th-rib fat than control cattle (Avendaño-Reyes et al., 2006). Recently,

Table 1. Effects of zilpaterol hydrochloride (fed for the final 30 d on feed plus a 3-d withdrawal) with or without a terminal Revalor-S implant on carcass traits of carcasses selected for cutability assessment

	No Revalor-S implant		Revalor-S implant			*P*-value[2]		
Item	No zilpaterol	Zilpaterol	No zilpaterol	Zilpaterol	SEM[1]	Zilpaterol	Revalor-S	Interaction
HCW, kg	376.97	397.55	389.61	399.99	9.174	0.01	0.12	0.27
Preliminary yield grade	3.40	3.20	3.13	3.09	0.101	0.23	0.06	0.38
Adjusted preliminary yield grade	3.61	3.41	3.33	3.27	0.062	0.13	0.03	0.45
12th-rib fat, cm	1.64	1.43	1.35	1.28	0.065	0.13	0.03	0.45
LM area, cm	87.89	99.03	96.44	111.57	2.664	<0.001	0.001	0.26
KPH fat, %	2.15	1.99	2.08	2.03	0.108	0.07	0.80	0.31
USDA yield grade	3.33	2.72	2.72	1.98	0.173	0.001	0.001	0.63
Bone maturity[3]	60.52	51.96	56.34	49.38	2.566	0.01	0.21	0.76
Lean maturity[3]	45.94	43.21	43.13	44.51	3.253	0.78	0.75	0.40
Overall maturity	54.69	48.93	51.47	48.08	1.991	0.05	0.34	0.57
Marbling score[4]	41.50	37.16	35.61	32.17	2.184	0.02	0.01	0.74
Quality grade[5]	716.32	676.51	663.05	626.43	21.846	0.01	0.01	0.90

[1]Pooled SE of simple-effect means, n = 30/treatment.

[2]Observed significance levels for the main effects of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS), Revalor-S implant (Intervet/Schering-Plough Animal Health), and the zilpaterol × Revalor-S implant interaction.

[3]Maturity: 10 = A^{10}; 20 = A^{20}; 30 = A^{30}; 100 = B^{00}.

[4]Marbling score: 30 = Slight^{00}; 40 = Small^{00}.

[5]Quality grade: 600 = Select^{00}; 700 = Low Choice^{00}; 800 = Premium Choice^{00}.

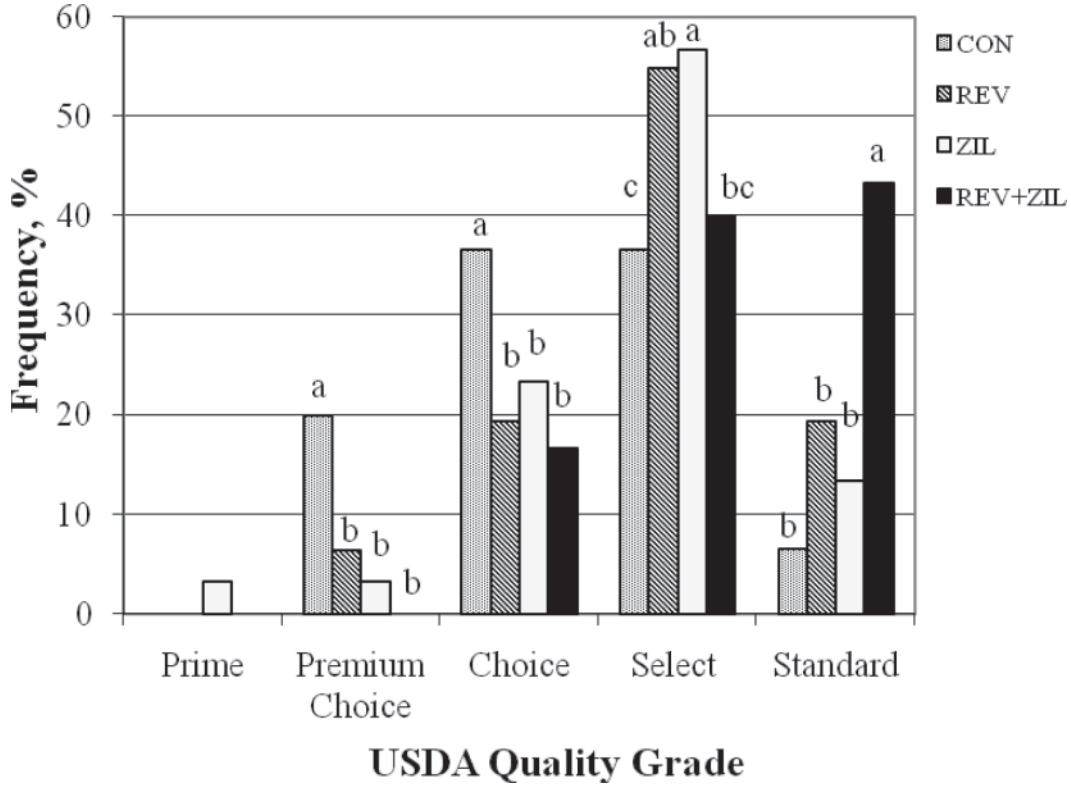

Figure 1. Frequencies (% of total) of USDA quality grades from carcasses of steers implanted or not implanted with a terminal Revalor-S implant (REV; Intervet/Schering-Plough Animal Health, DeSoto, KS) and fed diets with or without zilpaterol hydrochloride (ZIL; Intervet/Schering-Plough Animal Health) for the final 30 d on feed plus a 3-d withdrawal period. [a–c]Frequencies within a USDA quality grade that do not have a common letter differ, $P < 0.05$. CON = control.

Vasconcelos et al. (2008) reported ZH significantly decreased carcass 12th-rib fat compared with controls. In the present study, REV increased LM area and decreased yield grade, marbling score, and quality grade ($P < 0.05$). Feeding ZH resulted in an additive increase in LM area ($P < 0.001$). Longissimus muscle area was increased by 13 cm^2, resulting in a 14% increase with ZH supplementation. Vasconcelos et al. (2008) also reported that ZH significantly increased LM area compared with controls. In the present study, averaged over terminal implant treatments, HCW was increased ($P < 0.05$) 15 kg when steers were fed ZH. Avendaño-Reyes et al. (2006) reported an increase in HCW of 7% for steers fed ZH and 5% for steers fed ractopamine (**RAC**) vs. control cattle. No significant differences were found for KPH among treatments; however, Vasconcelos et al. (2008) reported a significant decrease in KPH for ZH-fed cattle compared with controls. Increased LM area with the feeding of ZH suggests that protein accretion, not decreased adipose tissue deposition, tends to be the main effect of ZH. These findings are similar to those noted with the feeding of the β-agonist, clenbuterol, in which certain studies reported increases in LM area of 16% (Ricks et al., 1984; Miller et al., 1988). Moreover, present results agree with those of Casey et al. (1997a,b), who reported increases in carcass LM area of 23% when ZH was fed.

Zilpaterol hydrochloride supplementation decreased ($P < 0.05$) carcass yield grade. Winterholler et al. (2007) reported the β-agonist RAC did not significantly affect carcass yield grades of steers. Moreover, in the present study, skeletal maturity scores were less ($P < 0.05$) with ZH supplementation, regardless of REV treatment. Similarly, overall maturity scores were less when ZH was fed ($P < 0.05$). No differences were noted among the REV, ZH, and REV+ZH treatments for bone maturity scores. In addition, no significant differences were detected among treatments for lean maturity scores. These findings agree with those of Vasconcelos et al. (2008), who reported no differences between ZH-fed cattle and controls for carcass maturity scores. Zilpaterol hydrochloride had an additive affect to REV on decreasing marbling score ($P < 0.05$) and overall quality grade ($P < 0.05$). Thus, these results suggest the feeding of ZH to cattle has a substantial negative effect on USDA quality grades. Similarly, Vasconcelos et al. (2008) reported decreased marbling scores for ZH-fed cattle compared with controls ($P < 0.01$). The frequencies of each quality grade for each treatment are shown in Figure 1. Control carcasses had an increased propensity for Premium Choice grades ($P < 0.05$), with 20% in the upper Choice categories compared with 6.5% for REV, 3.33% for ZH, and 0% for REV+ZH. Controls also had an increased percentage of carcasses grading USDA Choice, with 36.67%, compared with 19.35% for REV, 23.33% for ZH, and 16.67% for REV+ZH. The effects of ZH treatment were evident in the USDA Select and Standard quality grades, with REV+ZH-

Table 2. Effects of zilpaterol hydrochloride (fed for the final 30 d on feed plus a 3-d withdrawal) with or without a terminal Revalor-S implant on percent yield of subprimal cuts from fabricated carcasses

	No Revalor-S implant		Revalor-S implant			*P*-value[3]		
Subprimal[1]	No zilpaterol	Zilpaterol	No zilpaterol	Zilpaterol	SEM[2]	Zilpaterol	Revalor-S	Interaction
114 Shoulder clod	4.89	5.18	4.97	5.31	0.073	<0.001	0.05	0.58
Chuck clod tender	0.24	0.26	0.25	0.28	0.018	0.002	0.09	0.53
116A Chuck roll	5.65	5.68	5.97	5.94	0.063	0.96	0.001	0.60
116B Chuck mock tender	0.75	0.85	0.82	0.86	0.026	0.001	0.04	0.08
120 Brisket, boneless, deckle off	3.40	3.47	3.39	3.52	0.075	0.05	0.68	0.58
130A Short ribs, boneless	0.85	0.87	0.83	0.79	0.059	0.78	0.16	0.42
Deep pectoral meat	0.54	0.61	0.60	0.62	0.020	0.01	0.08	0.11
109B Blade meat	1.41[c]	1.65[a]	1.54[b]	1.62[ab]	0.041	0.001	0.17	0.04
112A Ribeye roll	3.12	3.24	3.19	3.29	0.053	0.03	0.23	0.78
121C Skirt steak, outer	0.43	0.40	0.41	0.39	0.018	0.07	0.13	0.58
121D Skirt steak, inner	0.64	0.68	0.66	0.68	0.025	0.05	0.44	0.42
124 Back ribs	1.08	1.04	1.09	1.00	0.026	0.006	0.38	0.15
Pastrami	0.36	0.39	0.38	0.41	0.013	0.05	0.14	0.57
167A Knuckle, peeled	2.02	2.11	2.09	2.37	0.058	0.001	0.003	0.05
169 Top (inside) round	5.37	5.92	5.73	6.20	0.132	0.001	0.01	0.71
171B Outside (flat) round	3.87	4.32	4.11	4.51	0.079	<0.001	0.001	0.58
171C Eye of round	1.42	1.60	1.56	1.80	0.041	<0.001	0.001	0.36
Shank meat	1.55	1.60	1.60	1.64	0.022	0.03	0.03	0.84
Heel meat	1.08	1.23	1.19	1.25	0.046	0.003	0.03	0.10
180 Strip loin, short-cut, boneless	2.86	3.11	3.03	3.22	0.064	<0.001	0.005	0.50
184 Top sirloin butt	2.87	3.06	2.98	3.07	0.079	0.001	0.06	0.14
189A Full tenderloin, defatted	1.57	1.67	1.61	1.74	0.033	<0.001	0.01	0.48
185A Bottom sirloin butt, flap	0.81	0.85	0.87	0.87	0.045	0.38	0.06	0.41
185B Bottom sirloin butt, ball tip	1.05[b]	1.28[a]	1.11[b]	1.10[b]	0.053	0.03	0.18	0.01
185C Bottom sirloin butt, tri-tip	0.64[b]	0.72[a]	0.71[a]	0.74[a]	0.028	0.002	0.007	0.04
193 Flank steak	0.47[b]	0.54[a]	0.52[a]	0.54[a]	0.014	0.001	0.02	0.02
Elephant ear (rose meat)	0.66	0.75	0.70	0.76	0.020	0.003	0.18	0.54
90/10 trimmings	4.68	5.07	5.50	5.98	0.281	0.07	0.003	0.81
80/20 trimmings	4.05	4.15	4.12	4.49	0.263	0.37	0.43	0.61
50/50 trimmings	8.79	8.23	8.05	7.35	0.307	0.004	0.001	0.71
Kidney and pelvic fat	2.73	2.67	2.69	2.40	0.123	0.17	0.21	0.34
Trimmed fat	13.77	11.54	11.34	10.04	0.659	0.002	0.001	0.28
Bone	16.16	15.04	16.15	15.08	0.244	0.001	0.96	0.91

[a–c]Within a row, simple-effect means that do not have a common superscript differ, $P < 0.05$.

[1]Institutional Meat Purchase Specifications (IMPS) number (USDA, 1990) followed by the common name of the subprimal. Expressed as a percentage of the chilled carcass weight.

[2]Pooled SE of simple-effect means, n = 30/treatment.

[3]Observed significance levels for the main effects of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS), Revalor-S implant (Intervet/Schering-Plough Animal Health), and the zilpaterol × Revalor-S implant interaction.

Table 3. Effects of zilpaterol hydrochloride (fed for the final 30 d on feed plus a 3-d withdrawal) with or without a terminal Revalor-S implant on 7, 14, and 21 d postmortem LM Warner-Bratzler shear force (WBSF) and cooking loss values

	No Revalor-S implant		Revalor-S implant			*P*-value[2]		
Item	No zilpaterol	Zilpaterol	No zilpaterol	Zilpaterol	SEM[1]	Zilpaterol	Revalor-S	Interaction
WBSF, kg								
7 d postmortem	3.38	5.05	4.31	5.42	0.201	<0.001	0.002	0.17
14 d postmortem	2.83	4.12	3.24	4.50	0.156	<0.001	0.01	0.91
21 d postmortem	2.68	4.08	3.32	4.52	0.225	<0.001	0.02	0.65
LM cook loss, %	22.27	21.15	21.95	21.97	0.568	0.65	0.33	0.31

[1]Pooled SE of simple-effect means, n = 30/treatment.

[2]Observed significance levels for the main effects of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS), Revalor-S implant (Intervet/Schering-Plough Animal Health), and the zilpaterol × Revalor-S implant interaction.

treated cattle grading 40% Select and 43.33% Standard ($P < 0.001$), whereas among control carcasses, 36.67% graded Select and 6.67% graded Standard.

Yield of Subprimal Cuts

Right sides from each carcass selected to be fabricated were broken into subprimals and trimmed to fat levels (approximately 7 mm) to simulate boxed beef packer levels. Treatment responses are presented in Table 2. For subprimals from the forequarter, REV increased ($P < 0.05$) the yield of the #114 shoulder clod, #116A chuck roll, and #116B chuck mock tender. Zilpaterol hydrochloride supplementation had an additive effect to REV of increasing ($P < 0.001$) the #114 shoulder clod and #116B chuck mock tender yield, but ZH had no effect ($P \geq 0.05$) on the #116A chuck roll. Feeding steers ZH increased ($P < 0.05$) the yield of the chuck clod tender, #120 boneless brisket, and deep pectoral meat compared with controls. In addition, ZH treatment increased ($P < 0.05$) the yield of the #112A ribeye roll compared with controls and increased ($P < 0.001$) blade meat yield when cattle were not reimplanted, but not in cattle that received a terminal REV implant (interaction, $P < 0.05$). For the remaining portion of the forequarter, no significant differences were found among treatments for the #121C skirt steak (outer) and the pastrami meat.

Implanting steers with REV increased ($P < 0.01$) the yield of the hindquarter subprimals: the #169 inside round, #171B outside round, #171C eye of round, #180 strip loin, #184 top sirloin butt, and the #189A full tenderloin. Zilpaterol hydrochloride supplementation had an additional effect of increasing ($P < 0.001$) yield for the #169 inside round, #171B outside round, #171C eye of round, #180 strip loin, #184 top sirloin butt, and the #189A full tenderloin. In addition, 50% lean trimmings were decreased ($P < 0.01$) and 90% lean trimmings had a tendency ($P = 0.07$) to be increased with ZH supplementation compared with controls. A ZH × REV interaction was detected for the yield of the #185B bottom sirloin butt, ball tip, #185C bottom sirloin butt, tri-tip, and the #193 flank steak. Zilpaterol hydrochloride supplementation decreased ($P < 0.01$) total trimmable fat and bone compared with controls. Other β-agonists such as $L_{644,969}$ and cimaterol have been shown to increase beef cutability. Moloney et al. (1990, 1994) have shown that $L_{644,969}$ increased the cutability of low- and high-priced cuts including the brisket, strip loin, inside, and outside round. In addition, Chikhou et al. (1993) reported Holstein steers supplemented with cimaterol had increased yields for the brisket, flank, strip loin, and inside round. Plascencia et al. (1999) found ZH treatment of Mexican cattle for 42 d significantly increased carcass yield of subprimal cuts from the round. Therefore, ZH supplementation had an additive effect with a terminal REV implant of increasing the yield of cuts from the hindquarter.

WBSF

Steaks from cattle supplemented with ZH had substantial increases in WBSF compared with control steaks (Table 3). A treatment × postmortem aging day interaction for WBSF of the LM existed; however, no ZH × REV interactions for LM WBSF were found. The terminal REV implant increased ($P < 0.05$) WBSF at 7, 14, and 21 d postmortem. Similarly, at 7, 14, and 21 d postmortem, WBSF of the LM also was increased ($P < 0.001$) by ZH supplementation. Zilpaterol hydrochloride supplementation increased WBSF of steaks by 60% at 7 d postmortem, 59% at 14 d postmortem, and 67% at 21 d postmortem compared with steaks from control carcasses. These results indicate that ZH has a similar effect to other β-agonists, such as clenbuterol of increasing WBSF (Miller et al., 1988; Schiavetta et al., 1990). Avendaño-Reyes et al. (2006) reported significant increases in WBSF for steers supplemented with RAC and ZH compared with controls. Warner-Bratzler shear force values of the LM indicate that an aging curve existed for all treatments, as WBSF decreased quadratically ($P < 0.01$) and cubically ($P < 0.05$) over time. Zilpaterol hydrochloride-treated steaks decreased from 5.05 kg at 7 d to 4.08 kg at 21 d postmortem, and REV+ZH-treated steaks decreased from 5.42 kg at 7 d to 4.52 kg at 21 d postmortem. It is evident, therefore, that given sufficient aging time, steaks from ZH-treated cattle would eventually reach the same tenderness lev-

Table 4. Effects of zilpaterol hydrochloride (fed for the final 30 d on feed plus a 3-d withdrawal) with or without a terminal Revalor-S implant on strip loin purge loss and estimated carcass composition[1]

	No Revalor-S implant		Revalor-S implant			*P*-value[3]		
Item	No zilpaterol	Zilpaterol	No zilpaterol	Zilpaterol	SEM[2]	Zilpaterol	Revalor-S	Interaction
Estimated carcass moisture, %	55.90	58.04	58.11	60.12	0.587	0.001	<0.001	0.92
Estimated carcass fat, %	26.97	23.63	24.53	21.55	0.742	<0.001	0.003	0.81
Estimated carcass protein, %	15.46	16.74	16.15	17.28	0.249	<0.001	0.01	0.75
Strip loin purge loss, %	1.01	1.44	1.24	1.66	0.104	<0.001	0.03	0.98

[1]Estimated carcass % protein, fat, and moisture were calculated using chemical analyses conducted on 90/10, 80/20, and 50/50 lean trimmings from carcass fabrication.
[2]Pooled SE of simple-effect means, n = 30/treatment.
[3]Observed significance levels for the main effects of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS), Revalor-S implant (Intervet/Schering-Plough Animal Health), and the zilpaterol × Revalor-S implant interaction.

els as controls. Cooking loss percent of the LM was not affected ($P \geq 0.05$) by ZH or REV treatment.

Strip Loin Purge and Carcass Chemical Analyses

Results for strip loin purge loss and carcass chemical analyses are shown in Table 4. There was no ZH × REV interaction for purge loss ($P \geq 0.05$). A terminal implant of REV increased ($P < 0.05$) strip loin purge loss. Feeding ZH increased ($P < 0.001$) the percentage of strip loin purge loss compared with controls.

Much attention has been given to the questions of whether β-agonists function to increase protein accretion or decrease protein degradation. Lean trimmings from each carcass were ground, and chemical analyses were conducted to estimate carcass protein, fat, and moisture (Table 4). In the present study, total carcass percentage of fat was decreased, whereas percentages of carcass protein and water were increased by feeding ZH. Results of the carcass cutability data suggested a reduced percentage of fat for ZH-supplemented steers. No ZH × REV interaction ($P \geq 0.05$) was found for estimated percentages of carcass fat, protein, and moisture. Implanting with REV increased carcass moisture ($P < 0.001$) and carcass protein ($P < 0.05$) and decreased ($P < 0.01$) estimated percentage of carcass fat. Zilpaterol hydrochloride supplementation increased ($P < 0.001$) carcass protein and moisture and decreased ($P < 0.001$) carcass fat compared with controls. Ricks et al. (1984) reported similar results for increased carcass protein with the β_2-agonist clenbuterol. Taken together, previous findings and present results indicate that ZH has a much greater effect on increasing protein accretion than on decreasing fat degradation.

Desmin Proteolysis, Muscle Fiber Diameter, and Collagen Content

Desmin degradation has been shown to be highly correlated to tenderness values for the LM (Rhee et al., 2004). Cooked cores were collected from steaks used in WBSF determinations to analyze protein degradation (data not shown in tables). No treatment × aging interaction was detected for desmin degradation ($P \geq 0.05$), nor was a ZH × REV interaction evident ($P \geq 0.05$). Zilpaterol hydrochloride supplementation did not alter the rate of proteolysis ($P \geq 0.05$) compared with controls. As a result of increased levels of protein found in chemical analyses, we hypothesized that treatment differences in WBSF were related in the level of desmin degradation. In contrast to our expectations, however, the disappearance of desmin indicated that postmortem proteolysis was occurring in ZH-treated steers at a rate similar to controls. Zilpaterol hydrochloride treatment neither increased nor decreased the level of desmin degradation in steaks aged for 7, 14, and 21 d, which indicates that the chemical effects of aging were occurring in a similar manner to that observed for controls.

Table 5. Effects of zilpaterol hydrochloride (fed for the final 30 d on feed plus a 3-d withdrawal) with or without a terminal Revalor-S implant on total LM collagen content and LM muscle fiber diameter in finishing steers

	No Revalor-S implant		Revalor-S implant			*P*-value[2]		
Trait	No zilpaterol	Zilpaterol	No zilpaterol	Zilpaterol	SEM[1]	Zilpaterol	Revalor-S	Interaction
Fiber diameter, μm	64.294	67.623	66.015	68.278	0.5236	<0.001	0.02	0.30
Collagen,[3] g/100 g	1.02[a]	0.72[b]	0.67[b]	0.75[b]	0.063	0.05	0.005	0.001

[a,b]Within a row, means that do not have a common superscript differ, $P < 0.05$.

[1]Pooled SE of simple-effect means, n = 30/treatment.

[2]Observed significance levels for the main effects of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS), Revalor-S implant (Intervet/Schering-Plough Animal Health), and the zilpaterol × Revalor-S implant interaction.

[3]For total collagen content there was a zilpaterol × Revalor-S implant interaction, $P = 0.001$. Collagen content from control steers was greater ($P \leq 0.001$) than all other treatment groups.

Muscle hypertrophy has been a consistent result of supplementing animals with a repartitioning agent. Present results indicated a drastic increase in LM fiber diameter for ZH-treated cattle compared with controls (Table 5). In addition, the terminal REV implant increased ($P < 0.05$) LM muscle fiber diameter compared with controls, and the effects of REV and ZH were additive. Muscle fiber diameters of LM samples from the ZH treatment had an average diameter of 67.623 μm, whereas LM diameters from the treatment REV+ZH had an average diameter of 68.278 μm. This difference reflects an increase of 5.18 and 6.19% for LM samples from ZH- and REV+ZH-treated cattle, respectively, compared with controls. Additional results from measurements taken in this experiment (Baxa , 2008) corroborate the changes in muscle fiber diameter as a major biological action of ZH. Baxa (2008) indicated ZH preferentially increased the mRNA abundance of myosin heavy chain IIx. This isoform of myosin would give rise to the largest diameter fibers, which would be classified as fast, glycolytic fibers. Taken together, these data indicate a potential mechanism by which ZH increases fiber diameter in cattle. These findings are supported by research with other β-agonists like cimaterol, which has been shown to increase muscle fiber diameter (Vestergaard et al., 1994). Moreover, Gonzalez et al. (2007) found that cull cows supplemented with TBA and RAC had increased muscle fiber diameter compared with controls. Increased muscle fiber size results in a greater total volume of protein to shear and ultimately an increase in WBSF of the LM. Pearson correlations indicated a slight association between WBSF at 7, 14, and 21 d and LM fiber diameter. At 7 d postmortem, the CV between WBSF and fiber diameter was 0.17 ($P = 0.12$). At 14 and 21 d postmortem, the CV between WBSF and LM fiber diameter was 0.24 ($P = 0.02$) and 0.20 ($P = 0.07$), respectively. Although Pearson correlations at 7 and 21 d are not significant, the authors tend to believe the increased WBSF associated with ZH-treated cattle can be attributed to increased LM fiber diameter size because protein degradation is not significantly different between treatments and collagen content is less in ZH-treated cattle.

A ZH × REV interaction ($P < 0.01$) was detected for the collagen concentration in the LM of steers. Zilpaterol hydrochloride treatment decreased ($P < 0.05$) total LM collagen concentrations in cattle that did not receive a terminal REV implant, but it was without effect in REV-implanted cattle. This decrease in collagen content with ZH should be favorable for tenderness; however, WBSF results are not supportive. Perhaps the increased muscle hypertrophy associated with feeding ZH creates a dilution effect that decreases the concentration of collagen in the LM.

In conclusion, results of the present experiment suggest feeding ZH for 30 d before slaughter followed by a 3-d withdrawal period in cattle that received an initial implant or an initial implant plus a terminal REV implant will increase carcass cutability traits, percentage of carcass protein, and increase the frequency of USDA yield grade 1 carcasses. Nonetheless, a negative effect of ZH was observed on carcass quality grade and on WBSF of the LM. Therefore, based on these changes in WBSF, the feeding of ZH to implanted cattle could adversely affect consumer acceptance of beef.

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