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Effects of zilpaterol hydrochloride and zilpaterol hydrochloride withdrawal time on beef carcass cutability, composition, and tenderness[1]

J. N. Shook,* D. L. VanOverbeke,* L. A. Kinman,* C. R. Krehbiel,* B. P. Holland,* M. N. Streeter,† D. A. Yates,† and G. G. Hilton*[2]

*Department of Animal Science, Oklahoma State University, Stillwater, 74078; and †Intervet/Schering-Plough Inc., Millsboro, DE 19966

ABSTRACT: The impact of zilpaterol hydrochloride (ZH) on carcass yield, composition, and tenderness was evaluated using 384 beef steers in a randomized complete block design. Main effects were the addition of 0 or 8.3 mg/kg of ZH for the final 20 d of feeding and each inclusion level was paired with withdrawal periods of 3, 10, 17, or 24 d. The 2 animals with BW closest to the pen average were selected for carcass fabrication to determine carcass yield, composition, and tenderness. The carcasses from animals fed ZH had greater (P = 0.008) individual side weights. Carcass fat determinations were unchanged ($P = 0.70$) by ZH. Weights of the strip loin ($P = 0.01$), peeled tenderloin ($P = 0.02$), and top sirloin butt ($P < 0.001$) were all improved with ZH. When expressed as a proportion of carcass weight, ZH increased percentage of carcass in the top sirloin butt ($P = 0.006$), bottom sirloin tri-tip ($P = 0.02$), top inside round ($P = 0.002$), bottom round flat ($P = 0.001$), and flank steak ($P = 0.02$). A longer withdrawal time (WT) increased ($P < 0.001$) carcass weights. Shoulder clod weights were greatest ($P < 0.001$) with 17-d WT from ZH, whereas chuck roll weights were greatest (P = 0.02) at 17 and 24 d of WT. Peeled tenderloins, top sirloin butts, and eye of rounds responded to WT, with increased ($P < 0.001$) weights seen at 10 d of WT as compared with all other WT. Shear force values were greater at each of the 3 aging times, 7 d ($P < 0.001$), 14 d ($P < 0.001$), and 21 d ($P = 0.003$), in steaks from ZH-fed steers compared with control steers. Protein percentages were greater in ZH steaks ($P = 0.03$) and ZH ground beef trim ($P < 0.001$). Percent moisture was increased ($P < 0.001$) in strip loin steaks at 3 and 10 d WT. Ground beef trim had an increase ($P = 0.04$) in percent moisture and a decrease ($P = 0.01$) in percent fat at 10 d WT. Carcass weights and yields were improved with ZH feeding and may continue to improve even up to 10 d after withdrawal of the supplement. Tenderness was slightly reduced with ZH supplementation but was unaffected by WT. Zilpaterol hydrochloride can be a valuable supplement to finishing beef steers to improve carcass lean yields and composition.

Key words: beef, cutability, tenderness, zilpaterol hydrochloride withdrawal

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INTRODUCTION

The use of β-adrenergic agonists (**β-AA**) to improve feed efficiency and enhance carcass composition in livestock species has been well documented since the early 1980s. Many β-AA act as repartitioning agents and have been shown to enhance lean meat production in many animal species. Zilpaterol hydrochloride (**ZH**; Zilmax, Intervet, Millsboro, DE) is a β-AA that has been approved in Mexico and South Africa for over 10 yr; however, it was not until 2006 that the compound was approved by the FDA for use in feedlot cattle in the United States.

Zilpaterol hydrochloride is marketed as a compound that will increase rate of BW gain, improve feed efficiency, and increase carcass leanness in cattle fed in confinement systems. Initial studies by Avendano-Reyes et al. (2006) documented an increase in final BW, increased ADG, and an improvement in G:F for cattle supplemented with ZH. Additionally, Avendano-Reyes et al. (2006) documented an increase in HCW, carcass yield, and loin muscle area with ZH. Whereas the study by Avendano-Reyes et al. (2006) indicated a tendency

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[2]Corresponding author: gretchen.hilton@okstate.edu

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for ZH fed cattle to have decreased 12th-rib fat, a study by Plascencia et al. (1999) found no effect on 12th-rib fat thickness with ZH inclusion. However, Montgomery et al. (2008) reported that feeding 8.3 mg/kg (DM basis) of ZH for 30 d significantly decreased 12-rib fat. When combined with an increase in loin muscle area and HCW, calculated yield grade was decreased (i.e., improved), which was an indication of ZH ability to improve lean yield. Leheska et al. (2009) reported significant increases in carcass muscle deposition/protein accretion with ZH.

Zilpaterol hydrochloride has also been shown to increase weight of gross primal and boneless closely trimmed primals, and boneless closely trimmed retail cuts as a percentage of carcass weight, when carcass weights were held constant (Plascencia et al., 1999). Additionally, slaughtering a lot of cattle on the same date can be problematic and may require longer than expected withdrawal periods and may result in withdrawal periods in excess of 3 d. Problems such has equipment failure, overscheduling of cattle, trucking issues, and market conditions (price fluctuations), among others, can arise at processing facilities and in the industry that can alter expected slaughter dates. If compounds such as ZH are used during the last 20 d of finishing and an appropriate 3 d WT has been scheduled, the extended time on feed can result in extended WT. Because ZH is rapidly eliminated in the urine (>95% in 72 h; Shelver and Smith, 2006), a withdrawal period of greater than 72 h could result in a loss of performance or a reversal in carcass yields. Furthermore, ZH has been shown to significantly increase Warner-Bratzler shear (**WBS**) values of loin muscle steaks; however, these reported values still range from severe to mild increases in WBS values (Casey et al., 1997; Avendano-Reyes et al., 2006; Hilton et al., 2009).

The objective of this study was to determine the effects of ZH and withdrawal time (**WT**) on beef carcass lean to fat ratios as well as carcass tenderness and proximate analysis.

MATERIALS AND METHODS

No approval was obtained from the Oklahoma State University Institutional Animal Care and Use Committee for the carcass phase of this experiment, because no animals were used in the experiments. All carcasses were obtained from a federally inspected harvesting facility. Institutional Animal Care and Use Committee approval was obtained for the live phase of the project at Oklahoma State University.

The studies were conducted on carcasses from Holland et al. (2009). A subset (n = 128) selected from 384 (BW = 356 ± 23.3 kg) British and British × Continental steers was used in this experiment. Steers were separated into 2 BW blocks and randomly assigned to pens (32 pens per block; 4 pens per treatment combination; 6 steers/pen) using a computer-generated schedule. Within each block, pens were randomly assigned to a 2 × 4 factorial arrangement of treatments. Main effects were the addition of 0 or 8.3 mg/kg (100% DM basis) ZH fed for 20 d at the end of the feeding period, and each supplementation level was paired with withdrawal periods of 3, 10, 17, or 24 d before slaughter (Holland et al., 2009). Zilpaterol hydrochloride treatment began at d 95 and 123 for heavy and light BW blocks, respectively. Cattle in ZH and control groups assigned to the same WT were weighed and slaughtered on the same days. Cattle were fed identical diets until the final finishing phase when ZH supplementation began. Zilpaterol hydrochloride treatment cattle were fed 8.3 mg/kg (100% DM basis) for 20 d, and monensin (Rumensin, Elanco Animal Health, Greenfield, IN) and tylosin (Tylan, Elanco Animal Health) were removed from the diet of ZH-treated cattle at this time for the remainder of the feeding period. Control cattle continued to be fed monesin and tylosin for the entire finishing phase.

Slaughter and Carcass Selection

For the 3-d withdrawal steers only, 2 steers from each pen assigned to the control and ZH treatments were selected for intensive sampling. Animals whose BW was closest to pen average were selected for the intensive fabrication (n = 32). These animals were loaded in the evening and hauled less than 5 km to the Robert M. Kerr Food and Agricultural Products Center (**FAPC**) located on the campus of Oklahoma State University (Stillwater), for slaughter the next morning. Furthermore, all 10-, 17-, and 24-d steers from each pen assigned to the control and ZH treatments were loaded in the evening and shipped 431 km to a commercial abattoir for slaughter the next morning. The 2 steers whose final BW was closest to their respective pen average were selected for slaughter (n = 96). After chilling for a similar time at both locations, carcasses were ribbed at the 12th rib, and USDA Quality and Yield grades and carcass traits were recorded (USDA, 1997). All carcass data were collected by trained Oklahoma State University personnel. Carcass sides were transported 431 km via commercial refrigerated truck (0 to −2°C) to the FAPC for further fabrication. One carcass was removed from the study upon arrival at FAPC due to excessive trimming at the commercial abattoir.

Carcass Fabrication

Once carcasses arrived at FAPC, they were stored in holding coolers (0 to 4°C) until fabrication. Cold side weights (**CSW**) were recorded before fabrication using a certified on-line rail scale. Carcasses were then fabricated into various North American Meat Processors Association subprimals, which included: 114E chuck shoulder clod (0.635 cm trim), 114F chuck shoulder tender, 116B chuck (mock) tender, 130A chuck short ribs, 116A chuck roll, 109B rib blade meat, 112A ribeye roll, lip-on, 124 rib back ribs, 120 brisket whole, 115D pectoral meat (trimmed to blue), pastrami meat (serratus ventralis from the plate), 121C outside skirt, 121D inside skirt, 180 strip loin (0.635 cm trim), 189A peeled tenderloin, 184 top sirloin butt, 185B bottom sirloin ball tip, 185D bottom sirloin tri-tip, 167A peeled knuckle, 168 top inside round (0.635 cm trim), 171B bottom round flat (0.635 cm trim), 171C eye of round (0.635 cm trim), 185A bottom sirloin flap (denuded), 171F heel meat, 193 flank steak, shank meat, and elephant ear (cutaneous trunci from the flank). All trim from fabrication was segregated into 1 of 3 lean trim categories: 90% lean/10% fat (90/10), 80% lean/20% fat (80/20), or 50% lean/50% fat (50/50). Kidney knob fat, all trimmed fat, and all bones were also collected and weighed. After all weights of each side were recorded and entered, fabrication yield was calculated to ensure that 99 to 100.5% of CSW was recovered. Weights were recorded for all previously mentioned products of fabrication and were expressed as a percentage of CSW. Once all weights were recorded, all 3 trim levels were combined together for each animal, ground, and analyzed for percent moisture, fat, and protein. All trim levels were combined to allow for an estimation of lean differences between control and ZH carcasses. Combining of trim levels allows for the most consistent comparison of proximate analysis of beef trim between treatments because different treatments produced different amounts, percentages, or both of trim (A. J. Garmyn, Oklahoma State University, Stillwater, OK; T. E. Lawrence, West Texas A&M, Canyon, TX; M. F. Miller, Texas Tech University, Lubbock, TX; J. C. Brooks, Texas Tech University, Lubbock, TX; T. H. Montgomery, Intervet/Schering Plough, Millsboro, DE; D. B. Griffin, Texas A&M University, College Station, TX; N. A. Elam, New Mexico State University, Clayton, NM; W. T. Nichols, Intervet/Schering Plough, Millsboro, DE; J. P. Hutcheson, Intervet/Schering Plough, Millsboro, DE; D. M. Allen, Intervet/Schering Plough, Millsboro, DE, unpublished data); therefore, to determine proximate analysis of all trim, 50/50, 80/20, and 90/10 needed to be combined.

Postmortem Aging and Strip Loin Fabrication

Upon completion of fabrication, strip loins (Institutional Meat Purchase Specification 180) were fabricated for shear force analysis. The anterior end of the strip loin was cut perpendicular to the long axis of the strip loin to allow for consistent and uniform steaks, the meat removed was used for proximate analysis. Proximate samples were vacuum packaged and frozen in a (−20 to −40°C) blast freezer and then held in a freezer (−10°C) until further analysis. Once the strip loins were cut perpendicular to the long axis of the strip loin on the anterior end, three 2.54-cm steaks were cut and assigned to 1 of 3 aging times (7, 14, or 21 d) based on the order the steaks were cut from the strip loin. For each additional strip loin fabricated, the order was advanced by one so that on the second strip loin, the steak 1 was assigned to age 14 d, steak 2 was assigned to age 21 d, and steak 3 was assigned to age 7 d. This pattern was continued for all strip loins fabricated. After cutting, all steaks were individually vacuum packaged and aged for their respective time under refrigeration at 0 to 4°C. After the assigned aging period, samples were frozen in a blast freezer (−20 to −40°C), and frozen samples were held in a freezer (−10°C) until further analysis.

WBS Force

Warner-Bratzler shear force was completed using the American Meat Science Association guidelines (AMSA, 1995) with the following modification: internal temperatures of each steak were recorded before cooking insuring that internal temperatures were >0 and <5°C. If temperatures were outside this range, steaks were either allowed to thaw for a longer period of time or replaced in refrigeration to return internal temperature to the desired range. Steaks were cooked using The Next Generation George Foreman Digital Grill (model GRP99, Applica Inc., Miramar, FL) to a medium degree of doneness (~71°C). Steaks were then placed on trays, covered with poly-vinyl wrap, and refrigerated overnight to achieve an ultimate steak temperature of 2 to 5°C. After the overnight chill, 2 cores from each of the lateral, middle, and medial portions (for a total of 6 cores; 1.27 cm) from each steak were removed parallel to the longitudinal orientation of the muscle fibers. Cores were shorn using a Warner-Bratzler Shear Testing Machine (G-R Elec. Mfg. Co., Manhattan, KS), and the peak shear force was recorded in kilograms and the average was determined. After each sample, the shear knife was cleaned, and the machine was reset to zero.

Proximate Analysis

Samples for proximate analysis were thawed similar to the previously mentioned method used for thawing WBS steaks. After thawing, samples were powder homogenized using a blender (model 51BL31, Waring, Torrington, CT). Samples were analyzed for nitrogen content using the combustion method procedures of the AOAC (1990). Samples were dried in an oven at 102°C for 24 h for moisture content determination. Lipid percentage was determined by ether extraction of the dried samples following the procedures of the AOAC (1990).

Data Analysis

In this study the interaction of ZH and WT was not significant so only main effect means are reported. Data were analyzed using the mixed model procedures (SAS Inst. Inc., Cary, NC). An ANOVA for a complete random design with the main effects of ZH and WT was analyzed. Two BW blocks (heavy BW and light BW) were included in the model as fixed variables; block was not significant so results were pooled over block

Table 1. Effects of zilpaterol hydrochloride[1] (ZH) inclusion into the diet and withdrawal time of ZH before slaughter on carcass cutout characteristics (n = 127)

	ZH			Withdrawal, d					
Item	0 mg/kg	8.3 mg/kg	$P > F$	3	10	17	24	$P > F$	SEM
Total side weight	180.97	184.30	<0.01	178.16[b]	184.69[a]	184.12[a]	183.60[a]	<0.001	1.24
Wholesale carcass lean[2,3]	50.03	51.49	<0.001	49.94	50.80	51.49	50.80	0.06	0.18
50/50 trim, kg	20.47	20.25	0.66	19.93	20.67	20.82	20.03	0.47	0.61
% 50/50 trim[2]	11.31	10.98	0.19	11.18	11.20	11.31	10.91	0.71	0.31
80/20 trim, kg	6.10	6.17	0.82	6.06	6.44	5.98	6.06	0.78	0.60
% 80/20 trim[2]	3.37	3.35	0.94	3.41	3.49	3.25	3.29	0.78	0.33
90/10 trim, kg	6.78	7.16	0.21	7.02	7.19	7.03	6.64	0.62	0.57
% 90/10 trim[2]	3.74	3.89	0.38	3.93	3.88	3.82	3.63	0.57	0.31
Kidney knob fat, kg	5.53	5.24	0.21	5.12	5.26	5.56	5.62	0.37	0.27
Total fat trim, kg	15.03	17.46	0.70	14.77	14.54	14.46	14.75	0.50	0.74
% carcass fat[2]	11.34	10.83	0.19	11.12	10.71	10.85	11.68	0.31	0.39
Total bone, kg	35.96	35.27	0.05	35.42	35.97	35.24	35.83	0.40	0.35
% carcass bone[2]	19.90	19.15	<0.001	19.92	19.51	19.15	19.53	0.07	0.20

[a,b]Within a row and main effect of withdrawal time, means with different superscripts differ ($P < 0.05$).

[1]Zilmax, Intervet, Millsboro, DE.

[2]Percentage of cold side weight.

[3]Total side weight minus 50/50 trim, 80/20 trim, 90/10 trim, kidney knob fat, total fat trim, and total bone.

effect. Carcass side was the experimental unit used for analysis. For ZH and WT, all carcasses (control and ZH fed) were included together for analysis. Least squares means were generated and separated using a pairwise *t*-test when the model displayed a treatment effect ($\alpha < 0.05$). Miller et al. (2001) used a range from 3.92 to 4.50 kg as intermediate and tough as greater than 4.50 kg when comparing beef steaks. The frequency of tender, intermediate, and tough steaks was determined using the method established by Miller et al. (2001) and were analyzed using the chi-square procedure.

RESULTS AND DISCUSSION

ZH

Results for growth performance characteristics, as well as USDA grade data, were reported by Holland et al. (2009). Zilpaterol hydrochloride inclusion in the diet had a significant effect on individual side weights with ZH-supplemented animals having heavier ($P = 0.008$) weights. These finding are in agreement with previous studies by Plascencia et al. (1999) and Avendano-Reyes et al. (2006) in which carcass weights increased with ZH. Furthermore, there was an increase ($P < 0.001$) in the percentage of total wholesale carcass lean (total side weight minus 50/50 trim, 80/20 trim, 90/10 trim, kidney knob fat, total fat trim, and total bone) with ZH supplementation (Table 1). However, no effect of ZH treatment on lean trim percentages or percent carcass fat was observed. A significant reduction ($P = 0.05$) in total bone weight was documented, which resulted in a decreased ($P < 0.001$) percentage of bone in the carcass side (Table 1). Carcass fat also remained unchanged by ZH in a study by Avendano-Reyes et al. (2006); however, in the same study, it was reported that ZH had no significant impact on percent carcass bone, which contradicts the findings of this study. Due to a decrease in percent bone and with percent fat being unchanged, the increase in carcass weight is presumed to be due to an increase in carcass lean.

Although most major primals from the forequarter, such as the shoulder clod, chuck roll, and ribeye roll, were not affected by ZH treatment, several cuts increased in weight with ZH inclusion. A significant increase in the weight of pectoral meat ($P = 0.03$), rib blade meat ($P = 0.03$), and pastrami meat ($P = 0.04$) was shown with ZH feeding. Zilpaterol hydrochloride inclusion also resulted in increased weight of the whole brisket ($P < 0.001$).

More of the muscles and primals from the hindquarter exhibited greater response to ZH as compared with those from the forequarter. More highly valued cuts, such as the strip loin ($P = 0.01$), peeled tenderloin ($P = 0.02$), and top sirloin butt ($P < 0.001$), all increased in weight with ZH supplementation. In addition to these cuts, several other cuts from the hindquarter were heavier with ZH, including the bottom sirloin tri-tip ($P = 0.005$), top inside round ($P < 0.001$), bottom round flat ($P < 0.001$), eye of round ($P = 0.02$), and flank steak ($P = 0.005$). Also, an increase in weight was observed in the heel ($P = 0.02$) and the shank ($P < 0.01$) with the inclusion of ZH. Whereas several of the primal and cut weights significantly increased, only the top sirloin butt ($P = 0.006$), bottom sirloin tri-tip ($P = 0.02$), top inside round ($P = 0.002$), bottom round flat ($P = 0.001$), and the flank steak ($P = 0.02$) increased when cut weight was expressed as a percentage of CSW. Although Avendano-Reyes et al. (2006) did not report individual subprimal weights, they reported that carcass yields were increased with ZH. However, when carcasses were deboned, ZH steers yielded equal amounts of lean as control steers (Avendano-Reyes et al., 2006). In a study by Plascencia et al. (1999), where

Table 2. Effects of zilpaterol hydrochloride[1] (ZH) inclusion into the diet and withdrawal time of ZH before slaughter on various wholesale beef cuts from the forequarter (n = 127)

	ZH			Withdrawal, d					
Item	0 mg/kg	8.3 mg/kg	$P > F$	3	10	17	24	$P > F$	SEM
Shoulder clod, trimmed, kg	8.88	9.02	0.20	8.41[c]	9.05[b]	9.53[a]	8.81[b]	<0.001	0.11
Shoulder clod, trimmed[2]	4.91	4.90	0.88	4.72[c]	4.90[b]	5.18[a]	4.80[bc]	<0.001	0.06
Chuck shoulder tender, kg	0.51	0.51	0.88	0.48[b]	0.63[a]	0.48[b]	0.46[b]	<0.001	0.02
Chuck shoulder tender[2]	0.28	0.28	0.66	0.26[b]	0.34[a]	0.26[b]	0.25[b]	<0.001	0.01
Chuck roll, kg	13.74	14.12	0.22	13.45[b]	13.48[b]	14.18[ab]	14.61[a]	0.02	0.43
Chuck roll[2]	7.59	7.66	0.69	7.56[ab]	7.29[b]	7.69[ab]	7.96[a]	0.02	0.23
Chuck mock tender, kg	1.53	1.75	0.23	1.47	1.61	1.90	1.58	0.39	0.18
Chuck mock tender[2]	0.85	0.95	0.30	0.83	0.87	1.04	0.86	0.46	0.10
Chuck short ribs, kg	1.37	1.36	0.87	1.04	1.39	1.41	1.38	0.49	0.06
Chuck short ribs[2]	0.76	0.74	0.84	0.72	0.76	0.76	0.75	0.81	0.03
Pectoral meat, trimmed to blue, kg	0.89	0.99	0.03	0.88	0.99	0.95	0.94	0.37	0.08
Pectoral meat, trimmed to blue[2]	0.49	0.54	0.06	0.49	0.54	0.52	0.51	0.60	0.04
Rib blade meat, kg	1.56	1.71	0.03	1.78[a]	1.81[a]	1.42[b]	1.54[b]	<0.001	0.09
Rib blade meat[2]	0.86	0.93	0.07	1.00[a]	0.98[a]	0.77[b]	0.84[b]	<0.001	0.05
Ribeye roll, kg	5.62	5.72	0.20	5.63	5.72	5.71	5.63	0.80	0.10
Ribeye roll[2]	3.10	3.11	0.88	3.16	3.10	3.10	3.07	0.44	0.05
Rib back ribs, kg	1.43	1.44	0.89	1.39[b]	1.59[a]	1.41[b]	1.35[b]	<0.001	0.34
Rib back ribs[2]	0.79	0.78	0.55	0.78[b]	0.86[a]	0.77[b]	0.74[b]	<0.001	0.02
Pastrami meat, kg	0.59	0.65	0.04	0.56[b]	0.66[a]	0.59[b]	0.67[a]	<0.01	0.34
Pastrami meat[2]	0.33	0.35	0.10	0.31[c]	0.36[ab]	0.32[bc]	0.37[a]	0.01	0.02
Brisket whole, boneless packer trim, kg	5.62	6.05	<0.001	5.30[b]	5.48[b]	6.76[a]	6.31[a]	<0.001	0.14
Brisket whole, boneless packer trim[2]	3.11	3.28	<0.01	2.97[b]	2.97[b]	3.40[a]	3.44[a]	<0.001	0.07
Inside skirt, kg	1.03	1.10	0.09	0.98[b]	1.14[a]	1.09[ab]	1.05[ab]	0.03	0.05
Inside skirt[2]	0.57	0.60	0.20	0.55	0.62	0.59	0.57	0.12	0.03
Outside skirt, kg	0.65	0.63	0.25	0.58[b]	0.66[a]	0.67[a]	0.65[a]	<0.01	0.02
Outside skirt[2]	0.36	0.34	0.10	0.33	0.36	0.36	0.36	0.06	0.01

[a–c]Within a row and main effect of withdrawal time, means with different superscripts differ ($P < 0.05$).

[1]Zilmax, Intervet, Millsboro, DE.

[2]Listed as a percentage of cold side weight.

individual subprimals were weighed and expressed as a percentage of carcass weight, several subprimals such as the sirloin, knuckle, inside skirt, and inside round were increased with ZH supplementation. However, in the same study, several subprimals were significantly reduced in weight or in percentage by ZH supplementation (Plascencia et al., 1999). This contradicts current findings in which no subprimals were significantly reduced in weight by ZH.

As shown in this study, the response to ZH seemed to be greater in hindquarter muscles compared with those recovered from the forequarter. Previous studies indicate that type II fibers have a greater response to β-AA stimulations as compared with other muscle fiber types (Miller et al., 1988; Smith et al., 1995). Furthermore, as reported by Kirchofer et al. (2002) there is a greater variation among fiber types within muscles of the chuck and the round is composed mainly of white muscle fibers. These findings could explain the variation in response between muscles within this study because those muscles with a greater proportion of white fibers had a greater response.

ZH WT

Cold carcass weight was significantly affected by ZH WT, with carcasses from animals withheld for 3 d having lighter ($P < 0.001$) weights compared with all other WT. However, this increase in weight most likely resulted from cattle being fed longer because of increased WT.

The forequarter also responded to the various WT. Shoulder clod weights were affected ($P < 0.001$) by WT with 3-d withdrawal weights being the lightest and 17-d withdrawal weights being the heaviest. Weights were similar between the 10 d and 24 d of withdrawal. Chuck roll weights were affected ($P = 0.02$) by WT; chuck rolls were heavier with 24 d WT than with 3- or 10-d WT. In addition to the shoulder clod and chuck roll, WT had a significant effect ($P < 0.001$) on brisket weight. Briskets were lightest at WT of 3 and 10 d and heaviest at withdrawal d 17 and 24 (Table 2). Additional minor cuts affected by WT included rib blade meat ($P < 0.001$), back ribs ($P < 0.001$), pastrami meat ($P = 0.003$), inside skirt ($P = 0.03$), and the outside skirt ($P = 0.005$; Table 2).

Much like the forequarter, most major subprimals from the hindquarter were affected by ZH WT. Peeled tenderloins were affected ($P < 0.001$) by ZH WT with tenderloin weights being the lightest at 3 d WT and heaviest at 10 d WT. Weights at 17 d WT were similar to those documented at WT of 24 d, but were less than for 10 d WT. Top sirloin butts were also affected ($P < 0.001$) by WT with the heaviest top sirloin butt weights

Table 3. Effects of zilpaterol hydrochloride[1] (ZH) inclusion into the diet and withdrawal time of ZH before slaughter on various wholesale beef cuts from the hindquarter (n = 127)

	ZH			Withdrawal, d					
Item	0 mg/kg	8.3 mg/kg	$P > F$	3	10	17	24	$P > F$	SEM
Strip loin, kg	4.87	5.09	0.01	4.93	5.12	4.94	4.94	0.41	0.09
Strip loin[2]	2.69	2.76	0.09	2.76	2.76	2.68	2.69	0.36	0.04
Peeled tender, side muscle on, kg	2.66	2.76	0.02	2.52[c]	2.86[a]	2.72[b]	2.74[ab]	<0.001	0.09
Peeled tender, side muscle on[2]	1.47	1.50	0.22	1.42[c]	1.55[a]	1.48[bc]	1.49[ab]	<0.01	0.05
Top sirloin butt, kg	5.47	5.82	<0.001	5.69[b]	6.06[a]	5.49[bc]	5.34[c]	<0.001	0.15
Top sirloin butt[2]	3.03	3.16	<0.01	3.20[a]	3.28[a]	2.98[b]	2.91[b]	<0.001	0.07
Bottom sirloin ball tip, denuded, kg	0.58	0.66	0.07	0.61[ab]	0.69[a]	0.68[a]	0.50[b]	0.01	0.05
Sirloin ball tip, denuded[2]	0.32	0.36	0.12	0.34[ab]	0.37[a]	0.37[a]	0.27[b]	0.02	0.02
Bottom sirloin tri-tip, denuded, kg	0.99	1.08	<0.01	1.02[b]	1.14[a]	1.08[ab]	0.90[c]	<0.001	0.04
Sirloin tri-tip, denuded[2]	0.55	0.59	0.02	0.57[a]	0.62[a]	0.59[a]	0.49[b]	<0.001	0.02
Knuckle, peeled, kg	5.16	5.26	0.34	4.93[b]	5.27[a]	5.29[a]	5.34[a]	0.02	0.12
Knuckle, peeled[2]	2.85	2.85	0.99	2.77	2.85	2.88	2.91	0.20	0.06
Top inside round, kg	9.71	10.36	<0.001	9.72	10.21	10.23	10.01	0.06	0.15
Top inside round[2]	5.37	5.62	<0.01	5.46	5.53	5.56	5.43	0.62	0.08
Bottom round flat, kg	6.59	7.14	<0.001	6.75	6.76	6.90	7.04	0.42	0.14
Bottom round flat[2]	3.64	3.87	<0.01	3.79	3.66	3.75	3.83	0.39	0.07
Eye of round, kg	2.59	2.78	0.02	2.52[b]	2.80[a]	2.78[a]	2.63[ab]	0.03	0.08
Eye of round[2]	1.43	1.50	0.08	1.41	1.52	1.51	1.43	0.16	0.04
Heel meat, kg	2.27	2.39	0.02	2.29	2.36	2.39	2.29	0.31	0.05
Heel meat[2]	1.26	1.30	0.10	1.28	1.28	1.30	1.25	0.54	0.02
Shank meat, kg	2.58	2.71	<0.01	2.59[b]	2.61[b]	2.62[b]	2.75[a]	0.05	0.07
Shank meat[2]	1.43	1.47	0.08	1.46[ab]	1.41[b]	1.42[b]	1.50[a]	0.05	0.04
Bottom sirloin flap, denuded, kg	1.32	1.34	0.69	1.20[b]	1.37[a]	1.40[a]	1.37[a]	<0.001	0.09
Bottom sirloin flap, denuded[2]	0.73	0.73	0.77	0.67[b]	0.74[a]	0.76[a]	0.74[a]	<0.01	0.05
Flank steak, kg	0.82	0.89	<0.01	0.79[c]	0.90[a]	0.84[bc]	0.89[ab]	<0.01	0.03
Flank steak[2]	0.45	0.48	0.02	0.44[c]	0.49[a]	0.46[bc]	0.48[ab]	0.02	0.02
Elephant ear, kg	1.50	1.57	0.18	1.23[c]	1.52[b]	1.78[a]	1.60[b]	<0.001	0.05
Elephant ear[2]	0.83	0.85	0.39	0.69[c]	0.83[b]	0.97[a]	0.87[b]	<0.001	0.03

[a–c]Within a row and main effect of withdrawal time, means with different superscripts differ ($P < 0.05$).

[1]Zilmax, Intervet, Millsboro, DE.

[2]Listed as a percentage of cold side weight.

occurring at 10 d WT and the lightest at 24 d WT. Top sirloin butt weights at WT 3 and 17 d were similar, with weights recorded at 17 d WT being similar to weights recorded at 24 d WT. Additionally, WT had a significant effect ($P = 0.03$) on eye of round weights. Weights increased from 3 to 10 d WT, but remained similar at 17 d WT. However, eye of round weights at 24 d WT were similar to those at 3 d WT. Moreover, knuckle weights were increased ($P = 0.02$) from 3 to 10 d WT but remained unchanged for the remaining WT. Furthermore, as with the forequarter, various minor cuts from the hindquarter were affected by ZH WT. These cuts included the bottom sirloin ball tip ($P = 0.01$), bottom sirloin tri-tip ($P < 0.001$), shank meat ($P = 0.05$), bottom sirloin flap ($P < 0.001$), flank steak ($P = 0.002$), and the elephant ear ($P < 0.001$; Table 3).

In a previous study in which ZH withdrawal was investigated (Casey et al., 1997), it was reported that ZH had no lasting effect on carcass or meat characteristics. In the current study, numerous subprimals continued to increase in weight as WT moved from 3 to 10 d, whereas several other subprimals continued to increase in weight throughout the entire 24-d withdrawal period. Whereas few data are available to support the idea of continued action of ZH with longer WT, a study by Sissom et al. (2007) suggested that ZH alters mRNA and protein concentrations of β-adrenergic receptors of muscle cells, which could affect the cellular response to ZH when exposed for an extended period.

Although it is understood that feeding β-AA to livestock increases lean:fat ratios, various theories remain as to how these compounds truly affect muscle and fat synthesis. Although various researchers still debate the true mechanisms of increased muscle accretion as being an increase in muscle cell hypertrophy, a reduction in muscle protein degradation, or a combination of both, it is apparent that an increase in lean mass is seen to a greater extent in ZH-fed cattle as opposed to cattle fed ractopamine hydrochloride as was reported by Avendano-Reyes et al. (2006).

WBS Force

Shear force values of strip loin steaks were significantly less for control animals compared with ZH-treated animals at 7 (3.84 vs. 4.65 kg; $P < 0.001$), 14 (3.44 vs. 4.18 kg; $P < 0.001$), and 21 (3.18 vs. 3.61 kg; $P = 0.003$) d of aging. At 7 d of aging, 17.44% of the control steaks exceeded the threshold for tender qualification and were considered intermediate/tough compared

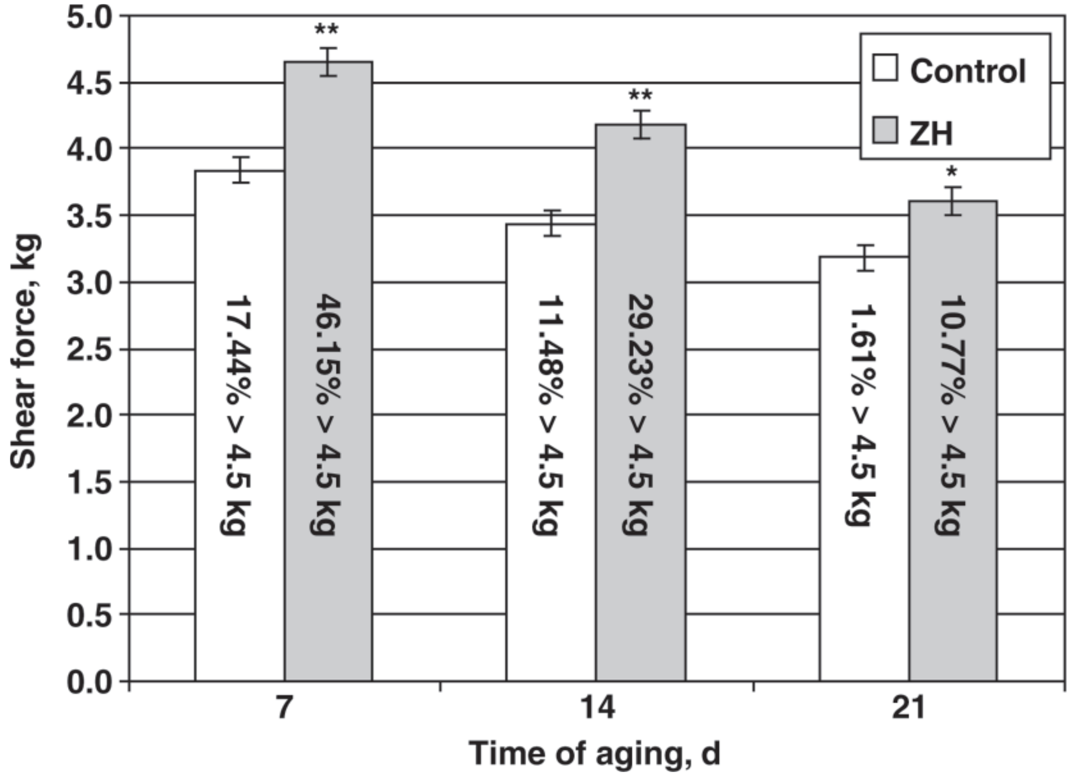

Figure 1. The main effect of zilpaterol hydrochloride (ZH; Zilmax, Intervet, Millsboro, DE) treatment on Warner-Bratzler shear force values of strip loin steaks. Within a specific aging time, means with a single asterisk (*) differ ($P < 0.01$), whereas means with a double asterisks (**) differ ($P < 0.001$).

with 46.15% of the ZH steaks that were intermediate/tough. Even though ZH steaks produced greater WBS values through 14 and 21 d aging periods, the percentage exceeding the tenderness threshold dropped to 1.61 and 10.77% for control and ZH steaks, respectively, by d 21 (Figure 1). Much like the present study, Strydom et al. (2009) reported an increase in WBS values with β-AA supplementation and also indicated favorable responses to aging time up to 14 d. Moreover, Strydom et al. (2009) concluded that tenderness effects due to β-AA inclusion were associated with their effect on calpastatin. Although calpastatin concentrations were not measured in the current study, tenderness effects due to ZH inclusion could be due to the effects of ZH on calpastatin activity.

Although WT tended ($P = 0.06$) to have an impact on WBS value at 7 d postmortem aging, it had little to no impact on WBS value at aging times of 14 ($P = 0.76$) and 21 d ($P = 0.73$). At 7 d of aging, animals withdrawn from ZH for 3 and 24 d produced steaks with the greatest shear force values with WBS values of 4.34 and 4.60 kg, respectively, whereas the least values were seen in steaks from animals withdrawn for 10 and 17 d as indicated by WBS values of 3.98 and 4.06 kg, respectively.

Much like the results in this study, increased WBS of steaks from animals supplemented with β-AA is commonly reported. However, O'Neill (2001) concluded that ZH did not cause tougher meat compared with nontreated animals. This, however, is a rare finding, as several studies have found that numerous β-AA including ZH increase WBS values (Pringle et al., 1993; Schroeder et al., 2003; Hilton et al., 2009).

Proximate Analysis

Zilpaterol hydrochloride supplementation had no impact on moisture ($P = 0.23$) or fat ($P = 0.27$) content of ground beef trim or the moisture ($P = 0.97$) and fat ($P = 0.11$) content of strip loin steaks. A significant increase ($P = 0.03$) was found in percent protein of ground beef trim with ZH supplementation; however, this increase was less than 1 percentage unit (Table 4). Inclusion of ZH also increased ($P < 0.001$) percent protein in strip loin steaks (Table 4). Although fat content was not statistically different between treatments, fat content in beef trim as well as in strip loin steaks was numerically less in steaks and trim from ZH-supplemented animals. This reduction in fat allows for a significant increase in protein of strip steaks and beef trim and was as expected due to the ability of ZH to increase protein accretion throughout the carcass.

Withdrawal time seemed to have a different effect on proximate analysis determinations compared with those seen with ZH inclusion. Moisture percentage ($P = 0.04$) and fat percentage ($P = 0.01$) of ground beef trim were significantly affected by ZH WT, whereas protein percentages were unchanged ($P = 0.56$). Ground beef moisture content was the greatest at 10 d withdrawal from ZH. Fat percentages were greatest in ground beef

Table 4. Effects of zilpaterol hydrochloride[1] (ZH) inclusion into the diet and withdrawal time of ZH before slaughter on meat quality characteristics (n = 127)

	ZH			Withdrawal, d					
Item	0 mg/kg	8.3 mg/kg	$P > F$	3	10	17	24	$P > F$	SEM
Strip loin steak									
Moisture %	74.67	74.66	0.97	75.37[a]	75.19[a]	74.01[b]	74.09[b]	<0.001	0.35
Fat %	4.47	3.61	0.11	3.50	4.44	4.09	4.14	0.65	0.54
Protein %	22.87	23.41	<0.001	22.95	23.40	23.02	23.20	0.14	0.25
Ground beef trim[2]									
Moisture %	50.74	51.52	0.23	50.17[b]	52.63[a]	50.76[b]	50.96[ab]	0.04	0.66
Fat %	33.48	32.45	0.27	33.95[a]	30.62[b]	34.81[a]	32.49[ab]	0.01	1.20
Protein %	13.91	14.43	0.03	14.35	14.32	13.95	14.07	0.56	0.39

[a,b]Within a row and main effect of withdrawal time, means with different superscripts differ ($P < 0.05$).

[1]Zilmax, Intervet, Millsboro, DE.

[2]Combination of 50/50, 80/20, and 90/10 trim.

trim from animals withdrawn for 3 and 17 d, whereas fat levels were least in animals withdrawn for 10 d. Animals withdrawn for 24 d had intermediate fat percentages (Table 4). Although ZH WT affected moisture and fat percentages in ground beef trim, ZH WT had no impact on fat ($P = 0.65$) and protein ($P = 0.14$) percentages in strip loin steaks, but did affect moisture content ($P < 0.001$). Moisture content in strip loin steaks was greatest at WT of 3 and 10 d, with withdrawal d 17 and 24 resulting in significantly less moisture content (Table 4). Although ZH WT did not significantly affect percent fat in strip loins steaks like seen in beef trim, the percentage fat did increase numerically as moisture content decreased, which resembles the same relationship seen between percent moisture and percent fat in beef trim.

Few data exist to explain the differences seen in proximate analysis of strip loin steaks and ground beef trim; furthermore, the differences that were seen due to ZH were to be expected. Zilpaterol hydrochloride has been shown to increase lean yields in carcasses, so it is logical to see a concurrent increase in the percent protein found in ground beef trim as well as in strip loin steaks with ZH supplementation. Moreover, although percent fat was not significantly reduced in either of the samples measured, reported values were numerically less for ZH compared with controls. Furthermore, there were no differences seen in protein levels across the various WT, which seems illogical because increases in various carcass cuts were seen with increased WT. This could be due to less effect of ZH on lean within the entire animal so there were minimal carryover effects of ZH after withdrawal on the lean in samples that were collected.

In conclusion, the repartitioning agent ZH, when fed 20 d before slaughter, increased carcass weights and yields in beef steers, which led to an increase in wholesale carcass lean. The WBS force values were increased with ZH supplementation; however, with appropriate aging, these values were reduced. Withdrawal time of ZH seemed to have no negative impact on product tenderness or proximate analysis of ground beef trim or strip loin steaks, and improvements in some carcass cuts were seen with 10 d of withdrawal from ZH.

LITERATURE CITED

AMSA. 1995. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of fresh meat. Natl. Livest. Meat Board, Chicago, IL.

AOAC. 1990. Official Methods of Analysis. 15th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Avendano-Reyes, L., V. Torres-Rodriguez, F. J. Meraz-Murillo, C. Perez-Linares, F. Figueroa-Saavendra, and P. H. Robinson. 2006. Effects of two β-adrenergic agonists on finishing performance, carcass characteristics, and meat quality of feedlot steers. J. Anim. Sci. 84:3259–3265.

Casey, N. H., E. C. Webb, and J. L. Martin. 1997. Effects of zilpaterol and its withdrawal on carcass and meat quality of young steers. Int. Congr. Meat Sci. Technol. Proc. 43:264–265.

Hilton, G. G., J. L. Montgomery, C. R. Krehbiel, D. A. Yates, J. P. Hutcheson, W. T. Nichols, M. N. Streeter, J. R. Blanton Jr., and M. F. Miller. 2009. Effects of feeding zilpaterol hydrochloride with and without monensin and tylosin on carcass cutability and meat palatability of beef steers. J. Anim. Sci. 87:1394–1406.

Holland, B. P., C. R. Krehbiel, G. G. Hilton, M. N. Streeter, D. L. VanOverbeke, J. N. Shook, D. L. Step, L. O. Burciaga-Robles, D. R. Stein, D. A. Yates, J. P. Hutcheson, W. T. Nichols, and J. L. Montgomery. 2009. Effect of extended withdrawal of zilpaterol hydrochloride on performance and carcass traits of finishing beef steers. J. Anim. Sci. doi:10.2527/jas.2009-1798

Kirchofer, K. S., C. R. Calkins, and B. L. Gwartney. 2002. Fiber-type composition of muscles of the beef chuck and round. J. Anim. Sci. 80:2872–2878.

Leheska, J. M., J. L. Montgomery, C. R. Krehbiel, D. A. Yates, J. P. Hutcheson, W. T. Nichols, M. Streeter, J. R. Blanton, and M. F. Miller. 2009. Dietary zilpaterol hydrochloride. II. Carcass composition and meat palatability of beef cattle. J. Anim. Sci. 87:1384–1393.

Miller, M. F., M. A. Carr, C. B. Ramsey, K. L. Crockett, and L. C. Hoover. 2001. Consumer thresholds for establishing the value of beef tenderness. J. Anim. Sci. 79:3062–3068.

Miller, M. F., D. K. Garcia, M. E. Coleman, P. A. Ekeren, D. K. Lunt, K. A. Wagner, M. Procknor, T. H. Welsh Jr., and S. B. Smith. 1988. Adipose tissue, longissimus muscle and anterior pituitary growth and function in clenbuterol-fed heifers. J. Anim. Sci. 66:12–20.

Montgomery, J. L., C. R. Krehbiel, J. J. Cranston, D. A. Yates, J. P. Hutcheson, W. T. Nichols, M. N. Streeter, R. S. Swingle, and T. H. Montgomery. 2008. Effects of dietary zilpaterol hydrochloride on feedlot performance and carcass characteristics of beef steers fed with and without monensin and tylosin. J. Anim. Sci. 87:1013–1023.

O'Neill, H. A. 2001. The effects of zilpaterol hydrochloride on dietary N-requirements and the quality and nutritional value of meat components. MS Thesis. Univ. Pretoria, Pretoria, South Africa.

Plascencia, A., N. Torrentera, and R. A. Zinn. 1999. Influence of the β-agonist, zilpaterol, on growth performance and carcass characteristics of feedlot steers. J. Anim. Sci. 77:(Suppl. 1):114. (Abstr.)

Pringle, T. D., C. R. Calkins, M. Koohmaraie, and S. J. Jones. 1993. Effects over time of feeding a β-adrenergic agonist to wether lambs on animal performance, muscle growth, endogenous muscle proteinase activities, and meat tenderness. J. Anim. Sci. 71:636–644.

Schroeder, A. L., D. M. Polser, S. B. Laudert, and G. J. Vogel. 2003. Effect of Optaflexx on sensory properties of beef. Optaflexx Exchange No. 3. Elanco Animal Health, Greenfield, IN.

Shelver, W. L., and D. J. Smith. 2006. Tissue residue and urinary excretion of zilpaterol in sheep treated for 10-days with dietary zilpaterol. J. Agric. Food Chem. 54:4155–4161.

Sissom, E. K., D. A. Yates, J. L. Montgomery, W. T. Nichols, M. N. Streeter, J. P. Hutcheson, and B. J. Johnson. 2007. Effects of zilpaterol on cultured bovine satellite cells. J. Anim. Sci. 85(Suppl. 1):295.

Smith, S. B., S. K. Davis, J. J. Wilson, R. T. Stone, F. Y. Wu, D. K. Garcia, D. K. Lunt, and A. M. Schiavetta. 1995. Bovine fast-twitch myosin light chain 1: Cloning and mRNA amount in muscle of cattle treated with clenbuterol. Am. J. Physiol. 268:E858–E865.

Strydom, P. E., L. Frylinck, J. L. Montgomery, and M. F. Smith. 2009. The comparison of three β-agonists for growth performance, carcass characteristics, and meat quality of feedlot cattle. Meat Sci. 81:557–564.