Effects of dietary zilpaterol hydrochloride on feedlot performance and carcass characteristics of beef steers fed with and without monensin and tylosin

J. L. Montgomery,*1 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§

*Intervet Inc., Millsboro, DE 19966; †Department of Animal Science, Oklahoma State University, Stillwater 74078; ‡Cactus Research Ltd., Amarillo, TX 79116; and §Division of Agriculture, West Texas A&M University, Canyon 79016

ABSTRACT: A feedlot experiment was conducted under commercial conditions in the Texas Panhandle using 3,757 feedlot steers (average of 94 steers/pen) to evaluate the effects of feeding zilpaterol hydrochloride with or without monensin and tylosin on feedlot performance and carcass characteristics. The experiment was conducted using a randomized complete block design. Treatments were arranged as a 2 (no zilpaterol vs. zilpaterol) × 2 (monensin and tylosin withdrawn vs. monensin and tylosin fed during the final 35 d on feed) factorial. Steers were fed for a total of 161 to 167 d, and treatments were administered during the final 35 d that cattle were on feed. When included in the diet, zilpaterol, monensin, and tylosin were supplemented at 8.3, 33.1, and 12.2 mg/kg (DM basis), respectively. Zilpaterol was included in the diet for 30 d at the end of the finishing period and withdrawn from the diet for the last 5 or 6 d cattle were on feed. Cattle were harvested and carcass data collected. There were no zilpaterol × monensin/tylosin interactions (P ≥ 0.12) for ADG or G:F. Feeding zilpaterol increased ADG (P < 0.001) by 0.20 kg and G:F (P < 0.001) by 0.029 kg/kg during the last 35 d on feed. Likewise, when feedlot variables were measured throughout the entire 161 to 167-d feeding trial, ADG (3.4%; P < 0.001) and G:F (3.9%; P < 0.001) were increased. Feeding zilpaterol increased (P < 0.001) dressing percent and HCW and decreased (P < 0.001) total liver abscess rate compared with controls. In addition, zilpaterol increased (P < 0.001) LM area by an average of 8.0 cm². There was a zilpaterol × monensin/tylosin interaction (P = 0.03) for marbling score. Zilpaterol decreased (P < 0.001) marbling score regardless of monensin and tylosin treatment, although withdrawal of monensin and tylosin for 35 d decreased marbling to a greater extent (31 vs. 17 degrees). Zilpaterol decreased (i.e., improved; P < 0.001) calculated yield grade regardless of monensin and tylosin treatment, but feeding zilpaterol in combination with the withdrawal of monensin and tylosin for 35 d decreased calculated yield grade to a greater extent (0.49 vs. 0.29) compared with the zilpaterol, monensin, and tylosin combination treatment (zilpaterol × monensin/tylosin interaction, P = 0.03). Results suggest that monensin and tylosin can be withdrawn from the diet during the zilpaterol feeding period (final 35 d on feed) with minimal effect on animal performance, although feeding zilpaterol in combination with monensin and tylosin seemed to moderate effects on carcass quality.

Key words: β-adrenergic agonist, beef cattle, carcass merit, finishing performance, zilpaterol hydrochloride

INTRODUCTION

Zilpaterol hydrochloride is a β₂-adrenergic agonist (βAA) pharmaceutical commercially available in Mexico and the Republic of South Africa as Zilmax (Intervet Inc., Millsboro, DE). Zilpaterol was approved in the United States by the Center for Veterinary Medicine in 2006 (FDA, 2006). Although significant information regarding the effects of other βAA on ADG, G:F, and carcass variables exists (Moloney et al., 1991; Beermann, 1993; Mersmann, 1998), very little has been reported on zilpaterol hydrochloride. In small studies conducted in Mexico and South Africa, ADG, G:F, dressing percent, carcass weight, and LM area have been shown to be enhanced in cattle with the use of zilpaterol (Casey et al., 1997a; Strydom et al., 1998; Plascencia et al., 1999). Positive effects of zilpaterol on feedlot perfor-
mance and carcass variables have also been reported by Montgomery et al. (2009).

Because previous reports regarding zilpaterol inclusion in diets for finishing cattle are limited and have been conducted primarily in small pens, the objective of this experiment was to increase the information available about zilpaterol and to report zilpaterol effects on US steers fed in commercial large pens. Monensin (Rumensin, Elanco Animal Health, Indianapolis, IN) and tylosin (Tylan, Elanco Animal Health) are commonly fed in combination to finishing cattle. At the time of approval of zilpaterol hydrochloride in the United States, cross-clearance for combined use with monensin and tylosin did not exist; thus, the second study objective was to determine effects of feeding zilpaterol with and without monensin and tylosin on feedlot performance and carcass traits. Additional effects of zilpaterol hydrochloride on carcass cutability and beef tenderness using samples obtained from cattle in the present experiment were reported by Hilton et al. (2009).

**MATERIALS AND METHODS**

Animals were handled in compliance with applicable local regulations and in accordance with the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 1999).

**Cattle**

A total of 5,247 steers were purchased for conducting this experiment. Steers were medium to large frame and predominantly Bos taurus-English or Bos taurus-Continental crosses. Cattle were received and processed according to routine management procedures at the study facility. From receipt until allotment, steers were maintained in holding pens, fed a standard receiving diet consisting of a moderate-concentrate mixed diet plus alfalfa hay, and allowed free access to drinking water. Before study initiation, steers were given 2 individually numbered ear tags, vaccinated with Vision 7 with SPUR (Intervet) and Reliant IBR/Lepto (Merial Ltd., Iselin, NJ), treated for internal parasites with Safe-Guard (Intervet) and external parasites with Tiguvon (Bayer Corp., Shawnee Mission, KS), implanted with Ral gro (Schering-Plough Animal Health, Kenilworth, N J), and administered a drench containing 1,000,000 IU of vitamin A and 200,000 IU of vitamin D. The BW of individual steers was measured (the single-animal scale was mounted on load cells and calibrated with certified weights before use). All animals were inspected for the presence of intact testicles, and bulls were excluded from the experiment. Only cattle weighing between 272 and 363 kg were included in the study candidate pool. Because of the number of cattle processed and eventually used in the study, cattle were received, processed, and started on the study in 2 large groups (2,547 and 2,700 steers) 4 wk apart.

For the first group of cattle, 1,871 steers were selected for allotment into 5 different blocks in 20 pens. For the second group of cattle processed 4 wk later, 1,886 steers were selected for allotment into 5 different blocks in 20 pens. Therefore, there were 10 blocks and 40 pens used for this experiment. Steers were blocked based on arrival, processing, and allotment dates. The number of steers assigned to each pen ranged from 81 to 114 (average = 94), which provided approximately 24 cm of bunk space and 13.9 m² of pen space/steer.

Immediately following allotment, cattle were weighed by pen to establish d 0 pen BW, and steers were moved to newly assigned dirt floor pens. On d 57 for the first 3 blocks, d 58 for the next 5 blocks, or d 59 for the last 2 blocks all steers were weighed by pen and reimplanted with Revalor-S (Intervet). Cattle were again weighed by pen on d 127 or 121 for the first and last 5 blocks, respectively, to establish starting BW before treatment initiation. Pens of cattle were weighed 5 d before actual treatment initiation so that this activity would have minimal effect on behavior of the steers and potential intake and growth performance. Morbidity and mortality were monitored daily throughout the experiment.

**Diets and Treatments**

During the first 21 d steers were gradually adapted to a 90% concentrate diet using 3 transition diets (36, 29, and 16% roughage, DM basis). The first transition diet contained lasalocid (Bovatec, Alpharma Animal Health, Fort Lee, NJ; 36.4 mg/kg, DM basis), whereas the second and third transition diets contained monensin (22.1 and 27.6 mg/kg, DM basis, respectively) and tylosin (12.2 mg/kg, DM basis). Ingredient and nutrient composition of the concentrate diet that was fed through d 130 or 125 for the first and last 5 blocks, respectively, is shown in Table 1. Feeding of the treatment diets commenced on d 131 or 126 for the first and last 5 blocks, respectively. The 4 treatments consisted of a 2 (zilpaterol hydrochloride; 0.0 or 8.3 mg/kg, DM basis) × 2 (monensin and tylosin; 0.0 and 0.0 or 33.1 and 12.2 mg/kg, respectively, DM basis) factorial arrangement of treatments. Following d 131 (blocks 1 through 5) or d 126 (blocks 6 through 10), each of the 4 treatment diets was fed for 30 consecutive days. After 30 d of feeding, zilpaterol was withdrawn from the treatments for 5 or 6 d before harvest; this is referred to as a 5-d withdrawal henceforth. Monensin and tylosin remained withdrawn to harvest for steers on the monensin/tylosin withdrawal treatments.

During the treatment period (final 35 d on feed) the basal diet was initially mixed in a Roto-Mix model 490-H mixer (Roto-Mix, Dodge City, KS) for 3 min. As appropriate for experimental treatments, zilpaterol hydrochloride, monensin, and tylosin were hand weighed for each load of feed and applied with a water-flush delivery system. For each treatment diet, the basal diet and respective drugs were combined and mixed in the Roto-Mix model 490-H mixer for 3 min at 1,800 rpm.
Once the treatment diets were mixed, they were delivered to their respective treatment pens. Feed bunks were evaluated visually at approximately 0600 h daily. The quantity of feed remaining in each bunk was estimated, and the daily allotment of feed for each pen was recorded. This bunk-reading process was designed to allow for little or no accumulation of unconsumed feed (0 to 0.5 kg/pen). Cattle were fed the finishing diet and treatment diets twice daily shortly after 0600 and 1300 h. Throughout the experiment, orts were composited by pen and treatment, and the DM content of bunk orts samples were determined in a forced-air oven by drying overnight at 100°C. During the acclimation period, orts were collected on weigh days. During the treatment period (final 35 d on feed), orts were collected in 7-d increments before feeding animals starting on the first day of treatment. In addition, daily samples of the treatment diets were collected during the treatment period. Treatment diets were composited in 7-d increments, and DM determinations used to calculate DMI and G:F per pen after correcting for orts. The 7-d treatment diet composites were also analyzed for ash, CP, ADF, Ca, and P (AOAC, 1990). The feeding management goal throughout the study was to have less than 0.5 kg of feed per bunk each morning.

### Harvest and Carcass Evaluation

The treatment period was initiated at a point when it was determined, based on days on feed, body condition, and visual fat depth, that approximately 50% of the control cattle would grade Choice at harvest (35 days).
Calculations and Statistical Analyses

For calculations, interim and final BW were shrunk 4% for calculating animal performance and dressing percent. Feedlot performance data were calculated with dead animals and animals removed from the experiment considered in the analyses (“deads in”). Average daily gain was calculated for each pen as (total final BW minus total initial BW)/total animal-days in each period or across the entire experiment. Similarly, DMI was calculated for each pen as (total feed minus orts)/total animal-days in each period or across the entire experiment, and this included animals that died or were removed from the experiment for health-related causes. Variation in DMI during the experiment was calculated separately for each treatment from reimplant to the start of the treatment diets and during feeding of the treatment diets (final 35 d on feed). The 2 methods described by Choat et al. (2002) were used. Because daily feed calls were targeted at <0.5 kg of feed in the bunk each morning, daily DMI was estimated from the daily feed call (i.e., amount of feed delivered to each pen per day). Therefore, the daily DMI values used to calculate variation in DMI are estimates only.

Feedlot performance data and carcass traits were analyzed using a 2 (zilpaterol treatment) × 2 (monensin/tylosin treatment) factorial arrangement of treatments in a randomized complete block design, where a pen of steers was the experimental unit. There were 10 blocks for each of the 4 treatments. Carcass-adjusted final BW was calculated as HCW/average dressing percent for all steers in each treatment. Carcass-adjusted ADG and G:F were calculated from carcass-adjusted final BW.

RESULTS

Morbidity, Mortalities, and Removals

During the last 35 d on feed, morbidity did not differ among treatments (P ≥ 0.19; Table 2). However, mortality was greater (P = 0.002) when zilpaterol was fed compared with no zilpaterol. Feeding zilpaterol increased mortality regardless of monensin and tylosin treatment, whereas morbidity was not affected. In the treatment with no monensin, tylosin, or zilpaterol there was 1 mortality due to digestive bloat and 1 mortality due to respiratory pneumonia during the last 35 d of the experiment. In the zilpaterol without monensin and tylosin treatment there were 5 mortalities due to digestive bloat and 1 mortality due to respiratory pneumonia during the last 35 d of the study. For the monensin and tylosin plus zilpaterol treatment there was 1 mortality due to digestive bloat, 1 mortality due to enterotoxemia, 1 mortality due to heart failure, and 2 mortalities due to respiratory pneumonia during the last 35 d of the experiment.

Feedlot Data

There was a tendency (P = 0.07) for a zilpaterol × monensin/tylosin interaction for final BW. When zilpaterol was fed, final BW was greater when monensin/tylosin was removed from the diet compared with when monensin/tylosin remained in the diet (Table 2). In contrast, final BW was similar among monensin/tylosin treatments when no zilpaterol was fed. Monensin/tylo-
sin did not affect ($P \geq 0.18$) final BW, carcass-adjusted final BW, empty BW, or final shrunk BW adjusted to 28% empty body fat. A zilpaterol × monensin/tylosin interaction ($P = 0.006$) was observed for final shrunk BW adjusted to 28% empty body fat. Similar to final BW, adjusted final shrunk BW was greater when monensin/tylosin was removed from the diet compared with when monensin/tylosin remained in the diet when zilpaterol was fed, whereas final BW was similar among monensin/tylosin treatments when no zilpaterol was fed.

No zilpaterol × monensin/tylosin interactions ($P \geq 0.12$; Table 2) were observed for performance response variables calculated during the last 35 d on feed, for the overall (d 0 to end) feeding period, or for carcass-adjusted performance. During the final 35 d on feed, feeding monensin/tylosin decreased ($P < 0.001$) DMI compared with removal of monensin/tylosin. No other effects ($P \geq 0.17$) of monensin/tylosin removal on performance response variables were observed.

Feeding zilpaterol for 30 d increased ADG (0.20 kg/d; $P < 0.001$), decreased DMI (0.31 kg/d; $P < 0.001$), and increased G:F (0.029 kg/kg; $P < 0.001$) during the final 35 d on feed (Table 2). Similarly, across the entire feeding period, ADG was increased (3.4%; $P = 0.001$), DMI was decreased (1.2%; $P = 0.009$), and G:F was increased (3.9%; $P < 0.0001$) when zilpaterol was fed. Carcass-adjusted overall ADG (2.7%; $P = 0.004$) and G:F (4.0%; $P < 0.001$) were increased by feeding zilpaterol compared with no zilpaterol.

### Intake Variation

Dry matter intake and day-to-day and pen-to-pen DMI variation were calculated from reimplant to the start of zilpaterol as well as during the last 35 d of the feeding period (Table 3). There was a period × zilpaterol interaction ($P < 0.001$) for DMI and a tendency ($P = 0.09$) for a period × zilpaterol interaction for daily DMI variation. These interactions resulted from decreased DMI and greater daily DMI variation when zilpaterol was added to the diet for 30 d during the last 35 d on feed. Dry matter intake variation within a pen across the period was not affected ($P = 0.42$) by feeding zilpaterol, but was decreased ($P = 0.03$) during the last 35 d on feed. In this experiment, monensin/tylosin decreased DMI, but did not affect ($P > 0.25$) daily or pen DMI variation when withdrawn during the final 35 d on feed (data not shown).

### Carcass Characteristics

Effects of zilpaterol and monensin/tylosin on carcass traits are shown in Table 4. Hot carcass weight and dressing percent were increased ($P < 0.001$) by 13 kg and 1.2 percentage units, respectively, when steers were fed zilpaterol. Feeding zilpaterol increased ($P < 0.001$) LM area by an average of 8.0 cm$^2$, although feeding monensin and tylosin tended to decrease LM area when fed in combination with zilpaterol (zilpaterol × monensin/tylosin interaction; $P = 0.09$). The ratio of LM

### Table 2. Effects of monensin/tylosin and zilpaterol fed for the last 35 d (with a 5-d withdrawal of zilpaterol) on feedlot cattle performance

| Item                          | Monensin/tylosin removed |          | Monensin/tylosin |          | P-value | Monensin/tylosin | Interaction |
|-------------------------------|--------------------------|----------|------------------|----------|---------|------------------|-------------|
|                              | No Zilpaterol | Zilpaterol | No Zilpaterol | Zilpaterol | SEM     | Zilpaterol      |             |
| BW, kg                        | 320.6        | 320.7     | 320.8           | 319.8     | 1.69    | 0.59             | 0.67        | 0.44       |
| Initial                       | 320.6        | 320.7     | 320.8           | 319.8     | 1.69    | 0.59             | 0.67        | 0.44       |
| Final                         | 559.3        | 571.9     | 562.8           | 565.0     | 3.44    | 0.01             | 0.53        | 0.67       |
| Carcass-adjusted final¹       | 557.0        | 567.3     | 560.2           | 562.9     | 3.33    | 0.03             | 0.83        | 0.18       |
| Empty¹                        | 517.6        | 537.0     | 517.7           | 533.2     | 1.95    | <0.001           | 0.23        | 0.21       |
| 28% Adjusted final³           | 571.8        | 612.9     | 575.4           | 603.2     | 2.58    | <0.001           | 0.18        | 0.006      |
| Last 35 d on feed             |              |           |                 |           |         |                  |             |
| ADG, kg/d                    | 1.42         | 1.62      | 1.40            | 1.59      | 0.054   | <0.001           | 0.39        | 0.79       |
| DMI, kg                      | 9.02         | 8.70      | 8.79            | 8.50      | 0.080   | <0.001           | <0.001      | 0.75       |
| G:F, kg/kg                   | 0.156        | 0.186     | 0.159           | 0.187     | 0.0053  | <0.001           | 0.67        | 0.76       |
| d 0 to finish³               |              |           |                 |           |         |                  |             |
| ADG, kg/d                    | 1.48         | 1.55      | 1.50            | 1.52      | 0.016   | 0.001            | 0.65        | 0.14       |
| DMI, kg                      | 8.75         | 8.67      | 8.72            | 8.61      | 0.044   | 0.009            | 0.17        | 0.71       |
| G:F, kg/kg                   | 0.169        | 0.179     | 0.172           | 0.177     | 0.0016  | <0.001           | 0.81        | 0.12       |
| Carcass adjusted¹            |              |           |                 |           |         |                  |             |
| ADG, kg/d                    | 1.47         | 1.52      | 1.48            | 1.51      | 0.016   | 0.004            | 0.95        | 0.42       |
| DMI, kg                      | 0.168        | 0.176     | 0.170           | 0.176     | 0.0017  | <0.001           | 0.45        | 0.47       |
| Mortality last 35 d, %        | 0.41         | 0.41      | 0.10            | 0.23      | 0.18    | 0.74             | 0.19        | 0.74       |
| Mortality last 35 d, %        | 0.10         | 0.62      | 0.09            | 0.57      | 0.16    | 0.092            | 0.63        | 0.89       |

¹Carcass-adjusted final BW was calculated as HCW/average dressing percent.
²Empty BW = (1.316 × HCW) + 32.29 (Guiroy et al., 2002).
³Shrunk BW adjusted to 28% empty body fat (AFBW) = {empty BW + [(28 − empty body fat) × 14.26]}/0.891 (Guiroy et al., 2002).
⁴Cattle were weighed and shipped to harvest after a 161-, 162-, 166-, or 167-d feeding trial.
area to HCW was 4.6% greater \((P < 0.001)\) when zilpaterol was fed. In contrast, 12th-rib fat thickness was decreased \((P < 0.001)\) by an average of 8.4% in cattle fed zilpaterol. In addition, zilpaterol decreased \((P < 0.001)\) KPH fat percentage regardless of monensin/tylosin treatment. There was a zilpaterol × monensin/tylosin interaction \((P = 0.03)\) for marbling score and a tendency \((P = 0.07)\) for a zilpaterol × monensin/tylosin interaction for USDA Quality grade. Feeding zilpaterol decreased \((P < 0.001)\) marbling score regardless of monensin/tylosin treatment, although withdrawal of monensin and tylosin for 30 d decreased marbling to a greater extent (31 vs. 17 degrees on average). Similar results were observed for quality grade. The distribution of USDA Quality grades is shown in Table 5. There was a zilpaterol × monensin/tylosin interaction \((P = 0.03)\) for USDA premium Choice carcasses. Feeding zilpaterol resulted in a decreased percentage of USDA premium Choice carcasses regardless of monensin and tylosin treatment, although withdrawal of monensin and tylosin for 30 d decreased premium Choice carcasses to a greater extent. Feeding zilpaterol decreased USDA total \((P < 0.001)\) and low \((P < 0.001)\) Choice carcasses, and increased Select \((P < 0.001)\) and No roll \((P < 0.001)\) carcasses compared with cattle not fed zilpaterol.

Table 3. Dry matter intake, daily DMI variation, and pen DMI variation before and during the zilpaterol treatment period during last 35 d of the finishing period

| Item                        | Reimplant to zilpaterol period | Final 35 d on feed period | SEM | Period | Zilpaterol | Interaction |
|-----------------------------|--------------------------------|---------------------------|-----|--------|------------|-------------|
| DMI, kg/d                   |                                |                           |     |        | Zilpaterol |             |
| No zilpaterol               | 8.85a                         | 8.91a                     | 0.051 | 0.03   | 0.003      | <0.001      |
| Zilpaterol                  | 8.87a                         | 8.60b                     |      |        |            |             |
| Daily DMI variation, kg     |                                |                           |     |        | Zilpaterol |             |
| No zilpaterol               | 0.14a                         | 0.16b                     | 0.039 | <0.001 | <0.001     | 0.09        |
| Zilpaterol                  | 0.16a                         | 0.23c                     |      |        |            |             |
| Pen DMI variation, kg       |                                |                           |     |        | Zilpaterol |             |
| No zilpaterol               | 0.44a                         | 0.29                      | 0.057 | 0.03   | 0.42       | 0.65        |
| Zilpaterol                  | 0.46                          | 0.36                      |      |        |            |             |

\(^{a,b}\)Means in the same row without a common superscript letter differ \((P < 0.05)\).

\(^{1}\)There were no ionophore × agonist or ionophore × agonist × period interactions \((P > 0.10)\).

\(^{2}\)Daily DMI variation = residual intake calculated as estimated DMI minus the average DMI for all pens within a treatment for each day analyzed within period; pen DMI variation = residual intake calculated as estimated daily DMI minus the average DMI for all days within the period for that pen. Sample variances were calculated on intake residuals in both methods.

Table 4. Effects of monensin/tylosin and zilpaterol on carcass characteristics

| Item                        | Monensin/tylosin removed | Monensin/tylosin | SEM | Zilpaterol | Monensin/tylosin Interaction |
|-----------------------------|--------------------------|------------------|-----|------------|-----------------------------|
| HCW, kg                     | 369                      | 384              |     |            |                             |
| Dressing percent            | 64.8                     | 66.0             | 0.11 |            |                             |
| LM area, cm\(^{2}\)         | 91.7                     | 101.1            | 0.85 |            |                             |
| LM area:HCW, cm\(^{2}\)/kg  | 0.249                    | 0.264            | 0.0025 |            |                             |
| 12th-rib fat, cm            | 1.18                     | 1.05             | 0.031 |            |                             |
| KPH, %                      | 2.00                     | 1.90             | 0.029 |            |                             |
| Marbling\(^{1}\)           | 420\(^{a}\)              | 391\(^{b}\)      | 4.9  |            |                             |
| Quality grade\(^{2}\)       | 11.28                    | 10.70            | 0.085 | <0.001    | 0.32                        |
| Preliminary yield grade     | 3.16                     | 3.03             | 0.031 |            | 0.72                        |
| Calculated yield grade      | 2.60\(^{a}\)             | 2.11\(^{b}\)     | 0.052 |            | 0.14                        |
| USDA Yield grade            | 2.61\(^{a}\)             | 2.13\(^{b}\)     | 0.051 | <0.001    | 0.16                        |
| Empty body fat, %           | 28.6                     | 27.4             | 0.18  | <0.001    | 0.66                        |
| Color score\(^{3}\)         | 5.12                     | 5.05             | 0.046 | 0.09      | 0.58                        |
| Total liver abscess rate, % | 28.6                     | 21.2             | 1.48  | <0.001    | 0.003                       |
| A–                          | 8.1                      | 5.5              | 5.7  | 3.8       | 0.89                        |
| A                           | 1.6                      | 1.4              | 1.3  | 1.1       | 0.41                        |
| A+                          | 8.8                      | 6.3              | 5.4  | 5.5       | 0.80                        |
| Other                       | 10.1                     | 8.0              | 10.4 | 8.1       | 1.01                        |

\(^{a}\)Means in the same row without a common superscript letter differ \((P < 0.05)\).

\(^{1}\)Marbling score: Slight\(^{0}\) = 300; Small\(^{0}\) = 400; Modest\(^{0}\) = 500.

\(^{2}\)Quality grade: 10.00 = low Choice; 11.00 = average Choice; 12.00 = high Choice.

\(^{3}\)Empty body fat = 17.76207 + (4.68142 × 12th-rib fat) + (0.01945 × HCW) + (0.81855 × quality grade) − (0.06754 × LM area). For calculations, numerical quality grades were Standard = 3 to 4; Select = 4 to 5; low Choice = 5 to 6; average Choice = 6 to 7; high Choice = 7 to 8; low Prime = 8 to 9; and average Prime = 9 to 10; Guirroy et al., 2002.

\(^{3}\)Color score: (1 to 9 scale, 1 being the lightest and 9 the darkest) 1 = light pink; 2 = pink; 3 = dark pink; 4 = light cherry red; 5 = cherry red; 6 = dark red; 7 = very dark red (considered 1/3 dark cutter); 8 = maroon (considered 2/3 dark cutter); 9 = dark maroon (considered full dark cutter).

\(^{5}\)Liver abscess scale: A– = 1 or 2 small (<2.5 cm) liver abscesses; A = 2 to 4 active liver abscesses with the main portion of the liver unaffected and normal in appearance; A+ = 1 or more large (>2.5 cm) active liver abscesses or open abscesses; Other = livers condemned for flukes, distoma, telangiec, other contamination.
There was a zilpaterol × monensin/tylosin interaction \((P = 0.03)\) for calculated yield grade (Table 4). Zilpaterol decreased \((P < 0.001)\) yield grade regardless of monensin and tylosin treatment, although feeding zilpaterol with the withdrawal of monensin and tylosin for 30 d decreased yield grade to a greater extent (0.49 vs. 0.29) compared with the zilpaterol, monensin, and tylosin combination treatment. The distribution of USDA Yield grades is shown in Table 6. There were zilpaterol × monensin/tylosin interactions for USDA Yield grades 1.00 \((P = 0.04)\) and 3.50 to 3.99 \((P = 0.02)\). A greater percentage of carcasses were in the USDA Yield grade 1 category, and a smaller percentage of carcasses were in the USDA Yield grade 3.50 to 3.99 category when zilpaterol was fed with withdrawal of monensin/tylosin than when fed in combination with monensin/tylosin. Withdrawing monensin/tylosin during the last 35 d on feed increased \((P = 0.003)\) the percentage of USDA Yield grade 1 carcasses. Feeding zilpaterol or without monensin and tylosin decreased \((P < 0.001)\) the frequency of USDA Yield grade 1 carcasses, and decreased the frequency of USDA Yield grade 3.00 to 3.49 \((P < 0.001)\), 3.50 to 3.99 \((P < 0.001)\), and 4.00 to 5.49 \((P < 0.001)\) carcasses compared with no zilpaterol. Zilpaterol did not affect \((P = 0.43)\) the percentage of USDA Yield grade 2.00 to 2.49 carcasses, but tended \((P = 0.07)\) to decrease the percentage of USDA Yield grade 2.50 to 2.99 carcasses compared with steers not fed zilpaterol. Calculated percentage empty body fat responded with a zilpaterol × monensin/tylosin interaction \((P = 0.04; \text{Table } 4)\). Feeding zilpaterol for 30 d with the withdrawal of monensin and tylosin decreased empty body fat percentage to a greater extent compared with the zilpaterol, monensin, and tylosin combination treatment. Averaged across monensin/tylosin treatments, zilpaterol decreased \((P < 0.001)\) empty body fat by 0.9 percentage units compared with no zilpaterol (27.6 vs. 28.5%, respectively).

Color scores tended \((P = 0.09)\) to be decreased by zilpaterol treatment resulting in a more cherry red and less dark red LM compared with controls (Table 4). Percentage of dark cutters was not affected \((P = 0.10)\) by feeding zilpaterol (average = 0.72%). Total liver abscess rate was decreased by zilpaterol \((P < 0.001)\) and by monensin/tylosin \((P = 0.003)\) compared with controls. Zilpaterol treatment resulted in a 2.2 percentage unit decrease in livers scored A− compared with steers not fed zilpaterol. Livers with 2 to 4 abscesses (scored A) and severely abscessed livers (A+) were not affected \((P ≥ 0.14)\) by zilpaterol treatment, although feeding monensin/tylosin with or without zilpaterol decreased \((P = 0.01)\) the percentage of severely abscessed livers. Feeding zilpaterol decreased \((P = 0.02)\) the percentage of livers scored as “other” (liver flukes, distoma, telangiec, other contamination).

### DISCUSSION

Experiments that have evaluated and reported the effects of feeding βAA on morbidity and mortality in feedlot cattle are limited. In the present experiment, 26 steers died and 63 were removed from the study for health-related causes during the entire experiment. Of the 26 mortalities, only 12 occurred during the treatment period (i.e., final 35 d on feed). Respiratory and digestive disorders were the largest cause of mortal-

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**Table 5.** Effect of feeding monensin/tylosin (MT) and zilpaterol (Z; 8.3 mg/kg, DM basis) to feedlot steers on USDA Quality grade distribution

| Treatment | Prime | Total Choice | Premium Choice | Low Choice | Select | No Roll |
|-----------|-------|--------------|----------------|------------|--------|---------|
| No MT/no Z, % | 1.2 | 57.5 | 15.9 | 41.6 | 38.3 | 3.1 |
| Z/no MT, % | 0.3 | 43.5 | 10.1 | 33.4 | 47.4 | 8.8 |
| MT/no Z, % | 1.2 | 59.0 | 14.2 | 44.7 | 35.7 | 4.1 |
| Z plus MT, % | 0.9 | 47.5 | 13.2 | 34.2 | 42.2 | 9.5 |
| SEM | 0.4 | 1.7 | 1.2 | 1.6 | 1.7 | 1.0 |
| Z, \(P > \chi^2\) | 0.07 | <0.001 | 0.003 | <0.001 | <0.001 | <0.001 |
| MT, \(P > \chi^2\) | 0.34 | 0.10 | 0.51 | 0.22 | 0.02 | 0.28 |
| Z × MT, \(P > \chi^2\) | 0.37 | 0.46 | 0.03 | 0.46 | 0.41 | 0.85 |

**Table 6.** Effect of feeding monensin/tylosin (MT) and zilpaterol (Z; 8.3 mg/kg, DM basis) to feedlot steers on USDA Yield grade distribution

| Treatment | 1.00 to 1.99 | 2.00 to 2.49 | 2.50 to 2.99 | 3.00 to 3.49 | 3.50 to 3.99 | 4.00 to 5.49 |
|-----------|--------------|--------------|--------------|--------------|--------------|--------------|
| No MT/no Z, % | 26.2 | 19.6 | 22.5 | 15.4 | 10.4 | 5.9 |
| Z/no MT, % | 46.7 | 22.9 | 19.1 | 7.5 | 2.7 | 1.6 |
| MT/no Z, % | 24.8 | 23.5 | 21.9 | 16.1 | 8.6 | 5.2 |
| Z plus MT, % | 38.9 | 22.9 | 20.5 | 10.6 | 4.8 | 2.4 |
| SEM | 1.7 | 1.4 | 1.4 | 1.2 | 1.0 | 0.8 |
| Z, \(P > \chi^2\) | <0.001 | 0.43 | 0.07 | <0.001 | <0.001 | <0.001 |
| MT, \(P > \chi^2\) | 0.003 | 0.12 | 0.76 | 0.08 | 0.91 | 0.97 |
| Z × MT, \(P > \chi^2\) | 0.04 | 0.22 | 0.46 | 0.24 | 0.02 | 0.26 |
ity. Respiratory disease was the greatest cause of morbidity with an average incidence of 12%. The extent of mortality and morbidity observed were considered “normal” by project directors at the experimental site (R. S. Swingle, unpublished data).

In the present experiment, feeding zilpaterol and withdrawing monensin/tylosin at the end of the feeding period did not affect morbidity, although feeding zilpaterol increased mortality regardless of whether monensin and tylosin were withdrawn, suggesting that total mortality was not associated with the removal of the ionophore. However, the greatest number of deaths from digestive disorders occurred when zilpaterol was fed and monensin/tylosin was removed. In experiments where cattle were fed in small pens (i.e., 10 animals/pen), no effects of feeding ractopamine (Schroeder et al., 2003; Gruber et al., 2007) or zilpaterol (Montgomery et al., 2009) on mortality were observed. To our knowledge, morbidity and mortality data have not been reported in similar commercial feedlot experiments in which βAA other than zilpaterol have been fed. Because changes in death loss have not been associated with feeding zilpaterol in experiments conducted in small pens (Montgomery et al., 2009), more experiments in large pens are warranted to determine if the response is consistent and to determine potential reasons for the response.

Effects of feeding zilpaterol on ADG and G:F in the present experiment were similar to zilpaterol effects on performance in steers reported by Casey et al. (1997b), Plascencia et al. (1999), and Montgomery et al. (2009), although improvements were less dramatic in the present experiment. For example, Plascencia et al. (1999) reported a 37% increase in ADG and a 39% improvement in feed efficiency (i.e., feed:gain) when zilpaterol was fed for 40 d during a 42-d finishing trial (with 2-d withdrawal). In the present experiment, ADG and G:F were increased 14.2 and 15.5%, respectively, when zilpaterol was fed vs. no zilpaterol (calculated for the final 35 d on feed). Although several factors may be involved in differences observed among experiments, it is important to note that the majority of studies reporting effects of feeding zilpaterol on steer performance have been conducted in small pens with limited numbers of animals. The present experiment was conducted under US commercial feedlot conditions in large pens, which may partly account for the decreased effects observed on performance variables compared with smaller pen studies.

The effects of zilpaterol hydrochloride on ADG and G:F in the present experiment is similar when compared with previous studies in which ractopamine hydrochloride has been fed to steers (Laudert et al., 2004; Gruber et al., 2007; Winterholler et al., 2007). During a 28-d feeding period, Gruber et al. (2007) reported a 15.3% increase in ADG and a 14.7% increase in G:F across diverse biological types of steers when 200 mg of ractopamine/d was fed. In a large pen commercial study with feedlot steers, ractopamine was shown to increase ADG by 4.5% and G:F by 4.0% over the entire 150- to 192-d feeding period when 200 mg/d was fed for the final 28 d on feed (Winterholler et al., 2007). In the same experiment, increasing days on feed from 150 to 192 decreased ADG, G:F, and DMI. Avendaño-Reyes et al. (2006) fed zilpaterol hydrochloride (60 mg/d) or ractopamine hydrochloride (300 mg/d) to steers for a 30-d feeding period (plus 3-d withdrawal for zilpaterol) and reported a 26 and 24% increase in ADG, a 26.9 and 25.4% increase in G:F, and a 19.5- and 10.6-kg increase in final BW, respectively. Similar to zilpaterol and ractopamine, other βAA such as clenbuterol (Ricks et al., 1984), L644,969 (Moloney et al., 1990; Wheeler and Koohmaraie, 1992; Chwalibog et al., 1996), and cimaterol (Quirke et al., 1988) have been reported to increase ADG and G:F when fed to cattle.

Feeding zilpaterol hydrochloride decreased DMI in the present study and in the study of Montgomery et al. (2009), while increasing BW gain. Similar to the present experiment, strong βAA such as clenbuterol, cimaterol, and L644,969 have been shown to decrease DMI (Ricks et al., 1984; Peters, 1989; Moloney et al., 1990). In contrast, feeding ractopamine to cattle has generally not influenced DMI (Gruber et al., 2007; Winterholler et al., 2007). One exception is the study by Avendaño-Reyes et al. (2006), in which feeding ractopamine resulted in decreased DMI and feeding zilpaterol did not affect DMI compared with controls. Diets fed in the Avendaño-Reyes et al. (2006) study were based on steam-rolled wheat and contained 21% roughage (DM basis), which is greater than finishing diets typically fed in the United States (Galvean and Gleghorn, 2002). Reasons for decreased feed intake when βAA are fed have not been elucidated, but may involve both direct (e.g., tissue specific) and indirect (e.g., endocrine) changes associated with fat and muscle metabolism (Beermann, 2002; Mersmann, 2002).

Monensin has been shown to decrease DMI and DMI variation in cattle fed high-concentrate diets (Burrin et al., 1988; Stock et al., 1995). In the present experiment, DMI was increased during the final 35 d on feed when monensin was withdrawn, consistent with the previous literature. However, variance in DMI was not affected by withdrawing monensin at the end of the feeding period. Feeding zilpaterol during the same period increased daily DMI variation. Although many factors might be involved with the increased variation, greater day-to-day DMI variation across pens within the zilpaterol treatment did not result in decreased animal performance. More experiments are needed to determine if the potential for increased DMI variation is related to changes in management required to deliver an additional ration near the end of the feeding period. Bunk management issues related to a decrease in feed intake, the addition of zilpaterol, removal of the ionophore, or some combination of factors.

In general, feeding cattle βAA has resulted in increased HCW and dressing percent as observed in the present experiment (Chiakhou et al., 1993; Fiems et al.,
Previous reports have indicated that feeding zilpaterol increased dressing percent, HCW, and LM area, whereas KPH and marbling score were generally not affected (Casey et al., 1997a; Plascencia et al., 1999). In the present experiment, HCW was increased by an average of 13 kg, dressing percent was increased by 1.2 percentage units, and LM area was increased by an average of 8.0 cm², consistent with previous experiments. Although previous reports have indicated no effect of zilpaterol on 12th-rib fat thickness (Casey et al., 1997a; Plascencia et al., 1999), the present experiment showed a 9.5% decrease in 12th-rib fat thickness when zilpaterol was fed. In addition, marbling was decreased by 24 degrees on average, and there was a significant shift from USDA Choice to USDA Select carcasses. In contrast, calculated yield grade was decreased (i.e., improved) 18.3%, and there was a significant shift from USDA Yield grade 3.00 to 3.49, 3.50 to 3.99, and ≥4.00 carcasses to USDA Yield grade 1 carcasses compared with control steers. Previous studies with other βAA in cattle have shown an improvement in yield grade when clenbuterol (Ricks et al., 1984; Miller et al., 1988; Schiavetta et al., 1990) or \( L_{641,969} \) (Moloney et al., 1990; Wheeler and Kooistra, 1992) was administered, similar to the present experiment.

Guiroy et al. (2002) reported that increasing the anabolic implant dose increased the BW at which animals reached 28% empty body fat. Using the same approach, we calculated empty body fat and final shrunk BW adjusted to 28% empty body fat for steers fed zilpaterol with or without monensin/tylosin removed during the final 35 d on feed. Similar to implanted cattle, our data indicate that steers fed zilpaterol would reach the same empty body fat (as % of empty BW) at a heavier BW compared with steers not fed zilpaterol. Calculated percentage empty body fat was 3.3% less for steers fed zilpaterol, resulting from decreased 12th-rib fat thickness and quality grade, and increased HCW and LM area. These data suggest that zilpaterol increases mature body size of steers compared with steers not fed zilpaterol at a common body composition (Owens et al., 1995; Guiroy et al., 2002) and is consistent with increased synthesis, decreased degradation, or both of muscle protein (Beermann, 2002) and increased lipolysis, decreased fatty acid synthesis and esterification, or both (Mersmann, 2002).

It is interesting to note that the increase in HCW was greater than the increase in final BW when zilpaterol was fed. In the present experiment, zilpaterol increased HCW 13 kg and final BW 7.4 kg compared with steers not fed zilpaterol. Albeit not as dramatic of a difference, Avendaño-Reyes et al. (2006) reported a 22- and 14-kg increase in HCW when zilpaterol and ractopamine were fed, respectively, whereas final BW were increased by 19.5 and 11 kg. This discrepancy suggests a shift in mass from noncarcass to carcass tissues when a βAA is fed. Several factors are potentially involved, including decreased gut fill due to reduced feed intake (present experiment), a greater repartitioning of fat and muscle in carcass than noncarcass tissues, or both. In normal mice, the growth-promoting effect of clenbuterol was almost exclusively confined to skeletal muscle growth, whereas the effect on heart, kidney, and spleen was minimal (3 to 6% over the controls), and liver (−8%) and epididymal fat pad (−60%) weights were decreased (Sharma et al., 1997). Similarly in pigs, salbutamol decreased liver and kidney weights, and decreased leaf fat by 17% compared with pigs not fed salbutamol (Hansen et al., 1994). Although speculative, decreases in mass of visceral organs, especially mesenteric and omental fat, may explain the greater response for HCW than final BW when zilpaterol is fed.

The literature regarding βAA effects on liver abscess rates is limited. The present study indicated that treatment of steers with zilpaterol resulted in a decrease in liver abscesses regardless of whether tylosin was fed in combination. However, the decrease in total liver abscess rate was not due to a decrease in heavily abscessed livers, but primarily to a decrease in livers scored A− [1 or 2 small (<2.5 cm) liver abscesses]. Although results are inconsistent across trials, Montgomery et al. (2008) reported that liver abscess rates were not affected when zilpaterol was fed. Although we cannot fully explain why zilpaterol seems to reduce liver abscess rates, the decrease may be associated with a decrease in feed intake that occurs with feeding zilpaterol and other βAA (Reeds and Mersmann, 1991; Bareille et al., 1997).

In conclusion, it appears from this experiment conducted in large pens under commercial conditions that monensin and tylosin can be withdrawn from the diet during the zilpaterol feeding period (last 30 d on feed) with minimal effect on animal performance. Feeding of the βAA zilpaterol hydrochloride for 30 d before harvest at 8.3 mg/kg (DM basis) increased ADG, G:F, and final BW in feedlot steers. Although feeding zilpaterol decreased marbling score when fed for 30 d, HCW, dressing percent, and LM area were markedly increased. In addition, 12th-rib fat and calculated yield grade were decreased (i.e., improved), suggesting that zilpaterol improved lean meat yield. Feeding zilpaterol in combination with monensin and tylosin seemed to moderate zilpaterol effects on both quality and yield grades.

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