Effect of castration method and analgesia on inflammation, behavior, growth performance, and carcass traits in feedlot cattle

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ABSTRACT: Our objective was to determine the effect of castration timing, method, and use of the analgesic meloxicam (MEL) on inflammation, behavior, performance, and carcass traits in feedlot cattle. This study was a randomized complete block design conducted over a 3-yr period. In total, 194 crossbred beef calves from a single ranch origin were randomized at birth to receive one of five treatments arranged as a 2 × 2 + 1 factorial: 1) bulls castrated within 48 h of birth (CON), 2) bulls surgically castrated on day 0 without MEL (SUR), 3) bulls surgically castrated on day 0 with MEL (SUR + MEL), 4) bulls band castrated on d 0 without MEL (BAN), and 5) bulls band castrated on day 0 with MEL (BAN + MEL). Upon feedlot arrival (day -11; average 287 ± 2.03 d of age), animals were blocked by initial BW (224 ± 4.5 kg) and assigned randomly to treatment pens in three consecutive years (*n* = 2 pens per treatment in each year). Oral MEL was administered at 1 mg/kg BW concurrent with applicable castration treatment on day 0. Data were analyzed using the MIXED and GLIMMIX procedures of SAS with pen (year) serving as experimental unit. From days 0 to 7, ADG was reduced (*P* = 0.01) for surgical (-0.42) compared to band (0.43 kg/d)

castration. Conversely, ADG was increased for surgical (1.74) vs. band (1.46 kg/d) castration from days 14 to 32. There was also an overall (day 0 to final) improvement in ADG for MEL (*P* = 0.02), but no effect of castration method was observed (*P* = 0.81). The CON group had the greatest (*P* = 0.05) marbling score. Backfat thickness was increased (*P* = 0.01) for MEL. A treatment × day interaction (*P* = 0.04) existed for serum haptoglobin, with SUR having the greatest (*P* < 0.01) concentration on days 1 and 4. Meloxicam administered in the surgically castrated treatment reduced (*P* = 0.01) serum haptoglobin concentration on day 1. Relative to baseline, standing duration for surgical castration was increased 113 min (*P* < 0.01), while banding caused 6.7 more lying bouts (*P* < 0.01) immediately following castration on day 0. Step count was greatest for BAN, intermediate for CON, and least for surgical (*P* < 0.01). Results suggest that MEL mitigated the more pronounced inflammation observed for surgical castration, whereas behavior was differentially altered for castration method indicative of a divergent pain response. Castration, regardless of method, transiently reduced ADG, but MEL administration improved overall ADG for both methods.

Key words: analgesia, beef cattle, behavior, castration, performance

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INTRODUCTION

Castration of beef cattle is a routine management practice within the United States (APHIS, 2011). Benefits of castration include elimination

of undesired breeding, reduction in aggressive behavior, and improved meat quality. Steers have more desirable meat quality due to improved quality grade and tenderness compared to intact males (Field, 1971; Klosterman et al., 1954; Seideman et al., 1982). Carcass composition differences are primarily influenced by testosterone that alters physiological growth; steers enter the fattening phase earlier with reduced muscle growth, whereas bulls have a greater impetus for muscle growth before fat deposition (Berg and Butterfield, 1968).

Of cow-calf producers that castrated their calves, 49.2% used surgical castration and 47.3% used band castration (USDA, 2009). The preferred castration method of bulls upon feedlot entry revealed a similar dichotomous trend with 52.3% surgically castrated, 41.1% band castrated, and 6.6% not castrated (APHIS, 2011). Castration methods produce different behavioral and physiological responses. Surgical castration has been observed to cause a more pronounced change in behavior and greater inflammatory response compared to banded cohorts (Fisher et al., 2001). Previous studies have shown that oral meloxicam (MEL) administration at the time of castration reduces the incidence of bovine respiratory disease (BRD) and improves ADG during the feedlot receiving period (Coetzee et al., 2012; Filho et al., 2014). However, the long-term impact of MEL on performance and carcass traits in feedlot cattle has not been well described. We hypothesized that delaying castration until feedlot entry would alter inflammation, behavior, growth performance, and carcass traits compared to calves castrated near birth. We further hypothesized that oral MEL administration would impact behavior changes associated with castration; therefore, the objective of this study was to determine if castration, method of castration, and/or oral MEL administration affects inflammation, behavior, performance, and carcass traits in finishing beef cattle.

MATERIALS AND METHODS

Animal methods and procedures were independently approved by the University of Arkansas (UA; protocol #12003) and West Texas A&M University (WTAMU; protocol #03-05-13) Animal Care and Use Committee.

Animals

This study was conducted over three consecutive years (2013 to 2015). In total, 194 Angus × Hereford male calves (42 steers and 152 bulls) arriving from

the University of Arkansas, Fayetteville, cow herd were utilized for this study. In each year, calves were born in the fall and entered the feedlot in July with a 10-d acclimation period in the feedlot prior to treatment application on day 0. At birth, calves were randomly assigned to one of five treatment groups determined from random number generation and order of birth. The treatments were as follows : 1) bulls castrated within 48 h of birth (CON), 2) bulls surgically castrated on day 0 without MEL (SUR), 3) bulls surgically castrated on day 0 with MEL (SUR + MEL), 4) bulls band castrated on day 0 without MEL (BAN), and 5) bulls band castrated on day 0 with MEL (BAN + MEL). Treatments were arranged in a 2 × 2 + 1 factorial to investigate the main effects of castration method (SUR vs. BAN) and analgesia (oral MEL) and their interaction with the addition of the CON treatment that arrived to the feedlot as steers. Castration of CON within 48 h of birth was performed using the banding technique without oral meloxicam administration. In the feedlot, surgical castration was performed by removing the ventral one-third of the scrotum with a scalpel, followed by emasculatation of the spermatic cords. The BAN treatments were castrated using the California bander (Inosol Co., El Centro, CA). Concurrent with the applicable castration treatments, meloxicam tablets (15 mg; Carlsbad Technology Inc., Carlsbad, CA) were counted according to individual BW, placed in gelatin capsules, and administered using a bolus device to achieve the targeted dosage of 1 mg/kg BW. Meloxicam is not approved for use in beef cattle by the U.S. Food and Drug Administration; therefore, MEL was recommended by a veterinarian as Extralabel Drug Use under the Animal Medicinal Drug Use Clarification Act with a veterinarian–client–patient relationship established prior to study initiation. A withdrawal time of 21 d was established for MEL (Mosher et al., 2011).

Administration of health and performance products was similar between years. Calves were administered a multivalent clostridial bacterin containing tetanus toxoid (Covexin 8, Merck Animal Health, Whitehouse Station, NJ) and a pentavalent modified-live virus respiratory vaccine (Bovi-shield Gold 5, Zoetis, Kalamazoo, MI) at approximately 60 d of age. At approximately 120 days of age, calves were administered the same vaccines and an anthelmintic (Dectomax, Zoetis) according to BW, removed from their dams and placed into weaning pens. Calves were provided a supplement at approximately 1% of their BW and allowed to graze a mixed-grass pasture during a 56-d weaning

period. Subsequently, calves were transported 793 km to the WTAMU Research Feedlot at the end of the 56-d weaning period. Within year, calves were blocked within each treatment group into a light and heavy BW block using the BW recorded at the end of the weaning period immediately prior to shipment. Upon feedlot arrival (day -11), calves were held overnight in a receiving pen with access to hay and water and processed the following morning (day -10) with s.c. injections of doramectin (Dectomax, Zoetis) and tulathromycin (Draxxin, Zoetis). Calves were assigned to pens according to treatment and BW block resulting in two pen replications per treatment each year (total of six pen replicates per treatment). The number of pen replicates was limited by time constraints and available funding; animals per pen was four to nine and varied by year because the number of male calves born in the cow herd origin varied. Nevertheless, the pen-level sample size was balanced across treatments within year. A 10-d postmetaphylactic interval and acclimation period was implemented before castration treatments were applied on day 0. Also on day 0, cattle were vaccinated with a pentavalent modified-live virus respiratory vaccine (Bovi-Shield Gold 5, Zoetis) and clostridial bacterin with tetanus toxoid (Covexin 8, Merck Animal Health). Each of the 3 yr, the light block were administered a growth implant in the caudal aspect of the right ear containing 36 mg of zeranol (Ralgro, Merck Animal Health) on day 0. A second growth implant was administered to cattle assigned to the light BW block at approximately day 80 for years 1 and 2 (extended release 40-mg estradiol and 200-mg trenbolone acetate; Revalor XS, Merck Animal Health) and year 3 (20-mg estradiol and 200-mg trenbolone acetate; Revalor 200, Merck Animal Health). In years 1 and 2, the cattle in the heavy BW block were administered an extended release growth implant containing 40-mg estradiol and 200-mg trenbolone acetate (Revalor- XS, Merck Animal Health) on day 0, whereas in year 3, a conventional growth implant containing 8-mg estradiol and 80-mg trenbolone acetate (Revalor IS, Merck Animal Health) was administered on day 0. In years 1 and 2, cattle in the heavy BW block were not reimplanted. In year 3, animals in the heavy BW block were reimplanted with a conventional growth implant containing 8-mg estradiol and 80-mg trenbolone acetate (Revalor IS, Merck Animal Health) on day 80. Cattle were fed common starter, transition, and finishing diets and feed bunk management followed standard protocol of the WTAMU Research Feedlot. Each year, the

starter diet was fed approximately 30 d, then the transition diet was fed along with the starter diet at 1:1 for approximately 3 d. After 3 d, cattle were fed the transition diet only for approximately 7 d, and then the finishing diet was fed along with the intermediate diet at 1:1 for approximately 3 d before the finishing diet only was fed for the remainder of the study. The calculated CP for the starter, transition, and finishing diets was 14.5%, 14.1%, and 14.0%, respectively. The calculated NE_m and NE_g was 76.5 and 48.9, 81.6 and 53.3, and 85.9 and 57.0 mcal/45.5 kg for starter, transition, and finishing diets, respectively. Cattle were harvested at a commercial beef processing facility and the harvest date was determined within BW block according to visual appraisal of estimated backfat by an evaluator experienced with cattle marketing. Treatments within each BW block were harvested on the same day. Carcass data were collected by WTAMU Beef Carcass Research Center personnel.

Sample Collection and Assay Procedures

Individual BW were collected at birth, branding (average of 60 d of age), weaning, prior to feedlot shipment (day -11), feedlot arrival (day -10), and days 0, 1, 4, 7, 14, 32, 70, and a final BW was determined from the average of two consecutive BW on the day prior to and day of harvest (average day fed = 219 ± 5.1). Blood was collected via jugular venipuncture from a treatment and BW block balanced, randomly selected subset of 50 animals/yr ($n = 150$) at the time of castration (day 0), 6-h postcastration (day 0.25) and days 1, 4, 7, 14, and 32. Blood was collected into an evacuated sampling tube without additive (BD Vacutainer, Franklin Lakes, NJ). To harvest serum, blood was centrifuged at $1,500 \times g$ for 20 min at 4 °C. Serum was decanted into triplicate aliquots and stored at -20 °C until subsequent analysis for bovine haptoglobin (**Hp**) concentration using a commercially available sandwich ELISA kit (Immunology Consultants Laboratory, Inc., Portland, OR) with an interassay CV of 7.51% and intraassay CV of 9.29%.

The same subset of 150 animals used for blood collection was used to determine behavior. Behavior variables were collected via 3-axis accelerometers (IceQube, IceRobotics, Midlothian, Scotland, United Kingdom) that were fitted around the metatarsus of the left rear leg on day -10 and removed on day 32. Previous validation of the accuracy of 3-axis accelerometers used in the current study is reported elsewhere (Robert et al., 2009; Nielsen et al., 2010). The accelerometers logged data every 15 min and the variables

included: time spent standing, time spent lying, number of steps taken, number of lying bouts, and a motion index determined from a proprietary algorithm. A baseline value for each behavior variable was determined for each treatment pen by determining the behavior variable means recorded from days -9 to -1. The anticipated impact of shipping and relocation on behavior was the impetus of the acclimation period prior to treatment application; however, it may have influenced the baseline value.

Statistical Analyses

For all statistical analyses, SAS version 9.4 (SAS Inst. Inc., Cary, NJ) was used and pen within year served as experimental unit. Fixed effects included in the model were castration method, meloxicam, and their interaction. Random effects in the model included block and year. An additional contrast of CON vs. castrated treatments was analyzed. Performance and noncategorical carcass variables were evaluated using the MIXED procedure of SAS. The MIXED procedure with repeated measures was used to evaluate Hp data. Day was used as the repeated statement with fixed effects of treatment, day, and treatment $\times$ day interaction. The GLIMMIX procedure was used to evaluate quality grade and behavior variables with a repeated statement included and compound symmetry selected as the covariance structure for behavior variables. An *F*-test was determined for method, meloxicam, their interaction, and the additional contrast of CON vs. castrates with significance established at $P \leq 0.05$. If an interaction was significant for a particular outcome variable, treatment mean separation for that variable was performed using the pdiff option in SAS. Tendencies were noted for a resulting *P*-value between 0.06 and 0.10.

RESULTS AND DISCUSSION

Growth Performance

Growth performance results are presented in Table 1. There was no difference ($P = 0.55$) in BW at weaning between steers castrated within 48 h of birth and intact bulls. These results are contrary to current industry dogma that bulls have heavier BW at weaning compared to steers, and the perception of reduced weaning weight in steers is one reason why castration prior to sale is estimated to be only 59.2% ((USDA, 2008). Brown et al. (2015) and Warnock et al. (2012) also observed no difference in weaning weight between steer and bull cohorts at weaning. The similar BW observed between steers and bulls at typical weaning age (205 d) is likely a function of very low testosterone production in prepubertal bulls (Miyamoto et al., 1989; Rawling et al., 1978). However, upon feedlot entry there was a tendency ($P \leq 0.10$) for CON to have heavier BW than castrated treatments on days 14, 32, and day of reimplant. Castration method had no effect ($P = 0.90$) on final BW, but there was a tendency ($P = 0.07$) for MEL cattle to have a heavier final BW, regardless of castration method. Despite reduced weight gain following castration, the castrated animals compensated for the transient decrease in performance because final BW did not differ ($P = 0.34$) between castrates and CON steers.

A main effect of castration method on ADG (Table 2) was observed for the first 2 wk following castration. From days 0 to 7, surgical castration decreased ($P = 0.01$) ADG compared to band castrated animals (-0.42 vs. 0.43 kg/d, respectively). Conversely, from days 7 to 14 surgical castration groups had increased ($P = 0.05$) ADG compared to the banded groups (2.57 vs. 2.15 kg/d, respectively). There was also a difference ($P < 0.001$) in ADG from days 14 to 32 with surgical castration

Table 1. Effect of castration method and meloxicam administration on body weight of feedlot cattle

BW, kg	Treatment ¹					SEM	Contrasts, <i>P</i> -value			
	CON	SUR	SUR + MEL	BAN	BAN + MEL		Method	Meloxicam	Interaction	CON vs. castrates
Weaning	204	201	200	200	202	22.02	0.96	1.00	0.77	0.55
Day 0	245	242	244	246	247	24.21	0.55	0.79	0.94	0.96
Day 7	249	237	240	248	249	22.44	0.03	0.65	0.86	0.24
Day 14	272	260	259	266	266	25.32	0.17	0.92	0.92	0.07
Day 32	310	293	274	296	296	22.47	0.25	0.40	0.69	0.10
Reimplant ¹	407	390	398	395	396	34.42	0.77	0.50	0.60	0.10
Final ²	618	593	619	601	614	13.55	0.90	0.07	0.52	0.34

¹Re-implant occurred at approximately day 80 each year.

²Cattle were fed an average of 219 d across year and BW block. Within year, all treatments within BW block were harvested on the same day.

Table 2. Effect of castration method and meloxicam administration on average daily gain of feedlot cattle

ADG, kg	Treatment					SEM	Contrasts, <i>P</i> -value			
	CON	SUR	SUR + MEL	BAN	BAN + MEL		Method	Meloxicam	Interaction	CON vs. castrates
Days 0 to 7	0.92	−0.45	−0.39	0.42	0.44	0.81	0.01	0.90	0.94	0.01
Days 7 to 14	2.69	2.78	2.36	2.23	2.06	0.52	0.05	0.16	0.55	0.15
Days 0 to 14	1.81	1.17	0.98	1.32	1.25	0.32	0.09	0.28	0.61	<0.01
Days 14 to 32	1.81	1.63	1.85	1.46	1.46	0.28	<0.01	0.18	0.19	0.02
Days 0 to Reimplant ¹	2.14	1.91	1.98	1.93	1.93	0.15	0.80	0.50	0.46	<0.01
Reimplant to final ²	1.59	1.50	1.66	1.52	1.62	0.11	0.78	0.01	0.56	0.81
Overall	1.78	1.66	1.78	1.68	1.75	0.13	0.81	0.02	0.51	0.17

¹Reimplant occurred at approximately day 80 each year.

²Cattle were fed an average of 219 d across year and BW block. Within year, all treatments within BW block were harvested on the same day.

having greater ADG compared to band castration (1.74 vs. 1.46 kg/d, respectively). Nevertheless, the performance reduction attributable to either castration method was transient; there was no effect ($P = 0.81$) of castration method on ADG over the entire finishing period. However, the CON group had greater ($P < 0.001$) ADG compared to castrates from day 0 to reimplant.

The similar final BW observed between castrated treatments and CON in the current study is consistent with reports from Jago et al. (1996) and Fisher et al. (2001) where cattle castrated post-puberty finished with harvest weights similar to cattle castrated at younger ages. Castration method was not observed to have an overall effect on ADG, which agrees with results from a meta-analysis of castration studies that reported castration method had no effect on overall growth performance (Bretschneider, 2005). Performance results from the current study also agree with Warnock et al. (2012), who reported that calves castrated prior to weaning had greater initial growth rate at feedlot entry compared to animals castrated after weaning.

Meloxicam is a nonsteroidal anti-inflammatory drug that preferentially, but not exclusively, binds to cyclooxygenase-2 receptors on various tissue types. Inhibition of cyclooxygenase activity causes systemic analgesia and reduces inflammation by inhibiting prostaglandin synthesis (Coetzee, 2011). Meloxicam administration had no effect ($P = 0.50$) on ADG from day 0 to reimplant. There was an effect ($P = 0.02$) of meloxicam administration on overall ADG with the meloxicam treatments having greater ADG compared to castrated animals that did not receive meloxicam, regardless of castration method. We expected to observe performance effects for meloxicam-treated castrates in the early interim periods, near the time of

meloxicam administration, yet differences did not occur until after reimplant. The increased within treatment variability for performance outcomes observed early in the feeding period (day 0 to reimplant) limited our ability to statistically resolve the effects of MEL during this time. However, the overall ADG was statistically increased for MEL and suggests carryover effects but may also be a function of less within treatment variability on ADG as the study progressed. There are conflicting reports on the impact of oral meloxicam administration on ADG of castrated calves. Brown et al. (2015) reported that oral meloxicam improved ADG the first 7-d postcastration in animals surgically castrated at weaning. However, Coetzee et al. (2012) reported that oral meloxicam administration 24-h prior to surgical castration did not affect growth performance but did reduce BRD morbidity. Meloxicam administration pre- and post-band castration (days −1, 0, and 1) also had no effect on animal performance in cattle that were 240 d of age at the time of castration (Repenning et al., 2013). Filho et al. (2014) reported improved ADG, G:F, and DMI during the feedlot receiving period in steers that were administered MEL daily for 7 d following 24-h road transportation. The difference in timing and duration of oral meloxicam administration could explain the difference in performance observed between studies.

Carcass Traits

There was no effect of castration method ($P \geq 0.36$) or method $\times$ meloxicam interaction ($P \geq 0.12$) on any carcass traits (Table 3). In agreement with our observation of increased overall gain, there was a tendency ($P = 0.10$) for meloxicam to increase HCW, but no difference ($P = 0.46$) existed

Table 3. Effect of castration method and meloxicam administration on carcass traits of feedlot cattle

Item	Treatment					SEM	Contrasts, <i>P</i> -value			
	CON	SUR	SUR + MEL	BAN	BAN + MEL		Method	Meloxicam	Interaction	CON vs. castrates
HCW, kg	375	359	377	366	373	11.28	0.82	0.10	0.48	0.46
Marbling Score ¹	50.11	45.85	48.17	46.08	45.87	2.97	0.52	0.51	0.43	0.05
USDA Choice, ² %	87.62	77.25	84.02	78.40	77.50	12.10	0.71	0.68	0.59	0.31
Backfat, cm	1.75	1.63	1.85	1.65	1.72	0.18	0.36	0.01	0.12	0.50
Ribeye, cm ²	87.94	83.61	88.45	85.87	87.29	2.6	0.73	0.05	0.30	0.36
KPH, %	3.50	3.41	3.81	3.67	3.66	3.42	0.71	0.19	0.15	0.41
USDA Yield Grade	3.28	3.21	3.37	3.22	3.28	0.92	0.76	0.42	0.70	0.92

¹minimum slight =100, minimum small= 200, etc.

²Percent of treatment group grading USDA Choice or better.

between CON and castrates. Marbling score was increased ($P = 0.05$) in CON treatment compared to castrates, with no difference with meloxicam administration ($P = 0.51$). Meloxicam administration increased backfat thickness ($P = 0.01$) and rib eye area ($P = 0.05$). No other differences in carcass traits were observed in this study ($P \geq 0.19$).

In the current study, castration method had no effect on carcass traits; however, meloxicam administration during castration increased rib eye area and backfat thickness. Champagne et al. (1969) reported similar carcass results; calf age at castration (birth vs. 2, 7, and 9 mo) had no impact on marbling score, backfat thickness, and *Longissimus* area. Brown et al. (2015) reported that castration timing (birth vs. weaning) and meloxicam administration had no effect on carcass traits. The current study evaluated castration in older bulls upon feedlot arrival and castration at a younger age (CON); early castration

did not impact carcass performance except for an improvement in marbling score.

Serum Haptoglobin

There was a treatment $\times$ day interaction ($P = 0.04$) for serum Hp concentration (Figure 1). No difference ($P > 0.92$) in serum Hp concentration existed on days 0 or 0.25. However, on day 1 the surgically castrated treatments had increased serum Hp concentrations ($P < 0.02$) compared with the band castration treatments and CON. Meloxicam administration had no effect ($P > 0.10$) on day 1 Hp concentrations. On day 4, SUR exhibited the greatest ($P < 0.001$) Hp concentration compared to all other treatments. There were no differences in Hp concentrations observed on days 7 or 14 ($P \geq 0.71$).

Haptoglobin is an acute phase protein synthesized by hepatocytes in response to stress,

Figure 1. Effect of castration method and meloxicam administration on serum haptoglobin concentration (mg/dL) of feedlot cattle. Effect of treatment, $P = 0.05$; day, $P < 0.001$; and treatment $\times$ day, $P = 0.04$. Contrasts = method, $P = 0.01$; meloxicam, $P = 0.13$; interaction, $P = 0.52$; and CON vs. castrates, $P = 0.21$. ^{abc}Least square means with uncommon superscript letters differ within day, $P < 0.05$.

inflammation, tissue damage, and/or infection (Cray et al., 2009; Petersen et al., 2004) and is used to indicate inflammation. Results suggest that the castration method affected inflammation because surgically castrated animals had greater serum Hp compared to band castrated animals. Similarly, Warnock et al. (2012) reported that surgical castration increased Hp concentration 2-d postcastration compared to band castration. Warnock et al. (2012) also reported that on day 15 band castration had greater Hp compared to surgical castration, but we did not detect such a difference for band castration. Meloxicam administration reduced serum Hp concentration in surgically castrated animals, but not band castration, possibly due to the reduced magnitude of inflammation observed for band castration in the current study. Similar decreases in the magnitude of Hp with meloxicam administration during surgical castration were reported by Roberts et al. (2015).

Behavior

A treatment $\times$ day interaction ($P < 0.001$) was observed for change in standing time (Figure 2). Surgically castrated groups spent more time standing ($P < 0.02$) compared to the band castration treatments and CON group immediately following castration (day 0) and remained increased for 2-d postcastration. There was no difference in standing time ($P \geq 0.28$) between CON, BAN, and BAN + MEL treatments on days 0, 1, and 2. However, on days 3 and 4, SUR + MEL spent more time standing ($P < 0.001$) compared to CON, BAN, and BAN

+ MEL but was not different ($P = 0.24$) from SUR and this observation may indicate loss of analgesia in SUR + MEL at this time. Standing time for SUR was similar ($P \geq 0.08$) to CON and BAN + MEL but did differ ($P = 0.02$) from the BAN treatment on days 3 and 4. On days 5 and 6, SUR + MEL had increased ($P \leq 0.02$) standing time compared to BAN and BAN + MEL, while meloxicam administration had no effect ($P \geq 0.20$) on change in standing time within castration method.

Number of lying bouts (Figure 3) also had a treatment $\times$ day interaction ($P < 0.001$). Band castration groups had an increase ($P \leq 0.02$) in the number of lying bouts on days 0 and 1 postcastration compared to SUR, SUR + MEL, and CON. On day 2, the number of lying bouts were decreased ($P = 0.05$) for SUR compared to SUR + MEL with no difference ($P \geq 0.16$) between the other treatments. On day 3, SUR + MEL and BAN + MEL differed ($P = 0.02$) with BAN + MEL having fewer number of lying bouts. The BAN group had an increased ($P = 0.03$) number in lying bouts on days 5 and 7 compared to the BAN + MEL treatment.

There was no treatment $\times$ day effect ($P = 0.99$) for motion index, but there was a main effect of method ($P = 0.01$) and meloxicam ($P = 0.02$; Figure 4). Band castration groups had an increased ($P < 0.001$) motion index compared to the surgically castrated groups. Meloxicam administration also decreased ($P < 0.001$) motion index compared to castrated controls, regardless of castration method. Motion index is generated from a proprietary algorithm that considers individual behavior variables combined. Correspondingly,

Figure 2. Effect of castration method and meloxicam administration on change in time spent standing from baseline values in feedlot cattle from days 0 to 7. Effect of treatment, $P < 0.001$; day, $P < 0.001$; and treatment $\times$ day, $P < 0.001$. Contrasts = method, $P < 0.01$; meloxicam, $P = 0.06$; interaction, $P = 0.60$; and CON vs. castrates, $P < 0.001$. ^aChange from baseline (average of days -9 to -1).

^{abc}Least square means with uncommon superscript letters differ within day, $P < 0.05$.

Figure 3. Effect of castration method and meloxicam administration on number of lying bouts per day of feedlot cattle from days 0 to 7. Baseline value is the average of days -9 to -1. Effect of treatment, $P < 0.001$; day, $P < 0.001$; and treatment $\times$ day, $P < 0.001$. Contrasts = method, $P < 0.001$; meloxicam, $P < 0.001$; interaction, $P = 0.01$; and CON vs. castrates, $P = 0.02$. ^{abc}Least square means with uncommon superscript letters differ within day, $P < 0.05$.

Figure 4. Effect of castration method and meloxicam administration on daily motion index of feedlot cattle from d 0 to 7. Baseline value is the average of days -9 to -1. Effect of treatment, $P < 0.001$; day, $P < 0.001$; and treatment $\times$ day, $P = 0.99$. Contrasts = method, $P = 0.01$; meloxicam, $P = 0.02$; interaction, $P = 0.11$; and CON vs. castrates, $P = 0.20$.

Petherick et al. (2014) reported that band castration in weaned bulls and mature bulls caused the animals to spend more time lying compared to surgically castrated animals.

Step count (Figure 5) was not affected by a treatment $\times$ d interaction ($P = 0.99$), but there was a main effect of method ($P \leq 0.001$) and meloxicam ($P = 0.05$). Similar to motion index, step count was increased ($P < 0.001$) for the banded groups compared to the surgically castrated groups. Meloxicam administration decreased ($P = 0.04$) the number of steps taken regardless of castration method. Petherick et al. (2014) also reported a tendency for mature bulls surgically castrated to take less steps following castration vs. banded mature bulls.

The differences in behavior variables observed in our study indicate that both methods of castration alter animal behavior following castration;

however, castration method had differential effects on behavior. Surgical castration caused animals to spend more time standing postcastration; whereas, band castration caused animals to have an increase in lying bouts along with a transient increase in steps. Similarly, White et al. (2008) found that surgically castrated beef calves had increased amount of standing time relative to precastration using 2-axis accelerometers. These different behavioral patterns may be due to distinct sensation of pain experienced between castration methods. Standing and lying are appropriate responses in an attempt to minimize stimulation of the sensitized nociceptors due to tissue damage (Handwerker and Reeh, 1991). Surgically castrated animals took less steps and spent more time standing, plausibly in an attempt to avoid contact with the open wound. The increase in motion index, steps, and lying bouts may

Figure 5. Effect of castration method and meloxicam administration on number of steps per day by feedlot cattle from d 0 to 7. Baseline value is the average of days -9 to -1. Effect of treatment, $P < 0.001$; day, $P < 0.001$; and treatment $\times$ day, $P = 0.99$. Contrasts = method, $P < 0.001$; meloxicam, $P = 0.05$; interaction, $P = 0.19$; and CON vs. CASTRATES $P = 0.26$.

indicate that banded animals have pain-induced hyper reaction to ischemia experienced by application of the band. Correspondingly, band castration has been reported to increase restless activity in animals when compared to surgically and burdizzo castrated animals (Robertson et al., 1994). Those authors also reported that banded animals had a decrease in normal lying behavior and an increase in abnormal lying position compared to surgical and burdizzo castration. The behavior observations in the current study and those from studies discussed above indicate that the method of castration results in distinct behavioral responses in beef bulls that likely indicate different sensation and timing of pain.

In conclusion, castration at the cow-calf origin resulted in long-term production and animal welfare benefits through the finishing period. Both castration methods reduced feedlot performance; however, the reduction in performance occurred at different times postcastration. Surgical castration decreased performance during the first week postcastration, while band castration decreased performance during the second week postcastration. Meloxicam administration improved overall ADG for either castration method. Serum Hp concentration was less for band castration compared to surgically castrated animals; whereas, meloxicam reduced serum Hp following surgical castration. Both castration methods briefly altered animal behavior indicative of acute pain, but with divergent adaptations. Further research is needed to determine if the performance and production benefits observed with oral meloxicam administered to castrated beef bulls is repeatable in the commercial feedlot setting.

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