Effects of zilpaterol hydrochloride on growth rates, feed conversion, and carcass traits in calf-fed Holstein steers

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ABSTRACT: Two experiments were conducted to evaluate the effectiveness of zilpaterol hydrochloride (ZH) to enhance growth performance and carcass characteristics in calf-fed Holstein steers. In Exp. 1, Holstein steers (n = 2,311) were fed in a large-pen trial in 2 phases at a commercial feed yard in the desert Southwest. In Exp. 2, a total of 359 steers were fed in a small-pen university study. In Exp. 1 and 2, cattle were implanted with a combination trenbolone acetate-estradiol implant approximately 120 d before slaughter. Cattle were fed ZH for 0, 20, 30, or 40 d before slaughter at a rate of 8.3 mg/kg (DM basis). A 3-d withdrawal was maintained immediately before slaughter. Cattle within an experiment were fed to a common number of days on feed. During the last 120 d before slaughter, ADG was not enhanced by feeding ZH for 20 d ($P = 0.33$ in Exp. 1, and $P = 0.79$ in Exp. 2). Gain-to-feed conversion was increased by feeding ZH for all durations in Exp. 1 ($P < 0.05$). Feeding ZH increased HCW by 9.3 (Exp. 2) to 11.6 (Exp. 1) kg at 20 d compared with the control groups. Across both experiments, dressing percent was increased for all durations of feeding ZH ($P < 0.05$). Although skeletal maturity score, liver integrity, lean color, fat thickness, and KPH were not affected by feeding ZH for 20 d in either experiment ($P \geq 0.6$), LM area was increased for all durations of feeding ZH ($P < 0.05$). The percentage of carcasses identified as USDA Choice was reduced ($P < 0.01$) for all durations of feeding ZH in Exp. 1. This effect was not observed in Exp. 2. Holstein steers clearly respond to the β-agonist ZH, and 20 d of feeding ZH with a 3-d withdrawal significantly increased carcass weights, muscling, and carcass leanness.

Key words: β-adrenergic agonist, carcass characteristic, Holstein steer, zilpaterol

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INTRODUCTION

Feeding calf-fed Holstein steers has become popular in the desert Southwest area of the United States for several reasons: 1) cattle are widely available, because California alone has approximately 20% of the dairy cow herd in the United States; 2) dairy beef cattle are able to tolerate increased heat and are unable to tolerate cold weather conditions; 3) they have relatively favorable BW gains with desirable feed conversion efficiency; 4) they have an increased genetic propensity to marble (Nour et al., 1983); and 5) because of the intensive management and early age on feed, the cattle lend themselves to age and source verification, which enhances their global marketability (Eng, 2005; Duff and McMurphy, 2007). Because dairy beef cattle have not been selected for muscling, carcass conformation is different from that of cattle of traditional beef genetics, leading to carcasses that have less overall muscle, most notably indicated by smaller ribeye areas (Knapp et al., 1989). Further, the low muscle-to-bone ratio contributes to a carcass dressing percent that is typically 2.5 percentage units less than carcasses from cattle selected for growth and muscling (Duff and Anderson, 2007). The use of growth-promoting technologies, including growth-promoting implants and, more recently, ractopamine hydrochloride, has enhanced the muscling characteristics of these cattle without appreciably decreasing carcass quality; thus, these technologies are frequently implemented (Vogel et al., 2009). In addition, the recent approval of zilpaterol hydrochloride (**ZH**; Zilmax, Intervet/Schering-Plough Animal Health, DeSoto, KS)

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Table 1. Composition and analyzed nutrient content (DM basis) of the finishing diets

Item	Experiment 1	Experiment 2
Ingredient, %		
Steam-flaked corn	69.5	71.0
Alfalfa hay	10.4	14.9
Sudangrass hay	4.6	—
Molasses	—	4.1
Yellow grease	5.1	5.1
Corn dried distillers grain	7.8	—
Wheat millrun	—	—
Urea	0.5	1.3
Calcium carbonate	1.2	—
Ultraferm[1]	0.8	—
Mineral premix[2]	0.2	2.6
Analyzed composition		
DM, %	84.9	84.4
CP, %	12.5	14.1
Ether extract, %	9.21	
Calcium, %	0.67	0.73
Phosphorus, %	0.28	0.25
NE_m,[3] Mcal/kg	2.32	2.20
NE_g,[3] Mcal/kg	1.61	1.52

[1]Monosodium glutamate-process by-product (Westway, Tomball, TX).

[2]Exp. 1: Trace minerals and vitamins were included in the mineral premix (Imperial Premix, Imperial, CA). Exp. 2: Mineral premix included trace minerals, vitamins, and calcium carbonate (University of Arizona, Tucson).

[3]Calculated using standard NRC (1984) nutrient values for ingredients.

as a feed additive to improve muscling, feed efficiency conversion, and ADG lends promise to enhancing both growth and muscle characteristics of calf-fed Holstein steers. Previous research indicates that feeding ZH enhances growth, feed conversion efficiency, and muscling (Casey et al., 1997; Plascencia et al., 1999; Vasconcelos et al., 2008), and to a larger extent than ractopamine (Avendano-Reyes et al., 2006). The objectives of the current research were to determine the effectiveness of feeding ZH on ADG, feed efficiency conversion, carcass quality, and muscle deposition in calf-fed Holstein steers.

MATERIALS AND METHODS

The California Polytechnic State University Institutional Animal Care and Use Committee approved procedures relating to animal care and use (Exp. 1), and the University of Arizona Institutional Animal Care and Use Committee approved procedures relating to animal care and use (Exp. 2).

Calf-fed Holstein steers were identified and tested in 2 separate feeding facilities in the desert Southwest area of the United States. Experiment 1 was conducted in 2 phases at a large commercial feed yard, whereas Exp. 2 was conducted in small pens at a university feed yard. Both sets of cattle were purchased from commercial calf-growing operations and were fed diets typical of the region (Table 1). All cattle were on feed for a minimum of 220 d before the beginning of the study. Slaughter dates for both studies were based on BW and visual appraisal of cattle finish. The treatments consisted of 0 (control), 20 (**Z20**), 30 (**Z30**), and 40 (**Z40**) d of feeding ZH, and ZH was administered at the end of the feeding period. All cattle were removed from ZH for 3 d immediately before slaughter, consistent with label requirements for the feed additive. In Exp. 1, cattle in each phase were slaughtered on 2 consecutive days, and phases were slaughtered 2 wk apart. In Exp. 2, cattle in all treatments were slaughtered on 1 d.

Exp. 1

Cattle Management. Approximately 2,400 cattle were identified in 2 phases from 4 different sources (2 sources per phase). From the 2,400 total cattle purchased, 2,334 were randomly selected within BW class and source to be used in the trial (control = 584, Z20 = 587, Z30 = 582, and Z40 = 581). Cattle not included in the study were removed for obvious health concerns or size nonconformity. The cattle had been on feed for at least 230 d before terminal implant. Cattle had previously been vaccinated and dewormed according to the standard protocols of the feed yard. The steers had previously been implanted with Synovex S (200 mg of progesterone and 20 mg of estradiol benzoate; Fort Dodge Animal Health, Overland Park, KS) approximately 120 d before terminal implant. Two weeks before terminal implant, all cattle were individually weighed and identified. Cattle were blocked by source and stratified by BW, with extreme heavy and light cattle removed from consideration. Cattle were randomly assigned treatments (control, Z20, Z30, or Z40). At terminal implant, steers were implanted with Revalor IS (80 mg of trenbolone acetate and 16 mg of estradiol; Intervet/Schering-Plough Animal Health), assigned a new individual ear tag number, and sorted into predetermined treatment groups. The treatments were randomly assigned to pens. Each treatment consisted of 6 pens per treatment.

Morbidity and mortality were monitored throughout the test phase. Cattle with health or injury concerns were removed from the trial.

Feeding Management. Diets were mixed in a continuous-flow mill (Table 1). Zilpaterol hydrochloride was added in a liquid supplement containing Ultraferm (monosodium glutamate-process by-product; Westway, Tomball, TX) and urea at 0.8% of the diet (DM basis). Cattle were fed twice daily with a commercial feed delivery truck according to feed yard standard operating procedures, and daily feed residual was minimal. Feed was offered for ad libitum intake. When cattle were begun on ZH diets, and when they were removed from ZH rations, the bunks were swept clean. Monensin (Rumensin; Elanco Animal Health, Greenfield, IN) was fed when ZH was not in the ration, but monensin was removed from the Z20, Z30, and Z40 groups when ZH was in the diet.

Feed samples for each diet were collected weekly after feeding, placed in plastic sample bags, frozen, and sent to SDK Laboratories (Hutchinson, KS) for nutrient analysis. An additional sample was sent to Intervet Pharmaceutical Laboratories (Lawrence, KS) for ZH analysis.

Cattle were shipped to a commercial processing facility in Brawley, California, for slaughter. All treatment cattle were slaughtered at the beginning of the slaughter for that day, and each phase was slaughtered over 2 consecutive days. Carcasses were chilled for approximately 40 h before grading and collection of carcass characteristic data.

Exp. 2

Cattle Management. A total of 391 Holstein steers were received from a commercial feedlot located 124 km from the University of Arizona feedlot (Tucson). Cattle had previously received vaccines and were dewormed on arrival at the commercial feedlot. All cattle received an initial implant with Synovex S and were reimplanted with Synovex Choice (100 mg of trenbolone acetate and 14 mg of estradiol benzoate; Fort Dodge Animal Health) at 146 and 41 d, respectively, before being shipped to the University of Arizona.

An original fed BW was determined for each animal, and animals were individually identified. On the following day, animals were sorted into treatment pens based on d-1 BW. Steer BW (d-1) were stratified from heaviest to lightest, with extreme heavy and light BW animals removed from consideration. Of the 391 steers received, 359 steers were used (control = 90, Z20 = 90, Z30 = 90, and Z40 = 89) and blocked by BW. Steers were randomly assigned to pens (40) and blocks (10) such that each treatment × pen × block combination of 9 steers did not differ in BW. Pens were then randomized to treatment. Two steers died during the study. No other adverse health observations occurred during the study.

Feeding Management. A slick bunk approach was used to minimize accumulated feed in the bunk. Dietary information is provided in Table 1. Steers were fed once daily using a ribbon mixer (Roto-Mix, Dodge City, KS) mounted on flatbed truck with a belt conveyor. Zilpaterol hydrochloride was included in a ground corn premix at 1% of the final diet. Control steers received an equal amount of ground corn. Zilpaterol hydrochloride premix was added directly to the ribbon mixer. Monensin-tylosin trace mineral premix (University of Arizona) was not included in the diets containing ZH. Samples were composited weekly and a sample was sent to Dairy One (Ithaca, NY) for nutrient analysis. Cattle receiving ZH had a 3-d withdrawal before slaughter.

Cattle were shipped to a commercial beef-processing plant (Tolleson, AZ) for slaughter. Hot carcass weights were obtained immediately, and carcass characteristics were collected after a 48-h chill. Liver abscess scores were assigned according to the method of Brink et al. (1990).

Carcass Evaluation (Exp. 1 and 2)

After slaughter, carcasses were electrically stimulated. Carcasses were initially spray chilled and were then chilled for a total of approximately 40 to 48 h. After chilling, carcasses were ribbed at the 12th rib. Carcasses were evaluated for skeletal and lean maturity, marbling score, and lean color. Fat thickness was measured, and preliminary yield grade was determined. Longissimus muscle area was measured using tracings of chromatography paper impressions scanned with Meatscan Image Analyzer software (AEW Consulting, Lincoln, NE). The USDA quality grades and yield grades (USDA, 1997), as assigned by a USDA grader, were recorded. Separate quality grades were assigned by a trained evaluator, and yield grades were calculated (USDA, 1997). Marbling score, KPH, and lean and skeletal maturity were assigned by trained evaluators.

Statistical Analysis

Trial data were analyzed as a randomized complete block design using MIXED procedures (SAS Inst. Inc., Cary, NC). Initial BW was tested as a covariate for all statistics of interest using the GLM procedures of SAS. A full-rank covariate model that included treatment and the treatment × initial BW interaction was used to test the linear relationship between initial BW and all statistics of interest. When a linear relationship was present for initial BW as a covariate ($P \leq 0.05$), a less than full-rank model testing treatment, initial BW, and the treatment × initial BW interaction was used to test the equality of slopes (Milliken and Johnson, 2002). Because the common-slope model for all statistics of interest could not be rejected ($P > 0.05$), the least squares means for all covariate models were adjusted at x = the mean. Pen was the experimental unit for all analyses. The model statement included treatment, and the random statement included block. Nonparametric binomial proportion data were analyzed using the GLIMMIX procedure of SAS with the same overall model used for the normally distributed data described above. Preplanned contrasts were used to test 1) the pairwise comparison of 0 vs. 20 d of ZH feeding; 2) 0 vs. the average of 20, 30, and 40 d of ZH feeding; 3) the linear effects of days fed ZH; and 4) the quadratic effect of days fed ZH. For all statistics of interest, model assumptions were tested to ensure variance components were analyzed appropriately. Heteroscedasticity was tested with a null model likelihood ratio test by treating all variance components as fixed effects and identifying treatment with the repeated or group option of the MIXED procedure. For cases of heteroscedasticity ($P < 0.15$), the largest SE value is reported. Univariate procedures were used to test the normality of model residuals by

Table 2. Effects of feeding zilpaterol hydrochloride for 20, 30, or 40 d on performance of finishing Holstein steers (Exp. 1)[1]

	Days fed zilpaterol					*P*-value[4]			
Item[2]	0	20	30	40	SEM[3]	0 vs. 20	0 vs. others	Linear	Quadratic
Initial BW, kg	479.3	482.3	479.7	480.9	5.7	0.08	0.23	0.40	0.18
Final BW,[5] kg	642.4	645.9	647.8	655.8	2.9	0.27	0.01	0.01	0.26
ADG, d 0 to end, kg	1.39	1.42	1.43	1.50	0.031	0.33	0.01	<0.01	0.30
DMI, d 0 to end, kg/d	9.87	9.59	9.60	9.63	0.16	0.14	0.01	0.83	0.92
G:F, d 0 to end	0.141	0.148	0.150	0.156	0.0038	0.04	<0.01	0.01	0.44

[1]Animals that died (n = 4) were excluded from all calculations. The cattle were on feed for 115 to 118 d.

[2]The linear relationship between initial BW and all statistics was tested to determine the need for covariate model analyses.

[3]Pooled SEM; n = 6 pens/treatment with 81 to 100 steers/pen.

[4]Observed significance level for contrasts: 0 vs. 20 = pairwise comparison of 0 vs. 20 d of zilpaterol feeding; 0 vs. others = 0 d vs. the average of 20, 30, and 40 d of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS) feeding; linear = linear effects of days fed zilpaterol; quadratic = quadratic effect of days fed zilpaterol.

[5]Designates that initial BW was used as a covariate for model analysis and to adjust the least squares means.

using a Shapiro-Wilks test. In cases of nonnormal distributions ($P < 0.15$), the data were rank transformed, analyzed by the same model as for nontransformed data, and compared against the original data to determine the most conservative probability values. Nonadditivity was tested by including a "predicted × predicted" term in the model statement of an additional mixed model in which all variance components were treated as fixed effects. For cases of nonadditivity ($P < 0.15$), the original data points were transformed with log and exponent transformations to alleviate nonadditive variance components and were then reanalyzed with the original model statement.

RESULTS

Performance

Exp. 1. Performance data are presented in Table 2. Final BW was increased by feeding ZH vs. the control in Exp. 1 ($P < 0.05$), but were not increased with 20 d of ZH ($P = 0.27$). Likewise, ADG was increased by feeding ZH in Exp. 1 ($P < 0.05$). Both BW and ADG were increased in a linear fashion with respect to days on ZH ($P < 0.01$). Dry matter intake was decreased by feeding ZH in Exp. 1 ($P < 0.05$). The G:F was increased by feeding ZH ($P < 0.05$).

Exp. 2. Performance data for Exp. 2 are presented in Table 3. Final BW was not increased by feeding ZH ($P = 0.36$). The ADG did not differ between ZH-fed cattle and control cattle in Exp. 2 ($P > 0.29$). Neither DMI nor G:F was influenced by feeding ZH for 20 d ($P \geq 0.18$). However, feeding ZH in general tended to improve G:F ($P = 0.05$).

Carcass Characteristics

Exp. 1. Hot carcass weight was increased ($P < 0.05$) by 11.6 kg by feeding ZH for 20 d (Table 4). This increase in HCW resulted in an approximate increase of 1.5 percentage units in dressing percent after feeding ZH for 20 d ($P < 0.05$). The distribution of carcasses into different HCW categories was shifted to heavier carcasses by feeding ZH. The percentage of lightweight (<363 kg) carcasses was reduced by feeding ZH ($P < 0.05$; Table 5). Feeding ZH did increase ($P < 0.05$) the percentage of heavy carcasses (>408 kg) in a linear fashion ($P < 0.04$).

Carcass muscle conformation was improved by feeding ZH. Feeding ZH increased LM area ($P < 0.05$). Al-

Table 3. Effects of feeding zilpaterol hydrochloride for 20 to 40 d on performance by finishing Holstein steers (Exp. 2)[1]

	Days fed zilpaterol					*P*-value[4]			
Item[2]	0	20	30	40	SEM[3]	0 vs. 20	0 vs. others	Linear	Quadratic
Initial BW, kg	518.8	517.2	519.4	518.5	11.5	0.05	0.32	0.19	0.06
Final BW, kg	588.0	587.4	594.0	591.9	10.5	0.89	0.36	0.29	0.23
ADG, d 0 to end, kg	1.33	1.35	1.43	1.41	0.057	0.79	0.29	0.43	0.45
DMI, d 0 to end, kg/d	9.14	8.85	9.06	8.66	0.156	0.18	0.11	0.39	0.11
G:F, d 0 to end	0.146	0.153	0.158	0.164	0.0061	0.36	0.05	0.16	0.99

[1]Animals that died (n = 2) were excluded from all calculations. The cattle were on feed for 52 d.

[2]The linear relationship between initial BW and all statistics was tested to determine the need for covariate model analyses.

[3]Pooled SEM; n = 10 pens/treatment with 9 steers/pen.

[4]Observed significance level for contrasts: 0 vs. 20 = pairwise comparison of 0 vs. 20 d of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS) feeding; 0 vs. others = 0 d vs. the average of 20, 30, and 40 d of zilpaterol feeding; linear = linear effects of days fed zilpaterol; quadratic = quadratic effect of days fed zilpaterol.

Table 4. Effects of feeding zilpaterol hydrochloride for 20 to 40 d on carcass characteristics and liver condemnations of finishing Holstein steers (Exp. 1)

	Days fed zilpaterol					P-value[3]			
Item[1]	0	20	30	40	SEM[2]	0 vs. 20	0 vs. others	Linear	Quadratic
HCW,[4] kg	394.4	406.0	407.4	411.6	2.6	<0.01	<0.01	0.01	0.37
Dressing percent	61.35	62.91	62.86	62.77	0.16	<0.01	<0.01	0.39	0.88
Marbling score[5]	474.9	455.2	445.1	451.5	5.3	0.06	<0.01	0.33	0.05
Color score[6]	5.03	5.07	5.12	5.09	0.024	0.28	0.04	0.58	0.13
Lean maturity score[7]	69.3	70.8	71.0	68.8	8.3	0.70	0.77	0.61	0.74
Skeletal maturity score[7]	67.3	65.6	65.3	66.3	1.6	0.39	0.33	0.71	0.70
Overall maturity score[7]	68.3	68.2	68.2	67.6	3.9	0.99	0.89	0.79	0.90
Fat thickness, mm	7.62	7.62	7.11	7.37	0.20	0.99	0.08	0.06	0.10
LM area, cm^2	81.2	86.3	90.1	89.7	1.3	<0.01	<0.01	0.02	0.08
HCW/LM area, kg/cm^2	4.86	4.71	4.52	4.59	1.9	0.10	<0.01	0.08	0.03
KPH, %	2.79	2.71	2.72	2.66	0.091	0.33	0.18	0.54	0.56
USDA calculated yield grade	3.09	2.94	2.69	2.75	0.055	0.05	<0.01	0.02	0.02
Noncondemned livers,[8] %	85.49	85.47	86.14	84.23	—	0.95	0.96	0.54	0.51
Abscessed livers,[9] %	12.75	12.79	11.70	14.42	—	0.97	0.96	0.44	0.31

[1]The linear relationship between initial BW statistics was tested to determine the need for covariate model analyses.
[2]Pooled SEM; n = 6 pens/treatment, with 81 to 100 steers/pen. In cases of heteroscedasticity, the largest SEM is reported.
[3]Observed significance level for contrasts: 0 vs. 20 = pairwise comparison of 0 vs. 20 d of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS) feeding; 0 vs. others = 0 d vs. the average of 20, 30, and 40 d of zilpaterol feeding; linear = linear effects of days fed zilpaterol; quadratic = quadratic effect of days fed zilpaterol.
[4]Designates that initial BW was used as a covariate for model analysis and to adjust the least squares means.
[5]Scores: 300 = Slight; 400 = Small; 500 = Modest.
[6]Scale of 1 to 9, with 1 = light pink, and 9 = dark maroon; normal cherry red beef color = 5.
[7]Scores: 0 to 99 = A maturity; 100 to 199 = B maturity; >200 = C maturity.
[8]The P-values for the distribution of condemned livers (includes A−, A, and A+ abscesses; flukes; telangiectasias; and any other reason for condemnation) would be identical to those for noncondemned livers.
[9]Includes A−, A, and A+ abscesses.

though feeding ZH in general reduced HCW/LM area ($P < 0.05$), this response was not detected by feeding ZH for 20 d ($P = 0.10$). Percentage of carcasses with a small LM area (<71 cm^2) was reduced by feeding ZH (Table 6). Likewise, percentage of carcasses with a large LM area (>96.8 cm^2) was increased in a linear fashion as the duration of ZH feeding was increased ($P < 0.05$). Color score was not influenced by feeding ZH for 20 d ($P = 0.28$), but feeding ZH in general significantly darkened meat color ($P < 0.05$). Lean maturity score, skeletal maturity score, KPH fat, and liver score were not influenced by feeding ZH ($P \geq 0.18$).

Marbling score was significantly reduced by feeding ZH in general ($P < 0.05$), but the trend was not linear with increased days on ZH ($P = 0.33$). Feeding ZH for 20 d tended ($P = 0.06$) to reduce the marbling score. The effect of the reduced marbling score was reflected in the decreased distribution of carcass quality grades (Table 7) and USDA stamped carcass quality grades (Table 8).

The USDA stamped yield grades 1 and 2 were increased, and yield grades 3 and 4 were reduced by feeding ZH ($P < 0.05$; Table 9). Feeding ZH for 20 d did not affect the percentage of carcasses with yield grade

Table 5. Effects of feeding zilpaterol hydrochloride for 20 to 40 d on the distribution of HCW of finishing Holstein steers

	Days fed zilpaterol				P-value[1]			
HCW category	0	20	30	40	0 vs. 20	0 vs. others	Linear	Quadratic
Exp. 1, %								
<363 kg	14.86	9.83	8.36	5.93	0.02	<0.01	0.03	0.31
363 to 386 kg	24.60	16.20	16.46	15.23	<0.01	<0.01	0.69	0.73
387 to 408 kg	29.19	24.86	26.62	23.07	0.11	0.06	0.52	0.21
>408 kg	31.35	49.10	48.56	55.78	<0.01	<0.01	0.04	0.13
Exp. 2, %								
<363 kg	58.47	40.00	36.81	39.86	0.01	<0.01	0.82	0.83
363 to 386 kg	25.97	32.22	31.67	35.14	0.78	0.90	0.99	0.54
387 to 408 kg	12.22	20.00	21.39	17.22	0.91	0.59	0.27	0.69
>408 kg	3.33	7.78	10.14	7.78	0.62	0.67	0.60	0.72

[1]Observed significance level for contrasts: 0 vs. 20 = pairwise comparison of 0 vs. 20 d of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS) feeding; 0 vs. others = 0 d vs. the average of 20, 30, and 40 d of zilpaterol feeding; linear = linear effects of days fed zilpaterol; quadratic = quadratic effect of days fed zilpaterol. Exp. 1: n = 6 pens/treatment, with final counts of 81 to 100 steers/pen; Exp. 2: n = 10 pens/treatment, with final counts of 8 to 9 steers/pen.

Table 6. Effects of feeding zilpaterol hydrochloride for 20 to 40 d on the distribution of carcass LM areas of finishing Holstein steers

	Days fed zilpaterol				P-value[1]			
LM area category	0	20	30	40	0 vs. 20	0 vs. others	Linear	Quadratic
Exp. 1, %								
<71.0 cm^2	9.55	3.90	1.74	1.87	0.01	<0.01	0.09	0.27
71.0 to 83.9 cm^2	55.77	36.54	24.89	23.91	<0.01	<0.01	<0.01	0.06
84 to 96.8 cm^2	30.95	49.56	50.57	53.55	<0.01	<0.01	0.18	0.73
>96.8 cm^2	3.73	10.00	22.80	20.67	<0.01	<0.01	<0.01	<0.01
Exp. 2, %								
<71.0 cm^2	6.67	2.22	1.11	3.33	0.85	0.80	1.00	1.00
71.0 to 83.9 cm^2	64.31	27.78	20.14	21.53	<0.01	<0.01	0.18	0.56
84 to 96.8 cm^2	27.92	58.89	57.36	49.17	<0.01	<0.01	0.19	0.60
>96.8 cm^2	1.11	11.11	21.39	25.97	0.28	0.19	0.32	0.84

[1]Observed significance level for contrasts: 0 vs. 20 = pairwise comparison of 0 vs. 20 d of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS) feeding; 0 vs. others = 0 d vs. the average of 20, 30, and 40 d of zilpaterol feeding; linear = linear effects of days fed zilpaterol; quadratic = quadratic effect of days fed zilpaterol. Exp. 1: n = 6 pens/treatment, with final counts of 81 to 100 steers/pen; Exp. 2: n = 10 pens/treatment, with final counts of 8 to 9 steers/pen.

4 ($P = 0.11$). Feeding ZH across all durations increased the percentage of carcasses with calculated yield grades less than 2.5, and decreased the percentage of carcasses with calculated yield grades greater than 3 ($P < 0.05$; Table 10).

Exp. 2. Hot carcass weight and dressing percent were increased by all durations of feeding ZH ($P < 0.05$; Table 11). Similar to Exp. 1, the percentage of lightweight carcasses (<363 kg; Table 5) was reduced by feeding ZH, although this trend was not linear. The percentage of heavy carcasses (>408 kg) was not influenced by feeding ZH ($P = 0.67$).

Muscling was increased by feeding ZH. The LM area was enhanced, and HCW/LM area was reduced by feeding ZH in general, and for 20 d ($P < 0.05$; Table 11). Color score, KPH, and liver score were not affected by feeding ZH ($P \geq 0.37$). Fat thickness was not influenced by feeding ZH for 20 d, but feeding ZH over all durations decreased fat thickness ($P < 0.05$). Unlike in Exp. 1, lean maturity and overall maturity score were increased ($P < 0.05$) by feeding ZH, although skeletal maturity was not affected ($P = 0.99$).

Marbling score was reduced and marbling distribution was affected by feeding ZH over all durations ($P < 0.05$; Table 11 and Table 12, respectively), but feeding ZH for 20 d did not reduce marbling ($P = 0.15$). The reduction in marbling score tended to be linear in nature across duration of feeding ZH ($P = 0.10$). Carcass quality grades and USDA stamped quality grades were not significantly reduced by feeding ZH for 20 d ($P \geq 0.14$; Tables 7 and 8).

Percentage of carcasses identified as yield grades 1 and 2 was not influenced by feeding ZH for 20 d ($P < 0.05$; Table 9). Feeding ZH across all durations reduced USDA stamped yield grade 3 carcasses ($P < 0.05$). Percentage of carcasses with a calculated yield grade of <2 was increased by feeding ZH for all durations. However, feeding ZH did not influence percentage of carcasses with yield grades between 2 and 2.5 and >3 ($P < 0.05$; Table 11).

DISCUSSION

The primary objective of these studies was to determine the efficacy of feeding ZH to calf-fed Holstein

Table 7. Effects of feeding zilpaterol hydrochloride for 20 to 40 d on the distribution of carcass quality grades of finishing Holstein steers

	Days fed zilpaterol				P-value[1]			
Quality grade	0	20	30	40	0 vs. 20	0 vs. others	Linear	Quadratic
Exp. 1, %								
Prime	4.69	4.07	2.75	1.52	0.61	0.07	0.06	0.57
Premium Choice	22.09	15.36	14.87	19.32	0.01	0.01	0.11	0.22
Choice	55.14	54.64	53.02	49.36	0.85	0.24	0.07	0.66
Select or less	18.08	25.94	29.37	29.80	0.01	<0.01	0.12	0.57
Exp. 2, %								
Premium Choice or greater	9.03	6.94	5.08	5.56	0.43	0.51	0.41	0.57
Choice	46.39	37.22	31.79	28.93	0.53	0.08	0.11	0.88
Select or less	44.58	55.83	63.13	65.52	0.14	0.01	0.21	0.73

[1]Observed significance level for contrasts: 0 vs. 20 = pairwise comparison of 0 vs. 20 d of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS) feeding; 0 vs. others = 0 d vs. the average of 20, 30, and 40 d of zilpaterol feeding; linear = linear effects of days fed zilpaterol; quadratic = quadratic effect of days fed zilpaterol. Exp. 1: n = 6 pens/treatment, with final counts of 81 to 100 steers/pen; Exp. 2: n = 10 pens/treatment, with final counts of 8 to 9 steers/pen.

Table 8. Effects of feeding zilpaterol hydrochloride for 20 to 40 d on the distribution of USDA stamped carcass quality grades of finishing Holstein steers

	Days fed zilpaterol				*P*-value[1]			
Quality grade	0	20	30	40	0 vs. 20	0 vs. others	Linear	Quadratic
Exp. 1, %								
Prime	5.09	4.96	3.28	2.24	0.93	0.13	0.03	0.60
Choice	76.07	66.43	63.16	62.56	<0.01	<0.01	0.14	0.63
Select	17.97	27.05	30.96	32.84	<0.01	<0.01	0.04	0.72
Standard or less	0.87	1.57	2.60	2.37	0.33	0.10	0.36	0.40
Exp. 2, %								
Choice or greater	40.28	37.78	35.97	32.22	0.72	0.38	0.41	0.84
Select or less	59.72	62.22	64.03	67.78	0.72	0.38	0.41	0.84

[1]Observed significance level for contrasts: 0 vs. 20 = pairwise comparison of 0 vs. 20 d of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS) feeding; 0 vs. others = 0 d vs. the average of 20, 30, and 40 d of zilpaterol feeding; linear = linear effects of days fed zilpaterol; quadratic = quadratic effect of days fed zilpaterol. Exp. 1: n = 6 pens/treatment, with final counts of 81 to 100 steers/pen; Exp. 2: n = 10 pens/treatment, with final counts of 8 to 9 steers/pen.

steers. Similar to effects of ractopamine hydrochloride in calf-fed Holsteins, ZH increases HCW and LM area. As expected, the anabolic effects of ZH are more pronounced than those of ractopamine hydrochloride (Vogel et al., 2009). In addition, ZH increases dressing percent. Improvements in muscling are slightly less than those observed in beef breeds (Avendano-Reyes et al., 2006). However, because of the light muscling of Holstein steers, the improvements are more important to total carcass quality. Previous studies with other β-agonists have demonstrated a significant interaction between β-agonist and genotype in other species. Bark et al. (1992) reported an increase in ractopamine response in pigs selected for muscle accretion compared with pigs with a low genetic capacity for muscle accretion. Further, Eisen et al. (1988) observed a greater growth response to cimaterol in mice selected for rapid growth compared with mice not selected for growth. These studies support the current study in which cattle not selected for muscle accretion or growth (calf-fed Holsteins) did not respond to ZH to the same degree as cattle of traditional beef genetics. However, this is further evidence that β-agonists are effective across divergent genetic backgrounds, but cattle selected for greater growth potential may have larger responses to β-agonists. Further, ZH can be used effectively to enhance muscle conformation in carcasses from cattle that typically demonstrate poor muscling capacity, as demonstrated by the dramatic increase in LM area.

Feeding ZH to calf-fed Holstein steers resulted in a slight increase in BW gain but a dramatic increase in HCW, thereby indicating a high efficiency of transfer of weight from BW gain to carcass gain. This has been demonstrated in previous studies with other β-agonists in cattle and in other species. Indeed, the transfer of weight from BW to carcass is more than 100%, indicating that some part of the noncarcass components are reduced in weight, and carcass components increased differentially compared with offal, hide, and so forth. Further studies must be conducted to determine which noncarcass components are reduced to the greatest degree to account for the dramatic increase in weight transfer efficiency from BW to HCW.

The β-agonists, and ZH in particular, increase muscling of the carcass to a larger extent than can be accounted for by an increase in carcass weight. This was demonstrated by the decrease in HCW/LM area. The increased muscling of the carcass is responsible for an

Table 9. Effects of feeding zilpaterol hydrochloride for 20 to 40 d on the distribution of USDA stamped carcass yield grades of finishing Holstein steers

	Days fed zilpaterol				*P*-value[1]			
Yield grade	0	20	30	40	0 vs. 20	0 vs. others	Linear	Quadratic
Exp. 1, %								
1	2.36	7.86	12.40	10.72	0.01	<0.01	0.13	0.06
2	35.67	47.41	55.33	46.65	<0.01	<0.01	0.81	<0.01
3	55.81	40.81	30.68	39.32	<0.01	<0.01	0.63	<0.01
4	6.15	3.92	1.59	3.32	0.11	0.01	0.58	0.23
Exp. 2, %								
1	1.11	5.56	5.56	8.89	0.64	0.64	0.74	0.49
2	45.69	54.29	71.53	65.97	0.25	<0.01	0.14	0.07
3	53.19	40.16	22.92	25.14	0.03	<0.01	0.05	0.63

[1]Observed significance level for contrasts: 0 vs. 20 = pairwise comparison of 0 vs. 20 d of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS) feeding; 0 vs. others = 0 d vs. the average of 20, 30, and 40 d of zilpaterol feeding; linear = linear effects of days fed zilpaterol; quadratic = quadratic effect of days fed zilpaterol. Exp. 1: n = 6 pens/treatment, with final counts of 81 to 100 steers/pen; Exp. 2: n = 10 pens/treatment, with final counts of 8 to 9 steers/pen.

Table 10. Effects of feeding zilpaterol hydrochloride for 20 to 40 d on the distribution of calculated carcass yield grade of finishing Holstein steers

	Days fed zilpaterol				*P*-value[1]			
Yield grade category	0	20	30	40	0 vs. 20	0 vs. others	Linear	Quadratic
Exp. 1, %								
<2	3.45	4.11	11.48	12.69	0.57	<0.01	<0.01	0.06
2 to 2.5	11.35	22.36	27.07	23.54	<0.01	<0.01	0.61	0.07
2.6 to 3	29.31	26.72	30.61	30.17	0.40	1.00	0.22	0.40
3.1 to 3.5	34.40	30.00	22.64	20.93	0.12	<0.01	<0.01	0.30
3.6 to 4	14.43	11.53	6.81	10.18	0.17	<0.01	0.41	0.02
>4	7.05	5.28	1.40	2.49	0.22	<0.01	0.11	0.04
Exp. 2, %								
<2	11.11	38.89	36.94	43.33	0.01	<0.01	0.83	0.36
2 to 2.5	28.19	30.00	38.47	38.33	0.78	0.22	0.27	0.49
2.6 to 3	43.89	22.22	21.11	15.00	0.01	<0.01	0.43	0.18
3.1 to 4	16.81	8.89	3.47	3.33	0.78	0.38	0.34	0.57

[1]Observed significance level for contrasts: 0 vs. 20 = pairwise comparison of 0 vs. 20 d of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS) feeding; 0 vs. others = 0 d vs. the average of 20, 30, and 40 d of zilpaterol feeding; linear = linear effects of days fed zilpaterol; quadratic = quadratic effect of days fed zilpaterol. Exp. 1: n = 6 pens/treatment, with final counts of 81 to 100 steers/pen; Exp. 2: n = 10 pens/treatment, with final counts of 8 to 9 steers/pen.

improved yield grade score, and suggests that the improvement in carcass value by using ZH will extend to fabrication of the carcass as well. Feeding ZH for longer durations will enhance muscling to a larger extent, and will likewise improve yield grade.

As observed in previous studies, marbling score is reduced by feeding ZH. Although calf-fed Holstein steers tend to marble very well, the extent of decline in marbling score is certainly no worse than, and likely is not as large as, the reduction in marbling observed in beef cattle. The reduction of marbling could be the result of either 1) a dilution effect attributable to the rapid increase in LM area, consistent with the results of Duckett et al. (1999), or 2) a reduction in marbling in the muscle. Further research must be conducted to determine the mechanisms responsible for the reduction in marbling score. Because there is no consistent effect of ZH on overall carcass maturity, the reduction in marbling score is responsible for the decline in USDA quality grade. It is not yet clear how much longer cattle must be on feed to offset the 8 to 10% reduction in USDA Prime and Choice quality grades.

Table 11. Effects of feeding zilpaterol hydrochloride for 20 to 40 d on carcass characteristics and liver condemnations of finishing Holstein steers (Exp. 2)

	Days fed zilpaterol					*P*-value[3]			
Item[1]	0	20	30	40	SEM[2]	0 vs. 20	0 vs. others	Linear	Quadratic
HCW, kg	357.9	367.2	372.5	369.0	6.8	<0.01	<0.01	0.38	0.01
Dressing percent	60.85	62.49	62.70	62.34	0.24	<0.01	<0.01	0.65	0.34
Marbling score[4]	423.4	407.1	393.1	391.3	8.6	0.15	<0.01	0.10	0.40
Color score[5]	5.04	5.04	5.02	5.00	0.045	1.00	0.65	0.46	1.00
Lean maturity score[6]	53.2	60.6	58.2	58.4	1.5	<0.01	<0.01	0.30	0.48
Skeletal maturity score[6]	59.1	63.5	57.2	56.6	3.4	0.24	0.99	0.09	0.23
Overall maturity score[6]	56.0	62.4	57.9	57.0	1.5	<0.01	0.07	0.01	0.29
Fat thickness, mm	6.86	6.35	6.10	5.84	0.38	0.21	0.03	0.24	0.95
LM area, cm^2	80.0	88.0	89.4	89.2	0.92	<0.01	<0.01	0.28	0.44
HCW/LM area, kg/cm^2	4.47	4.17	4.17	4.14	7.4	<0.01	<0.01	0.51	0.72
KPH, %	1.81	1.94	1.81	1.81	0.048	0.06	0.40	0.06	0.24
USDA calculated yield grade	2.58	2.23	2.15	2.10	0.083	<0.01	<0.01	0.13	0.87
Noncondemned livers,[7] %	74.31	80.00	82.08	73.89	—	0.36	0.37	0.34	0.36
Abscessed livers,[8] %	16.67	14.44	9.03	16.94	—	0.68	0.52	0.88	0.58

[1]The linear relationship between initial BW and all statistics was tested to determine the need for covariate model analyses.

[2]Pooled SEM; n = 10 pens/treatment, with 9 steers/pen. In cases of heteroscedasticity, the largest SEM is reported.

[3]Observed significance level for contrasts: 0 vs. 20 = pairwise comparison of 0 vs. 20 d of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS) feeding; 0 vs. others = 0 d vs. the average of 20, 30, and 40 d of zilpaterol feeding; linear = linear effects of days fed zilpaterol; quadratic = quadratic effect of days fed zilpaterol.

[4]Scores: 300 = Slight; 400 = Small; 500 = Modest.

[5]Scale of 1 to 9 with 1 = light pink, and 9 = dark maroon; normal cherry red beef color = 5.

[6]Scores: 0 to 99 = A maturity; 100 to 199 = B maturity; >200 = C maturity.

[7]The *P*-values for the distribution of condemned livers (includes A−, A, and A+ abscesses; flukes; telangiectasias; and any other reason for condemnation) would be identical to those for noncondemned livers.

[8]Includes A−, A, and A+ abscesses.

Table 12. Effects of feeding zilpaterol hydrochloride for 20 to 40 d on the distribution of carcass marbling scores of finishing Holstein steers

	Days fed zilpaterol				*P*-value[1]			
Marbling score category	0	20	30	40	0 vs. 20	0 vs. others	Linear	Quadratic
Exp. 1, %								
Slight or less	18.08	25.94	29.37	29.80	0.01	<0.02	0.12	0.57
Small	55.14	54.64	53.02	49.36	0.85	0.24	0.07	0.66
Modest	17.66	11.96	11.72	13.52	0.02	0.01	0.52	0.57
Moderate	4.43	3.40	3.15	5.80	0.41	0.70	0.06	0.21
Slightly abundant or greater	4.69	4.07	2.75	1.52	0.61	0.07	0.06	0.57
Exp. 2, %								
Slight or less	44.86	55.56	63.06	63.33	0.16	0.01	0.28	0.61
Small	45.14	36.67	32.50	31.11	0.59	0.14	0.19	0.92
Modest or greater	10.00	7.78	4.44	5.56	0.75	0.82	0.56	0.60

[1]Observed significance level for contrasts: 0 vs. 20 = pairwise comparison of 0 vs. 20 d of zilpaterol (Intervet/Schering-Plough Animal Health, DeSoto, KS) feeding; 0 vs. others = 0 d vs. the average of 20, 30, and 40 d of zilpaterol feeding; linear = linear effects of days fed zilpaterol; quadratic = quadratic effect of days fed zilpaterol. Exp. 1: n = 6 pens/treatment, with final counts of 81 to 100 steers/pen; Exp. 2: n = 10 pens/treatment, with final counts of 8 to 9 steers/pen.

Conclusions

Feeding ZH to calf-fed Holstein steers improves BW gain and feed conversion. Zilpaterol hydrochloride addresses one of the primary concerns of Holstein steers by dramatically increasing muscling. Although marbling score is decreased, market conditions may be such that feeding ZH will not result in substantial discounts that are attributable to the decrease in quality grade. Further, yield grades are improved because of the enhanced muscling-to-HCW ratio. Feeding ZH to calf-fed Holstein steers offers benefits to cattle feeders, and those benefits should extend to carcass value because of enhanced muscling and conformation.

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