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Effect of feedlot management system on response to ractopamine-HCl in yearling steers[1]

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ABSTRACT: Two experiments evaluated the effects of conventional and natural feedlot management systems (MS) on ractopamine-HCl (RAC) response in yearling steers. Feedlot performance, carcass characteristics, skeletal muscle gene expression, and circulating IGF-I concentrations were measured. The conventional system included a combined trenbolone acetate and estradiol implant, Revalor-S (IMP), as well as monensin-tylosin feed additives (IA). Treatments were arranged in a 2 × 2 factorial and included: 1) natural (NAT): no IMP-no IA, no RAC; 2) natural plus (NAT+): no IMP-no IA, RAC; 3) conventional (CON): IMP-IA, no RAC; and 4) conventional plus (CON+): IMP-IA, RAC. In Exp. 1, one hundred twenty crossbred steers (initial BW = 400 ± 26 kg) were allotted randomly to treatment in a randomized complete block design (BW was blocking criteria); pen was the experimental unit. In Exp. 2, twenty-four individually fed crossbred steers (initial BW = 452 ± 25 kg) were used in a randomized complete block design (BW was blocking criteria) and assigned to the same treatments as Exp. 1, with 6 steers/treatment. In Exp. 2, serum was harvested on d 0 and 31 and within the 28-d RAC feeding period, at d 0, 14, and 28. Longissimus biopsy samples were taken on d 0, 14, and 28 of the RAC feeding period for mRNA analysis of ß-adrenergic receptors and steady-state IGF-I mRNA. In Exp. 1, ADG, G:F, final BW, and HCW were greatest for CON+ ($P < 0.01$). During the final 37 d, RAC increased ADG ($P = 0.05$) and increased overall G:F ($P = 0.02$). Marbling score was reduced ($P = 0.02$), and yield grade was improved with RAC ($P = 0.02$), but RAC did not affect dressing percentage ($P = 0.96$) or HCW ($P = 0.31$). In Exp. 2, MS × RAC interactions were detected in ADG and G:F the last 28 d, overall ADG and overall G:F, final BW, and HCW ($P < 0.01$). Dressing percentage, yield grade, and marbling score were not altered by MS or RAC ($P > 0.10$). Circulating IGF-I concentration was increased on d 31 by the conventional MS, and concentration was greater throughout the study than NAT steers ($P < 0.01$). Circulating IGF-I concentrations were not changed by RAC ($P = 0.49$). Abundance of $ß_1$-AR mRNA tended to increase ($P = 0.09$) with RAC, but RAC did not affect $ß_2$-AR, $ß_3$-AR, or IGF-I mRNA ($P > 0.40$). Management system did not affect $ß_1$-AR, $ß_2$-AR, $ß_3$-AR, or IGF-I mRNA ($P > 0.18$), yet a trend ($P = 0.06$) for MS × RAC for $ß_2$-AR mRNA was detected. These results indicate that response to RAC is affected by feedlot management practices.

Key words: ß-adrenergic receptor, implant, insulin-like growth factor-I, management system, ractopamine-hydrochloride, steer

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INTRODUCTION

The efficiency of conventional beef production is greater today than ever before predominantly due to the usage of growth-promoting agents and feed-grade antibiotics (Stock et al., 1995; Fernández and Woodward, 1999). However, natural beef production systems, those that prohibit the use of ionophores, antibiotics, and implants, are a growing niche market in the United States cattle industry (Sawyer et al., 2003). The use of combined trenbolone acetate and estradiol-17ß (**TBA/E_2**) implants (**IMP**) increases ADG, G:F, and carcass protein deposition (Bartle et al., 1992; Johnson et al., 1996a). The addition of both monensin and tylosin to finishing cattle diets increased ADG 3% and gain efficiency 4% (Stock et al., 1995). Further, ß-adrenergic agonists (**β-AA**), such as ractopamine-HCl (**RAC**), are the most recently approved class of growth-promoting compounds for feedlot cattle, and studies have demonstrated that RAC administration increases ADG, G:F, and HCW with minimal changes in yield grade and

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Table 1. Composition of experimental diets for Exp. 1 and 2

Item	Treatment[1]			
	NAT	NAT+	CON	CON+
Ingredient	Percentage of DM			
Steam-flaked corn	59.89	59.89	59.89	59.89
Wet distillers grains, sorghum	30.00	30.00	30.00	30.00
Ground alfalfa hay	6.00	6.00	6.00	6.00
Vitamin-mineral premix[2]	1.88	1.88	1.88	1.88
Ground corn[3]	2.23	—	—	—
Feed additive premix[3]	—	2.23	2.23	2.23
Composition, analyzed				
DM, %	63.45	63.45	63.45	63.45
CP, %	16.44	16.44	16.64	16.64

[1]Treatments included: 1) natural (NAT): no implant-no monensin or tylosin, no ractopamine-HCl; 2) natural plus (NAT+): no implant-no monensin or tylosin, ractopamine-HCl; 3) conventional (CON): implant-monensin-tylosin, no ractopamine-HCl; 4) conventional plus (CON+): implant-monensin-tylosin, ractopamine-HCl. Implanted steers received a combined trenbolone acetate-estradiol-17β implant; steers that were administered ractopamine-HCl received 200 mg·steer^{-1}·d^{-1} of ractopamine-HCl for the final 28 to 37 d of the feeding period.

[2]Vitamin-trace mineral premix was formulated to provide (total diet DM): 0.30% salt, 5,295 IU/kg of vitamin A, 0.13 mg/kg of cobalt, 10 mg/kg of copper, 60 mg/kg of manganese, 0.25 mg/kg of selenium, 60 mg/kg of zinc, and 0.65 mg/kg of iodine.

[3]Added at the time of diet preparation to provide 300 mg of monensin and 90 mg of tylosin in ground corn carrier and mixed with basal diet for CON and CON+ steers only. During the final 28 d in Exp. 1 and final 37 d in Exp. 2, 200 mg·steer^{-1}·d^{-1} of ractopamine-HCl was hand-weighed and mixed together with feed additive mixture for CON+ steers. Steers in NAT+ steers were fed ground corn only until the final 28 d in Exp. 1 and final 37 d in Exp. 2 when ractopamine-HCl was hand-weighed and mixed with the ground corn to provide 200 mg·steer^{-1}·d^{-1} of ractopamine-HCl.

marbling score (Laudert et al., 2004; Winterholler et al., 2007).

To maximize production efficiency within a specific feedlot management system, it is crucial to understand the growth mechanisms of finishing cattle. Research is limited with RAC in finishing cattle programs, and there is still much to be discovered about the action and potential interaction of β-AA with other commonly administered growth-promoting agents. Therefore, the purpose of our study was to evaluate feedlot performance, carcass characteristics, circulating IGF-I concentration, and skeletal muscle gene expression in natural beef production systems compared with conventional production systems with or without RAC administration.

MATERIALS AND METHODS

Experiment 1

Procedures for this study were approved by the Kansas State University Institutional Animal Care and Use Committee.

Animals. English × Continental yearling steers (n = 120; 400 ± 26.0 kg of initial BW) were fed at the Beef Cattle Research Center, Manhattan, Kansas. Ultrasound measurements of initial backfat thickness and LM area were obtained using an Aloka 500-V real-time ultrasound machine (Corometrics Medical Systems, Wallingford, CT) equipped with a 17.2-cm, 3.5-MHz linear transducer. Steers were stratified by initial BW and initial ultrasound-measured backfat thickness and allotted randomly within strata to 12 pens such that initial pen BW was similar, with 10 steers per pen. Pen served as the experimental unit for statistical analysis.

This study was a randomized complete block design, and treatments were arranged as a 2 × 2 factorial, and factors included RAC (Elanco Animal Health, Greenfield, IN) administration level (0 or 200 mg·steer^{-1}·d^{-1}) for the final 37 d of the feeding period and a natural or conventional management system (**MS**). Steers assigned to conventional treatments were implanted with Revalor-S (Intervet Inc., Millsboro, DE; 120 mg of trenbolone acetate and 24 mg of estradiol-17β) in their right ear at trial initiation and fed a monensin-tylosin feed additive premix (**IA**) that provided 300 mg·steer^{-1}·d^{-1} of monensin (Rumensin, Elanco Animal Heath) and 90 mg·steer^{-1}·d^{-1} of tylosin (Tylan, Elanco Animal Health). Feed additives were delivered in a ground corn carrier and mixed into the total mixed ration; the equal amount of ground corn (without additives) was included in the total mixed ration of steers in the natural treatments. Treatments included: 1) natural (NAT): no IMP-no IA, no RAC; 2) natural plus (NAT+): no IMP-no IA, RAC; 3) conventional (CON): IMP-IA, no RAC; 4) conventional plus (CON+): IMP-IA, RAC. Throughout the finishing period, steers were fed a steam-flaked corn-based diet offered ad libitum. Diet composition (DM basis) is provided in Table 1.

Steers were weighed at d 0 and at approximately 28-d periods and 37 d before slaughter. At the completion of the study, cattle were weighed, and a 4% pencil shrink was applied to determine final BW. Cattle were

slaughtered across a 3-wk period, which corresponded to 116, 123, and 130 d on feed. At trial initiation, 1 pen from each treatment was assigned randomly to a slaughter date. Steers were transported 182 km to a commercial slaughter facility (Tyson Fresh Meats Inc., Emporia, KS). Carcass characteristics, including USDA yield and quality grades, were obtained 24 h after slaughter.

Statistical Analysis. Data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC). Data were arranged as a 2 × 2 factorial in a randomized complete block design, with pen serving as the experimental unit for feedlot and carcass characteristic analyses. In the model, management system, RAC, and MS × RAC were analyzed as fixed effects, and pen served as a random variable. Treatment means were computed using the LSMEANS option. When interactions were detected ($P < 0.05$, unless otherwise noted), least squares means were separated ($P < 0.05$) using the PDIFF option of SAS.

Experiment 2

Animals. Procedures for this study were approved by the Kansas State University Institutional Animal Care and Use Committee. Twenty-four English× Continental yearling steers with an average initial BW of 454 ± 25.3 kg were blocked by BW into 1 of 3 weight blocks: heavy, middle, and light. Within each weight block, steers were assigned randomly to 1 of 4 treatments, and each weight block contained 2 animals/treatment. Experimental design and treatments were identical to Exp. 1 with the exception that RAC was administered for the final 28 d. One steer from the NAT treatment was removed from the study due to poor performance. The ultrasound procedures and diet composition (provided in Table 1) were also the same as Exp. 1.

Jugular blood samples were collected on d 0 and 31 and within the 28-d RAC feeding period at d 0, 14, and 28. Sera were harvested for use in analyses of circulating IGF-I. Biopsies of the LM, between the ninth and last rib, were taken from all steers on d 0 (before feeding RAC), 14, and 28 (after RAC administration) for analysis of ß-adrenergic receptors and steady-state IGF-I mRNA. Procedures are described below. Across heavy, middle, and light weight blocks, d 0 biopsy samples corresponded with 46, 60, and 74 d postimplantation, respectively. The first and third biopsies were on the right side of the animal, but the third biopsy sample was taken on the left side of the animal, 5 cm cranial to the first. At the completion of the study, steers were weighed, and a 4% pencil shrink was applied to determine final BW. Carcass characteristics, including USDA yield and quality grades, were obtained 24 h after slaughter.

Analysis of Circulating IGF-I. Blood collection from each steer at each collection day was allowed to clot for 48 h at 4°C. After centrifugation (1,500 × *g* for 20 min), sera were harvested and stored at −20°C for subsequent analyses of circulating IGF-I. Sera were analyzed for IGF-I using a RIA, previously validated for use in bovine serum (Johnson et al., 1996b). Insulin-like growth factor binding protein interference was eliminated by glycyl-glycine extraction. All samples were run in a single assay and had an intraassay CV of 9%.

Longissimus Muscle Biopsy. Steers were restrained in a hydraulic squeeze chute, hair was removed from the biopsy site, and a local anesthetic (lidocaine HCl; 20 mg/mL; 8 mL per biopsy site) was administered. Biopsy site was cleaned with 70% ethanol and sterile surgical gauze. A 1-cm incision was made with a sterile scalpel. Tissue was collected (1.0 g) from the LM utilizing a sterile Bergstrom biopsy needle. The incision site was closed with veterinary tissue glue. A topical antibiotic spray was applied to the incision site and then covered with a spray-on aluminum bandage. All steers were monitored for swelling 24 and 48 h after biopsy.

Sample Preparation and RNA Isolation. Tissue collected from muscle biopsies were snap-frozen in liquid N immediately after the procedure, stored at −80°C, and total RNA was isolated from each muscle sample. Ribonucleic acid was isolated utilizing TRI Reagent (Sigma, St. Louis, MO). Briefly, 0.5 g of tissue was homogenized in liquid N. Once the liquid N evaporated, the tissue was homogenized with 3 mL of TRI Reagent to disrupt the cell membranes. The aqueous sample was transferred to 2 microcentrifuge tubes. Chloroform (0.2 mL) was added to the tubes with a 1-mL aliquot of homogenized LM sample. Samples were vortexed and then centrifuged at 12,000 × *g* for 15 min at room temperature. After the first extraction, 500 µL of isopropanol was added to each new tube. Samples were vortexed and then centrifuged a second time for 10 min at 12,000 × *g*. The resulting pellets were stored in 70% ethyl alcohol at −80°C until analysis.

The concentration of RNA was determined by absorbance at 260 nm. Electrophoresis of total RNA through a 1% agarose-formaldehyde gel followed by ethidium bromide staining to allow visualization of 28S and 18S rRNA was used to assess the integrity of RNA. Samples were then treated with DNase to remove any contaminating genomic DNA using a commercially available kit (DNA-free; Ambion, Austin, TX). Total RNA (1 µg) was then reverse-transcribed to produce the first-strand cDNA using TaqMan Reverse Transcription Reagents and MultiScribe Reverse Transcriptase (Applied Biosystems, Foster City, CA) following the protocol recommended by the manufacturer. Random hexamers were used as primers in cDNA synthesis.

Real-Time Quantitative PCR. Real-time quantitative PCR was used to measure the quantity of $ß_1$-, $ß_2$-, and $ß_3$-AR and steady-state IGF-I mRNA relative to the quantity of 18S rRNA in total RNA isolated from LM tissue steers. Measurement of the relative quantity of cDNA was carried out using TaqMan Universal PCR Master Mix (Applied Biosystems), 900 nM of the

Table 2. Sequence of bovine-specific PCR primers and TaqMan probes to be used for determination of expression of mRNA of IGF-I and β_1-, β_2-, and β_3-adrenergic receptors

Primer	Sequence (5′ to 3′)
IGF-I (accession #X15726)	
Forward	TGTGATTTCTTGAAGCAGGTGAA
Reverse	AGCACAGGGCCAGATAGAAGAG
TaqMan probe	6FAM-GCCCATCACATCCTCCTCGCA-TAMRA
β_1-adrenergic receptor (accession #AF188187)	
Forward	GTGGGACCGCTGGGAGTAT
Reverse	TGACACACAGGGTCTCAATGC
TaqMan probe	6FAM-CTCCTTCTTCTGCGAGCTCTGGACCTC-TAMRA
β_2-adrenergic receptor (accession #NM_174231)	
Forward	CAGCTCCAGAAGATCGACAAATC
Reverse	CTGCTCCACTTGACTGACGTTT
TaqMan probe	6FAM-AGGGCCGCTTCCATGCCC-TAMRA
β_3-adrenergic receptor (accession #X85961)	
Forward	AGGCAACCTGCTGGTAATCG
Reverse	GTCACGAACACGTTGGTCATG
TaqMan probe	6FAM-CCCGGACGCCGAGACTCCAG-TAMRA

appropriate forward and reverse primers, 200 nM of the appropriate TaqMan detection probe, and 1 µL of the cDNA mixture. Bovine primers and probes for β_1-, β_2-, and β_3-receptors and IGF-I are presented in Table 2. Commercially available eukaryotic 18S rRNA primers and probes were used as an endogenous control (Applied Biosystems; GenBank accession X03205). Assays were performed in an ABI Prism 7000 sequence detection system (Applied Biosystems) using thermal cycling parameters recommended by the manufacturer (50 cycles of 15 s at 95°C and 1 min at 60°C). Relative expressions of mRNA for β_1-, β_2-, and β_3-receptors and IGF-I were normalized to the 18S mRNA endogenous control and expressed in arbitrary units.

Statistical Analysis. Data were analyzed using the MIXED procedure of SAS. Data were arranged as a 2 × 2 factorial in a randomized complete block, with steer serving as the experimental unit for all feedlot, carcass characteristic, and gene expression analyses. In the model, MS, RAC, day of biopsy, and all possible interactions served as fixed effects. Individual steer was included as a random variable. Treatment means were computed using the LSMEANS option. When interactions were detected ($P < 0.05$, unless otherwise noted), least squares means were separated ($P < 0.05$) using the PDIFF option of SAS.

Data for circulating IGF-I concentration and skeletal muscle gene expression were analyzed as a 2 × 2 factorial in a randomized complete block design with 4 replicates and repeated measures over time. A split-plot analysis was employed to account for the repeated measures using the mixed model procedure of SAS with steer serving as the whole-plot experimental unit. In the model statement, biopsy day relative to RAC exposure, MS, RAC, and all possible interactions were included as fixed effects. Individual steer served as a random variable. When interactions were detected ($P < 0.05$, unless otherwise noted), least squares means were separated ($P < 0.05$) using the PDIFF option of SAS.

RESULTS AND DISCUSSION

Experiment 1

Performance. The conventional MS increased ADG and G:F before RAC administration, overall ADG, overall G:F, and final BW ($P < 0.01$; Table 3). This system tended ($P = 0.08$) to increase overall DMI (Table 3). Average daily gain was greater in CON+ steers versus NAT+ steers ($P < 0.01$) and greater in CON steers compared with NAT ($P < 0.05$). Feeding RAC increased ADG ($P = 0.05$) and G:F the last 37 d of the finishing period ($P = 0.03$). Gain efficiency was greater for both CON+ steers versus CON steers and for NAT+ steers compared with NAT ($P < 0.05$). Gain efficiency was greater for CON+ steers versus NAT+ steers ($P < 0.05$). There was no change in DMI in response to RAC over the entire feeding period ($P = 0.81$; Table 3). However, a MS × RAC interaction was detected ($P = 0.05$) for DMI the last 37 d such that intake was lower for NAT+ steers compared with CON and CON+ steers (Table 3).

The increase in production efficiency that we observed in the conventional system is consistent with published literature. When heifers were fed monensin and implanted with a testosterone-estradiol implant, no synergistic effect or interaction between monensin and implant was observed for measured traits (Utley et al., 1976). Furthermore, Utley et al. (1976) reported that ADG was increased by both feeding monensin and by administering a combination testosterone-estradiol implant, and the magnitude of this response was greatest for implanted heifers compared with heifers fed monensin. Likewise, Sawyer et al. (2003) reported no interaction in feedlot performance measurements

Table 3. Effect of management system on yearling steer feedlot performance and carcass characteristics in Exp. 1

	MS[1]							
	Conventional		Natural			*P*-value		
Item	No RAC[2]	RAC[2]	No RAC[2]	RAC[2]	SEM	MS	RAC	MS × RAC
Pens	3	3	3	3	—	—	—	—
Steers/pen, n	10	10	10	10	—	—	—	—
Performance								
Initial BW, kg	401	399	400	400	1.36	0.95	0.40	0.34
Final BW,[3] kg	562	574	536	539	0.68	<0.01	0.36	0.59
ADG before RAC, kg	1.65	1.74	1.40	1.34	0.05	<0.01	—	—
ADG last 37 d, kg	0.62	0.94	0.53	0.67	0.09	0.10	0.05	0.37
Overall ADG, kg	1.31	1.43	1.12	1.14	0.05	<0.01	0.21	0.38
Adjusted overall ADG,[4] kg	1.32	1.48	1.12	1.12	0.04	<0.01	0.88	0.07
DMI before RAC, kg	9.20	9.20	8.78	8.50	0.55	0.30	0.92	0.76
DMI last 37 d, kg	9.10	10.20	8.67	7.05	0.69	0.01	0.76	0.05
Overall DMI, kg	9.15	9.70	8.73	7.78	0.58	0.08	0.81	0.26
G:F before RAC	0.18	0.19	0.16	0.16	0.01	<0.01	—	—
G:F last 37 d	0.07	0.09	0.06	0.09	0.01	0.16	0.03	0.47
Overall G:F	0.14	0.15	0.13	0.14	0.01	<0.01	0.02	0.31
Adjusted overall G:F[4]	0.14	0.16	0.13	0.14	0.01	<0.01	<0.01	0.01
Adjusted final BW,[4] kg	563	579	537	537	7.72	<0.01	0.32	0.31
Carcass								
HCW, kg	358	368	341	341	5.00	<0.01	0.31	0.30
Dressing percentage	63.7	64.1	63.7	63.3	0.40	0.32	0.96	0.24
Initial ultrasound LM area cm^2	70.9	71.5	71.1	71.2	0.15	0.94	0.74	0.85
Final LM area, cm^2	85.29	93.16	84.77	86.58	2.52	0.20	0.09	0.27
Initial ultrasound 12th-rib fat, cm	0.51	0.43	0.43	0.41	0.13	0.24	0.24	0.42
Final 12th-rib fat, cm	1.07	0.91	0.84	0.86	0.05	0.02	0.16	0.13
KPH, %	2.06	2.02	2.05	1.98	0.10	0.80	0.59	0.91
USDA yield grade	2.4	2.0	2.1	2.0	0.08	0.22	0.02	0.06
Marbling score[5]	383	349	358	342	9.00	0.11	0.02	0.32

[1]MS = management system; conventional (300 mg of monensin, 90 mg of tylosin and Revalor-S implant) vs. natural (no monensin or tylosin).
[2]RAC = ractopamine-HCl: 200 mg/steer; 37 d.
[3]Final BW calculated as 96% of actual weight.
[4]Adjusted final BW was calculated as HCW/standard dress of 0.635.
[5]300 = slight[00]; 400 = small[00].

between implant and ionophore-antibiotic administration in steers implanted with Synovex-S (Fort Dodge Animal Health, Fort Dodge, IA) followed by Revalor-S (Intervet) and fed monensin-tylosin. Furthermore, Potter et al. (1985) evaluated the effect to monensin and tylosin on feedlot performance traits and found no interaction between the 2 additives but reported that monensin increased G:F by reducing DMI but did not affect ADG, whereas tylosin increased ADG by reducing the incidence of liver abscesses.

Though we cannot attribute the increases in production efficiency of the CON system to IMP alone, other research has demonstrated that both ADG and G:F were increased in steers administered a TBA/E_2 implant (Bartle et al., 1992; Johnson et al., 1996a). A portion of the enhanced feedlot performance in the CON system can be attributed to IMP.

Previous literature has demonstrated no interaction between IMP and IA, yet when considering the mechanism of action of IMP and RAC, it is obvious that there may be some potential interaction between the 2 growth-promoting agents. Studies with RAC fed at 200 $mg \cdot steer^{-1} \cdot d^{-1}$ for the final 28 d to terminally implanted steers have demonstrated that RAC increased ADG and G:F but had no effect on overall DMI (Gruber et al., 2007; Winterholler et al., 2007). In our study, there was no increase in overall ADG with RAC. However, when steers were implanted before RAC administration, ADG and G:F were greater than steers that were fed RAC only. Interestingly, we observed that DMI during the last 37 d was lower for NAT+ steers compared with CON and CON+ steers ($P = 0.05$). These results provide evidence that management practices implemented before RAC administration affect performance response to RAC inclusion.

Carcass Characteristics. The conventional MS increased HCW and 12th-rib fat thickness ($P < 0.05$). Dressing percentage, LM area, USDA yield grade, and marbling score were not affected by MS ($P > 0.10$; Table 3). Ractopamine improved yield grade and reduced marbling score ($P = 0.02$) and had a tendency to increase LM area ($P = 0.09$; Table 3). In our study,

Table 4. Effect of management system on individual yearling steer carcass characteristics in Exp. 2

	MS[1]							
	Conventional		Natural			*P*-value		
Item	No RAC[2]	RAC[2]	No RAC[2]	RAC[2]	SEM	MS	RAC	MS × RAC
Steers, n	8	8	7	8	—	—	—	—
Performance								
Initial BW,[3] kg	452	449	457	451	2.53	0.15	0.07	0.67
Final BW,[3] kg	590	632	584	547	13.05	<0.01	0.84	<0.01
ADG before RAC,[3] kg	1.63	2.03	1.4	1.37	0.15	<0.01	0.19	0.15
ADG last 28 d, kg	1.36	1.99	1.46	0.59	0.20	<0.01	0.51	<0.01
Overall ADG, kg	1.54	2.02	1.42	1.07	0.14	<0.01	0.61	<0.01
Adjusted overall ADG,[4] kg	1.56	1.94	1.32	0.91	0.14	<0.01	0.88	<0.01
DMI before RAC,[3] kg	9.49	9.66	9.05	9.34	0.69	0.55	0.72	0.93
DMI last 28 d, kg	8.94	10.24	8.58	7.13	0.78	0.03	0.92	0.08
Overall DMI, kg	9.26	9.8	8.85	8.55	0.69	0.21	0.86	0.51
G:F before RAC[3]	0.17	0.21	0.16	0.15	0.01	<0.01	0.16	0.04
G:F last 28 d	0.15	0.20	0.17	0.09	0.02	0.01	0.29	<0.01
Overall G:F	0.17	0.21	0.16	0.12	0.01	<0.01	0.92	<0.01
Adjusted overall G:F[4]	0.17	0.20	0.15	0.11	0.02	<0.01	0.60	0.02
Adjusted final BW,[4] kg	589	622	575	533	13.52	<0.01	0.74	0.01
Carcass								
HCW, kg	374	395	365	339	8.69	<0.01	0.74	0.01
Dressing percentage	63.4	62.5	62.5	61.8	0.88	0.31	0.35	0.94
Initial ultrasound LM area, cm^2	78.60	77.10	77.72	74.30	3.32	0.55	0.43	0.76
Final LM area, cm^2	97.94	103.10	99.87	83.03	7.29	0.19	0.39	0.12
Initial ultrasound 12th-rib fat, cm	0.62	0.65	0.70	0.79	0.11	0.29	0.56	0.73
Final 12th-rib fat, cm	1.07	1.13	1.02	1.24	0.21	0.89	0.46	0.69
KPH, %	2.25	2.00	2.08	2.08	0.23	0.84	0.56	0.56
USDA yield grade	2.3	2.3	2.1	2.9	0.52	0.65	0.43	0.43
Marbling score[5]	362	410	395	458	31.8	0.18	0.08	0.80

[1]MS = management system; conventional (300 mg of monensin, 90 mg of tylosin and Revalor-S implant) vs. natural (no monensin or tylosin).
[2]RAC = ractopamine-HCl: 200 mg/steer; 28 d.
[3]Initial and final BW calculated as 96% of actual weight.
[4]Adjusted final BW was calculated as HCW/standard dress of 0.635.
[5]300 = slight[00]; 400 = small[00].

we observed differences in carcass traits in the CON system compared with the NAT system. Moreover, previous research shows that monensin and tylosin have no major effect on carcass characteristics (Utley et al., 1976; Sawyer et al., 2003), and results from our carcass data agree with findings of others who investigated the effects of implant administration on carcass traits. Bruns et al. (2005) observed a similar increase in HCW with TBA/E_2 implant, but different from our results, noted that dressing percentage was increased by implant. Our data agree with Eversole et al. (1989), who observed no change in dressing percentage in steers implanted once. Hunt et al. (1991) reported that TBA/E_2 implant increased carcass fatness, which agrees with our data, because implant increased 12th-rib fat thickness. Conversely, Eversole et al. (1989), Bartle et al. (1992), and Johnson et al. (1996a) reported no change in 12th-rib fat thickness with TBA/E_2 implant.

In yearling steers administered RAC at 200 $mg \cdot steer^{-1} \cdot d^{-1}$ the final 28 d, Gruber et al. (2007) and Winterholler et al. (2007) reported an 8- and 5.5-kg increase in HCW with RAC, respectively, compared with control. The trend ($P = 0.09$) that we observed for larger ribeye area agrees with Winterholler et al. (2007). Our results indicated that RAC reduced marbling score ($P = 0.02$) and improved yield grade ($P = 0.02$); Gruber et al. (2007) reported a tendency ($P = 0.07$) for RAC to lower marbling score. However, others have reported no effect on quality grade or yield grade with RAC feeding (Laudert et al., 2004; Winterholler et al., 2007). Once again, based on these findings, response in carcass characteristics to RAC administration may be altered by the timing of certain management practices in relation to the timing of RAC administration.

Experiment 2

Performance. Management system × RAC interactions were detected in G:F before RAC ($P = 0.04$), ADG during the final 28 d ($P < 0.01$), G:F during the final 28 d ($P < 0.01$), overall ADG ($P < 0.01$), and overall G:F ($P < 0.01$; Table 4). Compared with NAT, CON+ had a greater total gain ($P < 0.01$) and greater G:F before RAC administration ($P < 0.01$). During the last 28 d, compared with NAT, CON+ steers had a greater ADG ($P = 0.05$), and NAT+ steers had a lower ADG than NAT steers ($P < 0.01$). Likewise, throughout the final 28 d of the feeding period, CON+ steers had a greater

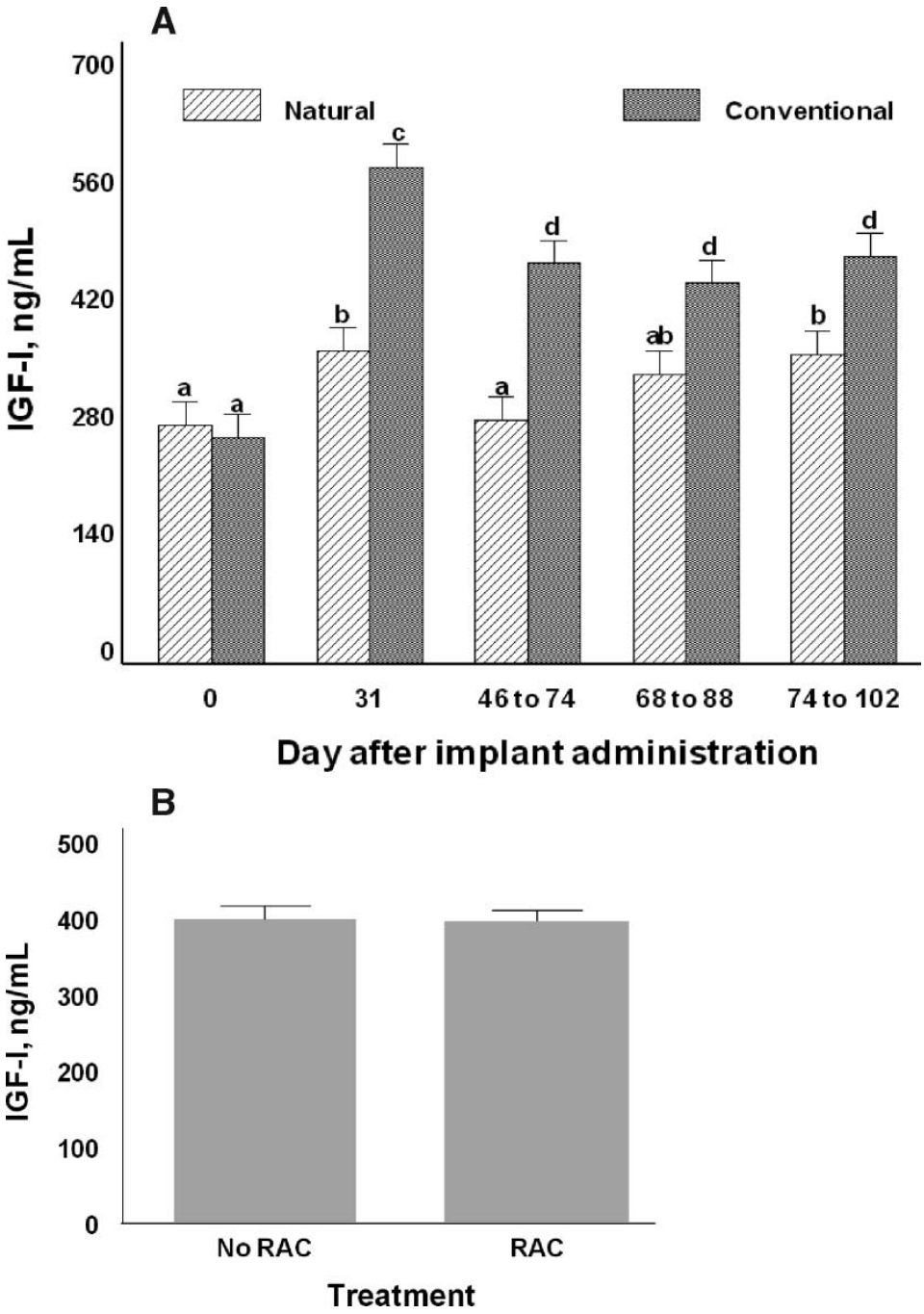

Figure 1. Panel A illustrates the effect of feedlot management system on the concentration of IGF-I in sera obtained in Exp. 2. Treatments included: 1) natural (NAT): no implant-no monensin or tylosin, no ractopamine-HCl; 2) natural plus (NAT+): no implant-no monensin or tylosin, ractopamine-HCl; 3) conventional (CON): implant-monensin and tylosin, no ractopamine-HCl; 4) conventional plus (CON+): implant-monensin and tylosin, ractopamine-HCl. Implanted steers received a combined trenbolone acetate-estradiol-17β implant; steers that were administered ractopamine-HCl received 200 mg·steer^{-1}·d^{-1} of ractopamine-HCl for the final 28 d of the feeding period. For the purpose of this analysis, data from CON and CON+ (n = 12) were analyzed as the conventional management system, and data from NAT and NAT+ (n = 11) steers were analyzed as the natural management system. Blood was collected on trial d 0 and 31 and ractopamine-HCl (RAC) administration d 0, 14, and 28. Steers were divided into 3 weight blocks, and as a result, there were 3 different RAC feeding periods relative to time on implant. A management system × time on implant interaction was detected ($P < 0.01$). There was no management system × ractopamine-HCl interaction ($P = 0.38$). $^{a–c}$Means not bearing a common letter differ ($P < 0.05$). Bars represent SE within treatments. Panel B illustrates IGF-I concentrations in sera obtained from steers administered ractopamine-HCl (RAC; n = 12) or not administered RAC (n = 11) in Exp. 2. Blood was collected on d 0, 14, and 28 of RAC feeding. Ractopamine-HCl had no effect on circulating IGF-I concentration ($P > 0.10$). Bars represent SE within treatments.

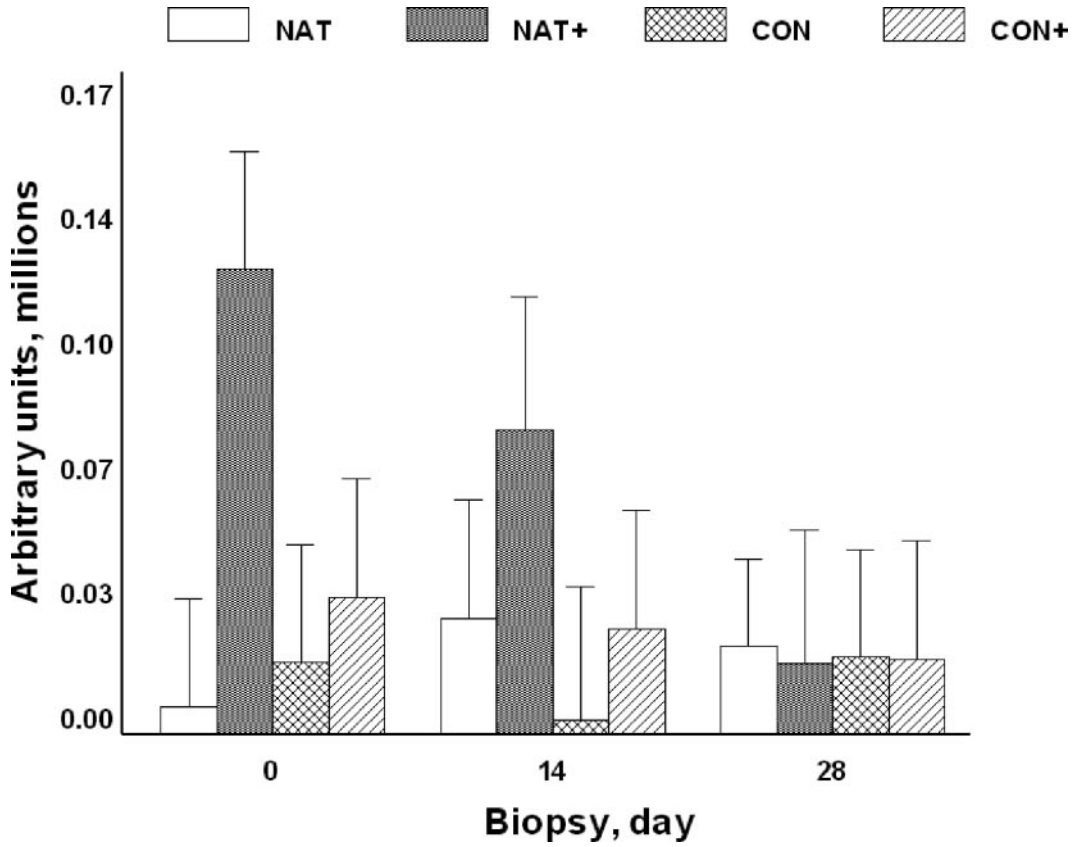

Figure 2. β_1-Adrenergic receptor mRNA concentrations in bovine LM tissue in yearling steers collected at 3 different biopsy days in Exp. 2. Treatments included: 1) natural (NAT): no implant-no monensin or tylosin, no ractopamine-HCl; 2) natural plus (NAT+): no implant-no monensin or tylosin, ractopamine-HCl; 3) conventional (CON): implant-monensin and tylosin, no ractopamine-HCl; 4) conventional plus (CON+): implant-monensin and tylosin, ractopamine-HCl. Implanted steers received a combined trenbolone acetate-estradiol-17β implant; steers that were administered ractopamine-HCl received 200 mg·steer^{-1}·d^{-1} of ractopamine-HCl for the final 28 d of the feeding period. Biopsies were taken from 4 steers in each of 3 treatment groups (NAT+, CON, and CON+) and 3 steers in NAT. Biopsy samples were obtained on d 0, 14, and 28 of ractopamine-HCl administration. Total RNA was isolated from skeletal muscle tissue, and relative β_1-adrenergic receptor gene expression was determined using real-time quantitative-PCR. A tendency for ractopamine-HCl to increase concentration of β_1-adrenergic receptor mRNA was observed ($P = 0.09$). Bars represent SE within treatments.

G:F compared with NAT ($P < 0.05$), and NAT+ steers had a lower G:F than NAT steers ($P < 0.05$). Steers in the NAT treatment group had lower overall ADG than CON+ steers ($P < 0.01$); conversely, NAT steers tended to have greater overall ADG than NAT+ steers ($P = 0.07$). Finally, steers in the NAT treatment group had lower overall G:F than CON+ ($P < 0.01$) and greater G:F than NAT+ steers ($P < 0.01$; Table 4).

Data from this experiment provide some evidence that the duration of MS before RAC administration may affect response to RAC. However, we cannot conclude this from our data, because MS duration before RAC feeding was confounded with initial BW in our study design. Postnatal skeletal muscle growth is accomplished via muscle fiber hypertrophy. Satellite cells are the source of DNA in a muscle cell and allow for sustained hypertrophy of the existing fiber (Allen et al., 1979). Implanting results in continued muscle fiber hypertrophy by stimulating proliferation of skeletal muscle satellite cells (Johnson et al., 1998). However, research with cull cows that were either administered a TBA/E_2 implant or not implanted and fed RAC or not fed RAC reported that none of the treatments changed satellite cell number (Gonzalez et al., 2007). Also, in lambs fed the β-AA, cimaterol, O'Connor et al. (1991) noted that although there was an increase in skeletal muscle mass, the DNA content of skeletal muscle fiber was not changed and overall was decreased with β-AA administration. This suggests that the increases in muscle mass that are characteristic of β-AA administration are due to changes in protein synthesis and protein degradation rather than alterations in the protein:DNA ratio of the muscle cell that would arise from satellite cell proliferation and incorporation to existing muscle fiber.

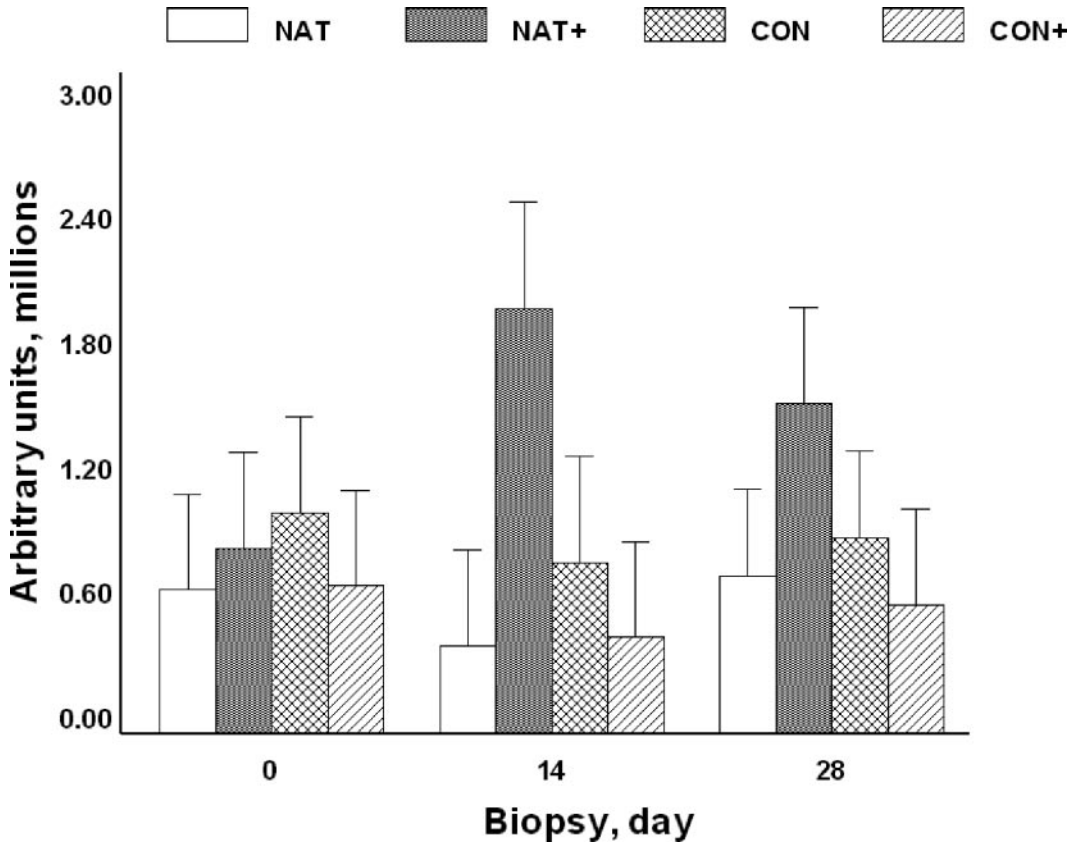

Figure 3. β_2-Adrenergic receptor mRNA concentrations in bovine LM tissue in yearling steers collected at 3 different biopsy days in Exp. 2. Treatments included: 1) natural (NAT): no implant-no monensin or tylosin, no ractopamine-HCl; 2) natural plus (NAT+): no implant-no monensin or tylosin, ractopamine-HCl; 3) conventional (CON): implant-monensin and tylosin, no ractopamine-HCl; 4) conventional plus (CON+): implant-monensin and tylosin, ractopamine-HCl. Implanted steers received a combined trenbolone acetate-estradiol-17β implant; steers that were administered ractopamine-HCl received 200 mg·steer^{-1}·d^{-1} of ractopamine-HCl for the final 28 d of the feeding period. Biopsies were taken from 4 steers in each of 3 treatment groups (NAT+, CON, and CON+) and 3 steers in NAT. Biopsy samples were obtained on d 0, 14, and 28 of ractopamine-HCl administration. Total RNA was isolated from skeletal muscle tissue, and relative β_2-adrenergic receptor gene expression was determined using real-time quantitative PCR. A tendency for a ractopamine-HCl × management system interaction was observed ($P = 0.06$). Bars represent SE within treatments.

The MS × RAC interaction that we detected in our study indicated that MS and RAC act in a synergistic manner to modulate yearling steer growth and may have been observed due to the relatively short time in a specific MS before RAC feeding. Ractopamine response may be augmented by the ability of implants to increase proliferation rate of satellite cells and sustain muscle fiber hypertrophy. Among the 3 weight blocks, steers were implanted 46, 60, and 74 d, respectively, before RAC administration. Steers in the NAT treatment group tended ($P = 0.07$) to have greater ADG than NAT+ steers and had greater ($P < 0.01$) G:F than NAT+. Steers in the CON+ treatment group had the greatest overall ADG and G:F of all treatments ($P < 0.01$). This study suggests that performance response to RAC is increased if yearling steers are implanted and fed monensin and tylosin before RAC administration. This observation may be due largely to the satellite cell-assisted muscle fiber hypertrophy that is enhanced with implanting. However, further research should be conducted to investigate this concept in feedlot cattle.

The conventional MS increased ADG and G:F before RAC administration ($P < 0.01$; Table 4). Conventional MS also increased ADG and G:F over the entire feeding period ($P < 0.01$) but had no effect on DMI ($P = 0.21$; Table 4). Feeding RAC the last 28 d of the feeding period had no effect on feedlot performance characteristics ($P > 0.25$) and had no effect on feedlot performance traits overall ($P > 0.60$; Table 4).

Lack of feedlot performance response to RAC administration in yearling steers does not agree with previously published work. Laudert et al. (2004) indicated that ADG and G:F were increased by feeding RAC the final 28 d of the feeding period, and in this study of Laudert et al. (2004), it is interesting to note that steers in this study were all implanted with a terminal implant. Perhaps one of the reasons we did not observe

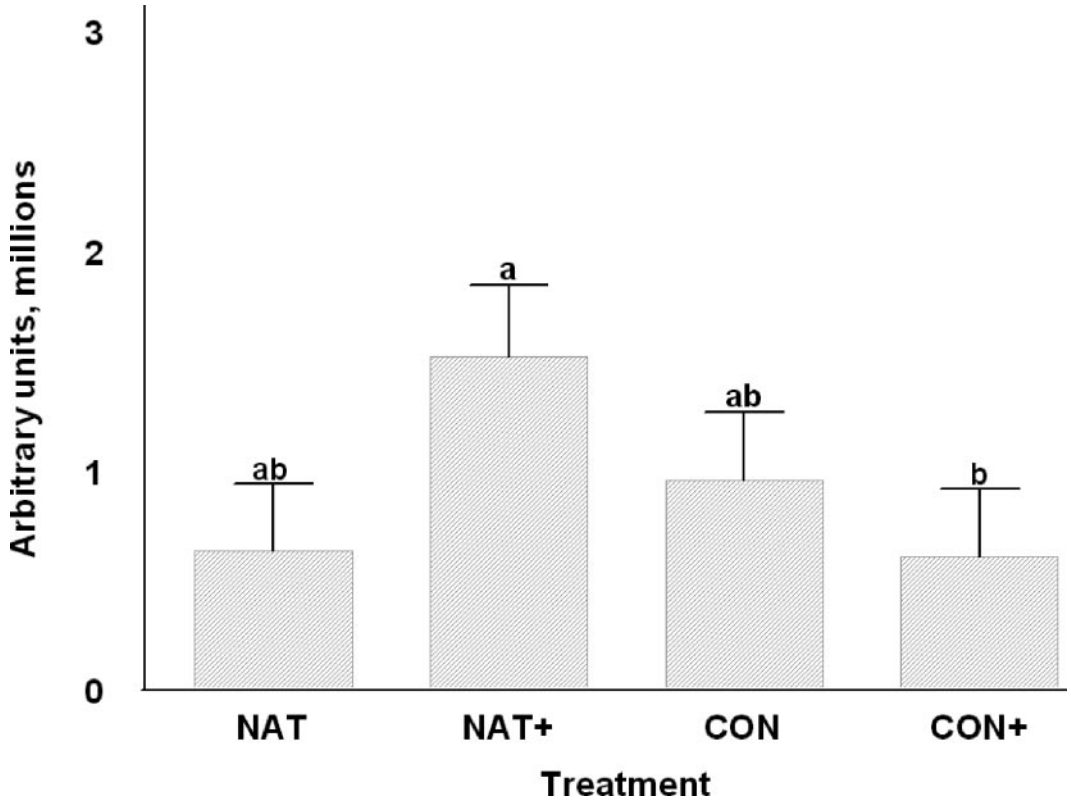

Figure 4. Management system × ractopamine interactive means for ß$_2$-adrenergic receptor mRNA abundance in bovine LM tissue in yearling steers collected at 3 different biopsy days in Exp. 2. Means represented in this figure are pooled across all 3 biopsy days. Treatments included: 1) natural (NAT): no implant-no monensin or tylosin, no ractopamine-HCl; 2) natural plus (NAT+): no implant-no monensin or tylosin, ractopamine-HCl; 3) conventional (CON): implant-monensin and tylosin, no ractopamine-HCl; 4) conventional plus (CON+): implant-monensin and tylosin, ractopamine-HCl. Implanted steers received a combined trenbolone acetate-estradiol-17ß implant; steers that were administered ractopamine-HCl received 200 mg·steer^{-1}·d^{-1} of ractopamine-HCl for the final 28 d of the feeding period. Biopsies were taken from 4 steers in each of 3 treatment groups (NAT+, CON, and CON+) and 3 steers in NAT. Biopsy samples were obtained on d 0, 14, and 28 of ractopamine-HCl administration. Total RNA was isolated from skeletal muscle tissue, and relative ß$_2$-adrenergic receptor gene expression was determined using real-time quantitative PCR. A tendency for a ractopamine-HCl × implant interaction was observed ($P = 0.06$). [a,b]Means not bearing a common letter differ ($P = 0.06$). Bars represent SE within treatments.

a strong response to RAC was due to the low number of animals/treatment.

Performance responses were similar in Exp. 1 and Exp. 2, and both suggest that management practices before RAC feeding increase performance responses. Previous research with alternative ß-AA provides some potential support to our findings. In Hereford steers that were not implanted but were administered clenbuterol across a wide interval, at either 10 mg·steer^{-1}·d^{-1} or 50 mg·steer^{-1}·d^{-1} for different time periods, researchers did not document an increase in ADG or G:F in steers that received the low (10 mg·steer^{-1}·d^{-1}) dose across all treatment durations (Ricks et al., 1984). Furthermore, in the same study with clenbuterol administration, researchers noted no change in G:F in the steers that were administered 50 mg·steer^{-1}·d^{-1} of clenbuterol for the longest treatment length. However, Schiavetta et al. (1990) documented that administration of 7 mg·steer^{-1}·d^{-1} of clenbuterol for 50 d increased both ADG and G:F in young steers that were not implanted.

Carcass Characteristics. A MS × RAC interaction ($P < 0.05$) was detected for HCW; compared with NAT, CON+ cattle had heavier carcasses ($P < 0.05$) and NAT+ steers had lighter carcasses ($P < 0.05$). Management system increased HCW ($P < 0.01$), and RAC had no effect on the measured carcass traits ($P > 0.05$; Table 4).

In previous research, RAC has had positive effects on carcass characteristics. Laudert et al. (2004) noted that steers that were administered RAC 28 d at 200 mg·steer^{-1}·d^{-1} had a 5.6-kg increase in HCW as well as an increase in dressing percentage and LM area with no changes in 12th-rib fat thickness, percentage of KPH, USDA yield grade, or marbling score. More dramatic results have been documented in steers administered clenbuterol. According to Ricks et al. (1984), clenbuterol increased LM area 11 to 16%, reduced LM fat depth 26 to 42%, and lowered percentage of KPH. Yet, the MS

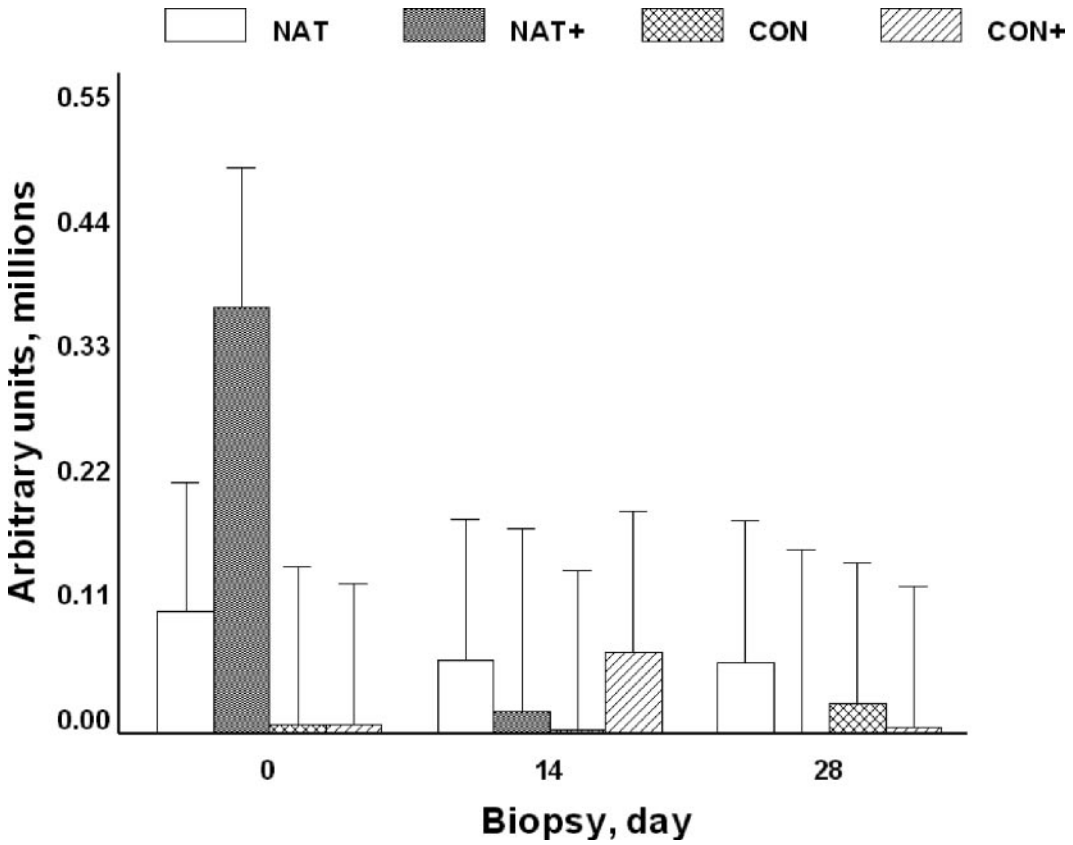

Figure 5. ß$_3$-Adrenergic receptor mRNA concentrations in bovine LM tissue in yearling steers collected at 3 different biopsy days in Exp. 2 Treatments included: 1) natural (NAT): no implant-no monensin or tylosin, no ractopamine-HCl; 2) natural plus (NAT+): no implant-no monensin or tylosin, ractopamine-HCl; 3) conventional (CON): implant-monensin and tylosin, no ractopamine-HCl; 4) conventional plus (CON+): implant-monensin and tylosin, ractopamine-HCl. Implanted steers received a combined trenbolone acetate-estradiol-17ß implant; steers that were administered ractopamine-HCl received 200 mg·steer^{-1}·d^{-1} for the final 28 d of the feeding period. Biopsies were taken from 4 steers in each of 3 treatment groups (NAT+, CON, and CON+) and 3 steers in NAT. Biopsy samples were obtained on d 0, 14, and 28 of ractopamine-HCl administration. Total RNA was isolated from skeletal muscle tissue, and relative ß$_3$-adrenergic receptor gene expression was determined using real-time quantitative-PCR. No differences in mRNA abundance were detected across treatment groups ($P > 0.30$). Bars represent SE within treatments.

× RAC interaction that we detected suggests that MS could possibly affect RAC response.

Circulating IGF-I Concentrations. The CON MS increased circulating IGF-I concentration on d 31 ($P < 0.01$), and circulating IGF-I concentrations remained greater for CON steers compared with NAT steers throughout the duration of the experiment ($P < 0.01$; Figure 1). Similar increases in circulating IGF-I concentration in steers receiving a combined TBA/E$_2$ implant have been documented by Frey et al. (1995), Johnson et al. (1996a), and Dunn et al. (2003).

Ractopamine-HCl had no effect on circulating IGF-I concentrations throughout the final 28 d on feed ($P = 0.75$; Figure 1). Similarly, Dawson et al. (1993) reported no differences in IGF-I ($P < 0.05$) values in steers fed cimaterol. In research conducted in sheep, O'Connor et al. (1991) noted that cimaterol administration in lambs had no effect on IGF-I concentration, and Young et al. (1995) reported no changes in plasma IGF-I concentration in sheep fed clenbuterol. Conversely, some studies have demonstrated reductions in circulating IGF-I concentration with ß-AA administration. Chikhou et al. (1991) indicated that cimaterol reduced IGF-I levels in cattle, and Beermann et al. (1987) observed reductions in IGF-I in lambs fed cimaterol. Although our data suggest that circulating IGF-I concentrations are not affected by RAC, it does not take into account the effects of IGFBP. Though we did not investigate IGFBP levels, RAC may be affecting IGFBP in such a manner that some quantity of IGF-I cannot be expressed.

Longissimus Muscle β_1-, β_2-, and β_3-AR and IGF-I mRNA Concentrations. Management system did not affect the abundance of ß$_1$-AR mRNA ($P = 0.18$), and there was no change in ß$_1$-AR mRNA concentration across biopsy day ($P = 0.49$). However, RAC administration tended to increase the concentration of ß$_1$-AR mRNA ($P = 0.09$; Figure 2). This value is affected largely by the exceptionally high abundance of ß$_1$-AR

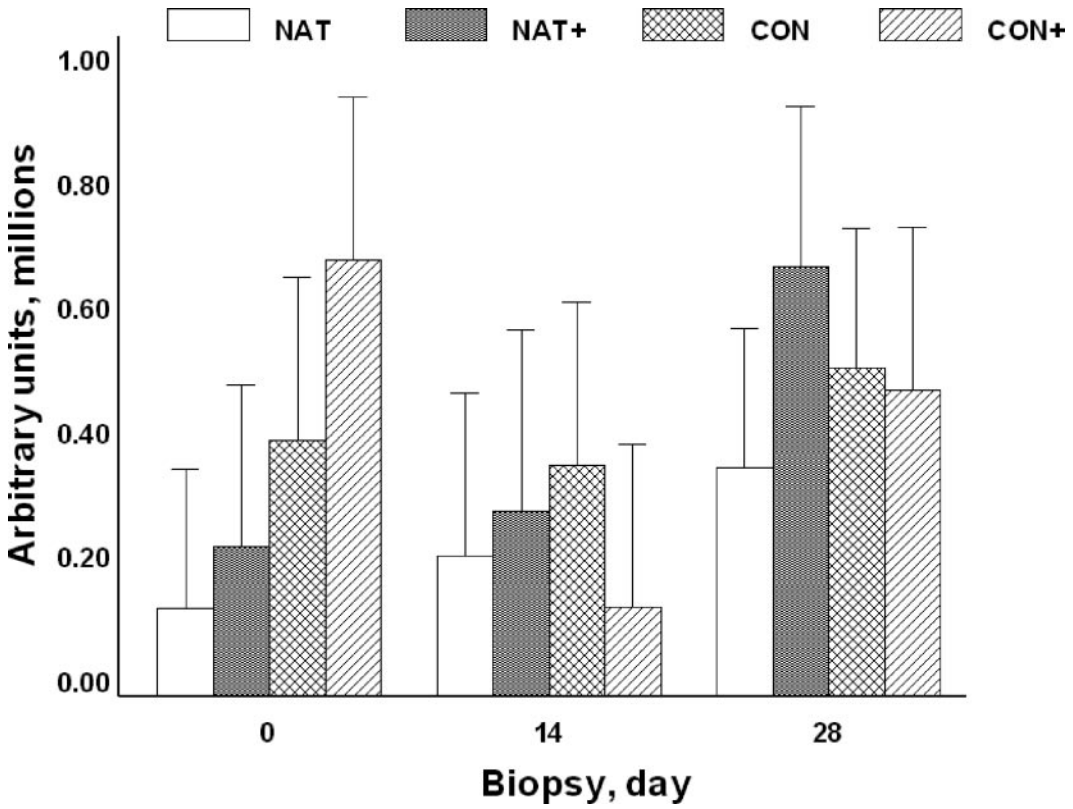

Figure 6. Steady-state IGF-I mRNA concentrations in bovine LM tissue in yearling steers collected at 3 different biopsy days in Exp. 2. Treatments included: 1) natural (NAT): no implant-no monensin or tylosin, no ractopamine-HCl; 2) natural plus (NAT+): no implant-no monensin or tylosin, ractopamine-HCl; 3) conventional (CON): implant-monensin and tylosin, no ractopamine-HCl; 4) conventional plus (CON+): implant-monensin and tylosin, ractopamine-HCl. Implanted steers received a combined trenbolone acetate-estradiol-17ß implant; steers that were administered ractopamine-HCl received 200 mg·steer^{-1}·d^{-1} of ractopamine-HCl for the final 28 d of the feeding period. Biopsies were taken from 4 steers in each of 3 treatment groups (NAT+, CON, and CON+) and 3 steers in NAT. Biopsy samples were obtained on d 0, 14, and 28 of ractopamine-HCl administration. Total RNA was isolated from skeletal muscle tissue, and relative IGF-I gene expression was determined using real-time quantitative-PCR. No differences were detected in mRNA concentration across the treatment groups ($P > 0.40$). Bars represent SE within treatments.

mRNA that was reported in the NAT+ group before RAC administration (Figure 2). Moody et al. (2000) noted that RAC binds primarily to the $ß_1$-AR, and, accordingly, one would expect a decrease in the abundance of the receptor. To further support this fact, Kim et al. (1992) noted that the density of ß-adrenergic receptors in rats declined with cimaterol administration.

No differences were found in the abundance of $ß_2$-AR mRNA across all 3 biopsy days ($P = 0.90$). Yet there was a tendency for a MS × RAC interaction in $ß_2$-AR mRNA ($P = 0.06$; Figure 3). At d 14 of RAC administration, steers that were not implanted but fed RAC tended to have a greater ($P = 0.07$) abundance of $ß_2$-AR mRNA than at d 0; however, by d 28, there was no difference ($P = 0.24$) in the abundance of $ß_2$-AR mRNA compared with d 0. From d 14 to 28 of RAC administration, the abundance of $ß_2$-AR mRNA decreased ($P < 0.04$). Different from steers in the NAT+ group, the abundance of $ß_2$-AR mRNA in steers in the CON+ group was relatively unchanged over the RAC feeding period. Further, when comparing the MS × RAC interactive means, there was a tendency for the abundance of $ß_2$-AR mRNA to be greater in NAT+ steers compared with CON+ steers ($P = 0.06$; Figure 4). These data suggest that MS may have an effect on the expression of the $ß_2$-AR.

Moreover, previous work with implants and RAC has indicated that abundance of $ß_2$-AR mRNA differs with implant strategy. In the study of Winterholler et al. (2007), $ß_2$-AR mRNA abundance tended to increase with RAC feeding in yearling steers that were implanted and administered RAC. In this study, steers were implanted for a longer duration before RAC administration than steers in the present study. Likewise, in a study that analyzed the effect of implant combination on response to RAC administration, $ß_2$-AR mRNA abundance tended to increase with RAC feeding (Sissom et al., 2007). Once again, heifers in their experiment were implanted for a greater time before RAC feeding relative to steers in the present study. Howev-

er, Walker et al., (2007) indicated that RAC decreased the abundance of β_2-AR mRNA in Holstein steers that were implanted for only 28 d before RAC administration. Evidence from these findings as well as the data in the present study indicate that CON could potentially hinder the expression of the β_2-AR.

It is difficult to speculate the effect that both implant and RAC have on the expression of β-receptors. However, there is some crossover in the mechanisms of action of steroidal implants and β-AA (Sissom et al., 2006). Steroidal implants have both a genomic and nongenomic component. The mode of action of the nongenomic component is not clearly understood; however, some evidence suggests that the nongenomic component of steroidal implants may function via the second messenger system, much like β-AA (Falkenstein et al., 2000). Interaction of the 2 systems may not only affect the response of the 2 growth-promoting agents when used in tandem but could potentially have some effect on the β-receptor population.

There were no differences ($P > 0.10$) in the abundance of β_3-AR (Figure 5) or IGF-I mRNA abundance across the 4 treatments (Figure 6). Pampusch et al. (2003) observed increases in IGF-I mRNA abundance in steers implanted with trenbolone acetate-estradiol-17β as day after implanting increased from 0 to 26. In our study, across the 3 BW blocks, the initial biopsy was taken at d 46, 60, and 74, respectively, after implantation, and there were only 6 animals that were biopsied at this time point that were implanted. One reason that we did not observe a change in IGF-I mRNA abundance as previously documented by Pampusch et al. (2003) from implanting could be due to steroid depletion. However, at the initial biopsy day, IGF-I mRNA abundance for implanted steers was increased ($P < 0.05$) compared with nonimplanted steers, consistent with previous published literature in this area (Figure 6).

In conclusion, the results from these 2 experiments and other studies indicate that conventional beef management systems work effectively to enhance feedlot performance and some carcass traits. Natural beef production systems result in reduced growth rates, poorer G:F, and produce lighter weight carcasses. Although no significant findings were reported in the gene expression data that we obtained in this study, results indicate that further research should be conducted to increase our understanding of how these growth-promoting agents are able to elicit biological responses and the potential mechanism of action of each class of growth promotant to achieve optimal performance when utilizing different growth promoting agents.

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