Chromium supplementation alters both glucose and lipid metabolism in feedlot cattle during the receiving period\textsuperscript{1,2,3}

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\textbf{ABSTRACT:} Crossbred steers (n = 20; 235 ± 4 kg) were fed for 53 d during a receiving period to determine if supplementing chromium (Cr; KemTRACE Chromium Propionate 0.04%, Kemin Industries, Des Moines, IA) would alter glucose or lipid metabolism of newly received cattle. Chromium premixes were supplemented to add 0 (Con) or 0.2 mg/kg of Cr to the total diet on a DM basis. Cattle were fitted with jugular catheters on d 52. A glucose tolerance test (GTT) and an insulin sensitivity test (IST) were conducted on d 53. Blood samples were collected from –60 to 150 min relative to each infusion. Serum was isolated to determine glucose, insulin, and NEFA concentrations. Throughout GTT, no differences were detected in glucose concentrations, glucose clearance rates (k), or preinfusion insulin concentrations (P > 0.50), but insulin concentrations postinfusion tended (P = 0.06) to be greater for the Cr-supplemented steers. This caused an increase in the insulin to glucose ratio (I:G) from 0 to 150 min postinfusion for the Cr-supplemented steers (P = 0.03). In addition, NEFA concentrations during GTT were lower (P ≤ 0.01) for Cr-supplemented steers both preinfusion and postinfusion. During IST, there was no treatment effect on glucose concentrations preinfusion (P = 0.38), but postinfusion glucose concentrations were greater (P < 0.01) in the Cr-supplemented steers. The k of Cr-supplemented steers tended (P = 0.06) to be faster than Con steers from 30 to 45 min postinfusion. During the same test, there was no treatment effect detected for insulin concentrations (P > 0.33). The I:G were not affected by treatment (P > 0.40). Concentrations of NEFA were reduced (P < 0.01) both preinfusion and postinfusion during IST for Cr-supplemented steers. Results of this study indicate that supplementation of Cr can significantly alter lipid metabolism. This suggests that these steers had less dependence on lipid metabolism for energy or sensitivity of adipose tissue to antilipolytic signals was reduced. Results of glucose and insulin metabolism were inconsistently modified after a GTT and an IST.

\textbf{Key words:} chromium propionate, glucose metabolism, glucose tolerance test, insulin sensitivity test, lipid metabolism, receiving cattle

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INTRODUCTION

Chromium was first reported as an essential nutrient for normal glucose metabolism in rats by Schwarz and Mertz (1959). Conventional diets were believed to provide domestic animals adequate Cr. However, studies over the past 20 years have shown that Cr supplementation has altered glucose and/or lipid metabolism in swine (Matthews et al., 2001) and ruminants (Gentry et al., 1999; Sumner et al., 2007), and affected production in swine (Lindemann et al., 1995) and ruminants (Kegley et al., 1997a; Hayirli et al., 2001).

Researchers initially thought Cr altered glucose metabolism as a part of the glucose tolerance factor (Tuepfer et al., 1977) but more recently Sun et al. (2000) claimed that Cr modifies glucose metabolism through an oligopeptide known as chromodulin. Chromodulin consists of glycine, cysteine, aspartate, and glutamate, and binds with high affinity to 4 chromic ions (Vincent, 2000, 2001). This enables Cr to be involved in the autoamplification of insulin signaling to maintain the active conformation of insulin receptors and cause greater glucose uptake (Vincent, 2000, 2001).

Performance results in beef cattle supplemented with Cr have varied from 0 to 30% increase in ADG (Chang and Mowat, 1992; Kegley and Spears, 1995). However, organic sources of Cr, such as Cr-propionate or Cr-methionine, have shown more consistent, favorable effects on glucose metabolism (Kegley et al., 2000; McNamara and Valdez, 2005). Currently, Cr-propionate is the only Cr source permitted for supplementation to cattle diets in the United States and no research has been conducted to determine the effect of dietary Cr-propionate on glucose and lipid metabolism in receiving feedlot steers. Supplementation of Cr is expected to increase glucose uptake and decrease lipolysis. Therefore, the objectives of this study were to determine the effect of Cr-propionate on glucose and lipid metabolism, after a glucose tolerance test (GTT), followed by an insulin sensitivity test (IST).

MATERIALS AND METHODS

All procedures involving live animals were approved (#10048-08) by the Texas Tech University Animal Care and Use Committee.

Cattle

Twenty-five steers (British × Continental) were purchased at the Tulia Livestock Auction barn (Tulia, TX) to be used for GTT and IST. Steers were transported (105 km) to the Texas Tech University Beef Center at New Deal (off-truck average BW = 221 kg) on June 22. The cattle were housed in dirt-lot pens with ad libitum access to sudangrass hay in the feedbunk overnight. The next 2 mornings, a 63% concentrate basal ration was fed on top of additional hay. No additional hay was offered after the third day postarrival. Initial processing, on June 23, included: 1) measurement of BW [Pearson squeeze chute, Thedford, NE; set on 4 electronic load cells (Gallagher Smart Scale Systems, North Kansas City, MO; accuracy of ± 0.90 kg)]; scales were calibrated with 454 kg of certified weights (Texas Department of Agriculture before use); 2) placement in the ear of a uniquely numbered tag; 3) recording of phenotypic description; 4) vaccination with a modified live virus vaccine to protect against bovine viral diarrhea virus (Type I and Type II), bovine rhinotracheitis virus (Titanium 3, Agri Laboratories, St. Joseph, MO), and clostridial bacterin toxoid to help prevent diseases caused by Clostridium chauvoei, septicum, novyi, sordellii, and perfringens (Types C & D; Vision 7 with SPUR, Merck Animal Health, Whitehouse Station, NJ); 5) treatment for internal parasites with Ivomec Plus (Merial, Duluth, GA); and 6) antibiotic treatment with Micotil (Elanco Animal Health, Greenfield, IN). Cattle were also implanted with Ralgro (36 mg zeranol, Merck Animal Health) on d 0 (June 25).

Experimental Design, Treatment, and Pen Assignment

Processing BW were used for stratification. Five steers were not used in the experiment because of BW, temperament, or thriftiness, leaving 20 steers for use in the experiment (n = 20; 235 ± 4 kg). Steers were randomly assigned to 1 of 2 treatments: 1) control (Con; 0 mg/kg of Cr); or 2) 0.2 mg/kg Cr (provided 0.2 mg/kg of Cr to the entire diet on a DM basis from KemTRACE Chromium Propionate 0.04%, Kemin Industries, Des Moines, IA). On d 0, initial BW was recorded and cattle were sorted into their home pen (1 pen/treatment; 4.5 m wide × 9.1 m pipe feedlot pens with a dirt floor and concrete aprons around water troughs and feedbunks). On d 14, cattle were vaccinated again [Pyramid 2 plus Type II BVD, Pfizer Animal Health, Kalamazoo, MI, and autogenous bacterin (isolates included Pasteurella multocida, Histophilus somni, Mannheimia haemolytica, and Mycoplasma bovis), Newport Laboratories, Worthington, MN]. Cattle were on feed for 53 d.

Management, Feeding, and Weighing

Cattle were fed once daily in the morning (0700 to 0800 h) and adjustments in feed delivery for each pen were made to guarantee ad libitum access to feed. Cattle were fed a 63% concentrate diet from d 0 to 14. Concentrate level was increased at d 14 and 28 (to 73% and 83% concentrate diets, respectfully). The 83% concentrate
Table 1. Diet composition

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>%1</th>
<th>% concentrate in diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam-flaked corn</td>
<td>63%</td>
<td>73%</td>
</tr>
<tr>
<td>Alfalfa hay, ground</td>
<td>44.25</td>
<td>53.28</td>
</tr>
<tr>
<td>Cottonseed hulls</td>
<td>24.00</td>
<td>17.50</td>
</tr>
<tr>
<td>Cottonseed meal</td>
<td>13.00</td>
<td>9.50</td>
</tr>
<tr>
<td>Supplement premix2</td>
<td>7.70</td>
<td>8.30</td>
</tr>
<tr>
<td>Limestone</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Urea</td>
<td>0.04</td>
<td>0.45</td>
</tr>
<tr>
<td>Tallow</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Molasses</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>Chromium premix3,4</td>
<td>2.00</td>
<td>2.00</td>
</tr>
</tbody>
</table>

1DM basis.
2Supplement for the diet contained (DM basis): 66.383% cottonseed meal; 0.500% Endox (Kemin Industries, Inc., Des Moines, IA); 0.648% dicalcium phosphate; 10% potassium chloride; 4.167% ammonium sulfate; 15.000% salt; 0.002% cobalt carbonate; 0.196% copper sulfate; 0.001% ethylenediamine dihydroiodide; 0.333% manganese oxide; 0.125% selenium premix (0.2% Se); 0.986% zinc sulfate; 0.010% vitamin A (1,000,000 IU/g); 0.157% vitamin E (500 IU/g); 0.844% Rumensin (176.4 mg/kg; Elanco Animal Health, Indianapolis, IN); and 0.563% Tylan (88.2 mg/kg; Elanco Animal Health). Concentrations in parenthesis are expressed on a 90% DM basis.
3Chromium premix for the control treatment contained (DM basis): 98% ground corn and 2% corn oil.
4Chromium premix for the 0.2 mg/kg treatment contained (DM basis): 95.5% ground corn, 2% corn oil, and 2.5% KemTRACE chromium propionate 0.04%. 

All premixes were made at the Texas Tech University Burnett Center Feed Mill (New Deal) in a paddle-type mixer (Marion Mixers Inc., Marion, IA). The supplement premix included standard trace minerals, vitamins, monensin (Rumensin, Elanco Animal Health), and tylosin (Tylan, Elanco Animal Health). Ingredients for the Cr premix included ground corn, corn oil, and Cr (Cr was excluded in the control premix). Samples were taken from each premix and stored in Ziploc bags (S. C. Johnson and Sons, Inc., Racine, WI) in the freezer (−20°C) until sent to Servi-Tech Laboratories (Amarillo, TX) for total Cr analysis. (The Cr was measured by nitric acid/hydrogen peroxide digestion and inductively coupled plasma analysis.) Analyzed concentrations of total Cr in the Cr premixes were 1.09 ± 0.344 mg/kg (Con) and 12.23 ± 0.742 mg/kg (Cr treatment). The Cr premixes were added at a rate of 2% (DM basis) of the bunk call (total feed delivered) made earlier that morning. Immediately after the feed was evenly poured into the bunk, the Cr premix was proportionally sprinkled across the top of the feed and mixed thoroughly by hand with an individual plastic scoop for each treatment. Control diet samples were taken daily, composited weekly, and subsamples were stored in a freezer (−20°C) until

sent to Servi-Tech for analysis of chemical composition and total Cr (Table 2).

On d 52, Con and Cr-treated steers were weighed (324 and 314 ± 7.8 kg, respectively), fitted with jugular vein catheters, and housed in a metabolism barn (0800 to 1100 h). For the cannulation procedure, a 2- to 3-cm incision was made in the skin to more easily access the jugular vein. Temporary indwelling jugular catheters consisting of ~30 cm of sterile Tygon tubing (AAQ04133; US Plastics; 1.27 mm i.d. and 2.286 mm o.d.) were inserted into the jugular vein using a 14-gauge × 5.08-cm, thin-walled, stainless steel biomedical needle (3 mm o.d.). The catheter was maintained in place using livestock identification tag cement (Nasco, Atlanta, GA) and 5.08-cm wide porous surgical tape around the incision site, and then the entire neck region of each steer was wrapped with Vet Wrap (Valley Vet Supply, Marysville, KS) to ensure stability of the catheterization site. The remaining tubing not inserted into the steer served as the catheter extension for collection of blood samples. During these procedures, steers were restrained in a working chute for ~10 to 15 min. After these procedures, steers were moved to a facility that contained individual stalls (2.13 m long × 0.76 m wide) that housed the steers through the duration of the study. Steers were placed so that treatments were alternated by stall. The extension tubing of the catheter was extended above the stall to allow researchers to collect blood throughout the study without disturbing the steers, whether the steers were standing or lying. Steers were individually fed and watered during their time in the metabolism barn. Feed was offered at 1100 h on d 52 and clean water was continuously available (88SW Galvanized Stock Waterer, Miller Manufacturing Company, Inc., Eagan, MN.) On d 53, steers were fed at 0500 h and feed was removed at 0600 h. A GTT and an IST were conducted on d 53 by infusing the steers with 1 mL of a 50% glucose solution/kg of BW (Dextrose 50%, Durvet, Inc., Blue Springs, MO) at 0900 h and 0.1 mL of an insulin solution/kg of BW [0.1 IU of bovine insulin/kg of BW (Sigma-Aldrich Inc., St. Louis, MO)] at 1400 h, respectively. The insulin infusate (1 IU/mL) was made using sterile PBS and con-

Table 2. Chemical composition of control diet bunk samples

<table>
<thead>
<tr>
<th>Item</th>
<th>% concentrate in diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM, %</td>
<td>63%</td>
</tr>
<tr>
<td>CP, %</td>
<td>13.9</td>
</tr>
<tr>
<td>NDF, %</td>
<td>33.7</td>
</tr>
<tr>
<td>NE\textsubscript{m}, Mcal/kg</td>
<td>1.61</td>
</tr>
<tr>
<td>NE\textsubscript{p}, Mcal/kg</td>
<td>1.02</td>
</tr>
<tr>
<td>Total analyzed chromium, mg/kg\textsuperscript{2}</td>
<td>5.30</td>
</tr>
</tbody>
</table>

1DM basis.
2Avg concentrations for each step-up diet (DM basis).
tained 1 mg bovine serum albumin/mL (Sigma-Aldrich Inc.). The ambient temperature of the barn during the 2 metabolism challenges was 33 ± 0.68°C. Whole blood samples (~9 mL) were collected into blood tubes with no additives at –60, –45, –30, –15, 0, 7.5, 15, 30, 45, 60, 90, 120, and 150 min, relative to each infusion. Before every sample was collected, at least 3 mL of “waste” was aspirated through the extension tube and discarded. After every sample collection, 5 mL of saline solution was injected into the extension tube, followed by 3 mL of heparin. Whole blood was allowed to clot for 30 min at room temperature and serum was collected after centrifugation at 1,250 × g for 20 min at 4°C. Serum was stored at –80°C until analyzed for glucose, insulin, and NEFA concentrations.

**Serum Analyses**

Glucose concentrations were determined by modification of the enzymatic Autokit Glucose (Wako Diagnostics, Richmond, VA) for a 96-well format. Briefly, 300 μL of prepared working solution was added to 2 μL of serum or prepared standards in a 96-well plate. Plates were incubated at 37°C for 5 min and then read using a plate reader at 505 nm. Concentration of glucose was determined by comparing unknown samples to a standard curve of known glucose concentrations. The minimum detectable concentration is 0.1 mg/dL. The intra-assay and interassay CV during GTT were 14.4% and 12.7%, respectively. Data are presented as the concentration in mg/dL.

Insulin concentrations were determined by a bovine-specific insulin ELISA, according to the manufacturer instructions (Cat # 80-INSBO-E01; Alpco Diagnostics, Salem, NH). The minimum detectable concentration is 0.1 ng/mL and the intra-assay and interassay CV during GTT were 14.4% and 12.7%, respectively. The intra-assay and interassay CV during IST were 6.3% and 12.2%, respectively. Data are presented as the concentration in ng/mL.

Concentrations of NEFA were determined by modification of the enzymatic HR Series NEFA-HR (2) assay (Wako Diagnostics) for a 96-well format. Briefly, 200 μL of the prepared Color Reagent A were added to 5 μL of serum or prepared standards in a 96-well plate. Plates were incubated at 37°C for 5 min and then read using a plate reader at 550 nm. Next, 100 μL of prepared Color Reagent B was added to the 96-well plate. Plates were incubated for an additional 5 min at 37°C and read for a second time using a plate reader at 550 nm. Concentrations of NEFA were determined by comparing unknown samples to a standard curve of known NEFA concentrations. The minimum detectable concentration is 0.0014 mmol/L and the intra-assay and interassay CV during GTT were 7.8% and 17.1%, respectively. The intra-assay and interassay CV during IST were 8.8% and 15.8%, respectively. Data are presented as the concentration in mmol/L.

Glucose clearance rates (k) were determined using incremental serum glucose (mg/dL) concentrations between 30 (t1) and 45 min (t2), and between 45 (t1) and 120 min (t2) postinfusion during GTT. From 30 to 45 min post glucose infusion, insulin production should peak, causing glucose concentrations to sharply decrease. Glucose and insulin concentrations should return to baseline values by 120 min post glucose infusion. During IST, incremental serum glucose (mg/dL) concentrations between 15 (t1) and 30 min (t2), and between 30 (t1) and 45 min (t2) postinfusion were used. Glucose concentrations should reach minimum concentrations by 45 min post insulin infusion, but the clearance rate of glucose may vary among animals. This equation was adapted from Kaneko (1989):

\[
k = \frac{\ln[Glu1]-\ln[Glu2]}{t_2-t_1} \times 100 = \% \text{ min}^{-1}
\]

In this equation, k (percentage per min) is the fractional turnover (or clearance rate) of serum glucose as calculated from the natural log (ln) of circulating concentrations (Glu) between 2 corresponding time points (t1 and t2). The glucose half-life (T1/2) was calculated during the same time periods previously mentioned for each respective challenge using this equation:

\[
T_{1/2} = \frac{0.693}{k} \times 100 = \text{ min}
\]

In this equation, T1/2 is the half-life (min) of serum glucose and k is the calculated glucose clearance rate determined during t1 and t2.

Insulin to glucose ratios (I:G) were determined from –60 to 150 and 0 to 150 min relative to GTT and IST. The I:G was calculated by dividing circulating insulin concentrations (ng/mL) by circulating glucose concentrations (mg/dL).

**Statistical Analyses**

Glucose, insulin, NEFA, and I:G data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC) specific for repeated measures, with treatment, time, and time × treatment interaction included as fixed effects. Variance components were the covariance structure used. Preinfusion (–60 to 0 min) and postinfusion (0 to 150 min) data were analyzed separately. Glucose clearance rate and T1/2 were analyzed using the MIXED procedure of SAS with treatment included as a fixed effect. Individual steer served as the experimental unit. A P-value of ≤0.05 was considered significant and 0.05 > P ≤ 0.10 was considered a tendency.
supplemented 0.4 mg/kg of high-Cr yeast or CrCl₃, steers when compared with nonsupplemented steers and steers (2000) both reported a significant time × dietary treatment interaction on plasma glucose concentrations postinfusion. There were no differences between treatments preinfusion or postinfusion (P > 0.50). Data are presented as the least squares means ± SE of the mean (n = 10 steers/treatment mean).

**RESULTS AND DISCUSSION**

**Glucose Tolerance Test**

No time × treatment interaction was detected pre-glucose or postglucose infusion for any blood metabolite measured (P > 0.57). Glucose concentrations before the infusion were not different between treatments (P = 0.53; Figure 1). Bunting et al. (1994), Kegley and Spears (1995), and Kegley et al. (1997b) reported no difference in basal glucose concentrations when supplementing 0 or 0.37 mg/kg of Cr-tripicolinate, 0 or 0.4 mg/kg of CrCl₃, high-Cr yeast, or Cr nicotinic acid complex, or 0 or 0.4 mg/kg of CrCl₃ or Cr nicotinic acid complex, respectively. In contrast, Sumner et al. (2007) reported that basal glucose concentrations were increased when supplementing growing Holstein heifers with 10 and 15 mg/d of Cr-propionate. These Cr doses of 10 and 15 mg/d were more than 6 and 9 times the average concentrations of 1.6 mg/d of Cr that the current study supplemented. As expected, glucose concentrations sharply increased postinfusion and peaked at 7.5 min (P < 0.01). Glucose concentrations declined from peak concentrations and reached baseline concentrations at 120 min postinfusion. There were no differences between treatment means for glucose concentrations postinfusion (P = 0.88). Kegley and Spears (1995) and Kegley et al. (2000) both reported a significant time × dietary treatment interaction on plasma glucose concentrations postinfusion. When compared with nonsupplemented steers and steers supplemented 0.4 mg/kg of high-Cr yeast or CrCl₃, steers supplemented with 0.4 mg/kg of Cr nicotinic acid complex displayed an increase in glucose concentrations at 15 min postinfusion but no differences between treatments by 30 min postinfusion (Kegley and Spears, 1995). In contrast, Kegley et al. (2000) observed that plasma glucose concentrations of calves supplemented with 0.4 mg/kg of Cr-L-methionine were less than calves supplemented with 0.8 mg/kg of Cr-L-methionine and nonsupplemented calves at 5 and 10 min postinfusion, but no differences were reported by 15 min postinfusion.

No differences were found between treatments for k or T½ from 30 to 45 or from 45 to 120 min postinfusion (P > 0.35; Table 3). Previous researchers have concluded that supplemental Cr as Cr-picolinate (Bunting et al. 1994), Cr-nicotinic acid complex (Kegley and Spears, 1995), and Cr-propionate (Sumner et al., 2007) improve the k and/or T½ after GTT. Kegley et al. (2000) and Kegley et al. (1997b) reported no differences between treatments in k or T½ when supplementing 0, 0.4, or 0.8 mg/kg of Cr-L-methionine and 0.4 mg/kg of CrCl₃ or Cr-yeast, respectively. A study in sheep revealed that Cr supplementation (0.4 mg/kg of Cr-tripicolinate) decreased k but had no effect on T½ (Gentry et al., 1999).

Glucose results after GTT have varied in previously reported experiments. These variations in glucose data have been attributed to disparities in basal Cr level of the diet, level of Cr supplementation, and most importantly the source of Cr supplementation (Spears, 2000). Additionally, variations in the amount of glucose infused could cause inconsistencies associated with accurately measuring k, T½, and I:G. Infusion levels have varied from 0.45 g/kg of BW⁰.⁷⁵ (Sumner et al., 2007) to 0.25 g/kg of BW (Kegley and Spears, 1995), to 0.5 g/kg of BW (Bunting et al., 1994; Gentry et al., 1999; Kegley et al., 2000). The current study used 0.5 g/kg of BW, which caused mean peak glucose concentrations to reach 232 ± 14.3 mg/dL in Con steers and 247 ± 15.2 mg/dL in Cr-supplemented steers. Researchers have concluded that the renal threshold for glucose in milk-

**Table 3. Effect of chromium propionate on glucose and insulin kinetics after an intravenous glucose tolerance test in beef steers**

<table>
<thead>
<tr>
<th>Item</th>
<th>Chromium inclusion level, mg/kg¹</th>
<th>SEM²</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose clearance rate, %/min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 to 45 min</td>
<td>2.12</td>
<td>0.548</td>
<td>0.56</td>
</tr>
<tr>
<td>45 to 120 min</td>
<td>0.75</td>
<td>0.153</td>
<td>0.38</td>
</tr>
<tr>
<td>Glucose half-life, min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 to 45 min</td>
<td>30.1</td>
<td>10.73</td>
<td>0.98</td>
</tr>
<tr>
<td>45 to 120 min</td>
<td>105.9</td>
<td>17.20</td>
<td>0.69</td>
</tr>
<tr>
<td>Serum insulin (ng/mL):serum glucose (mg/dL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤60 to 150 min</td>
<td>0.0092</td>
<td>0.0078</td>
<td>0.27</td>
</tr>
<tr>
<td>0 to 150 min</td>
<td>0.0090</td>
<td>0.0065</td>
<td>0.03</td>
</tr>
</tbody>
</table>

¹DM basis.
²SE of treatment means (n = 10 steers/treatment mean).
fed calves is ~150 mg/dL (Hostettler-Allen et al., 1994) and others proclaim it is ~200 mg/dL (Wijayasinghe et al., 1984). Jerry Spears suggested that circulating glucose concentrations >180 mg/dL cause glucosuria in lighter BW cattle (J. W. Spears, North Carolina State University, Raleigh, personal communication). Glucose concentrations within the urine were not measured in the current study, but it is likely that the cattle experienced glucosuria the first 30 to 45 min after administration of the glucose bolus. Glucosuria likely caused glucose to clear out of the circulatory system at an accelerated rate through the 15- and 30-min sample. This would have prevented serum glucose concentrations from increasing further at these time points. Blood glucose concentrations fell below the renal threshold between the 30-and 45-min sample.

Insulin concentrations did not differ between treatments before the glucose infusion ($P = 0.58$; Figure 2). Concentrations increased postinfusion ($P < 0.01$), with Cr-supplemented cattle producing numerically greater peak concentrations at 30 and 45 min postinfusion, after which insulin concentrations of both treatments decreased at a similar rate back to baseline concentrations by 120 min postinfusion. Steers supplemented with Cr tended ($P = 0.06$) to produce greater circulating insulin concentrations postinfusion ($1.60 ± 0.10$ ng/mL) when compared with Con steers ($1.35 ± 0.10$ ng/mL). Insulin concentrations after GTT have been increased in cattle supplemented with Cr-nicotinic acid complex and Cr-L-methionine (Kegley and Spears, 1995; Kegley et al., 2000; respectively). Bunting et al. (1994) and Sumner et al. (2007) reported no overall effects of Cr-tripicolinate or Cr-propionate on insulin concentration after GTT. Kegley et al. (1997b) reported that cattle supplemented with CrCl$_3$ displayed decreased insulin concentrations 10 to 25 min postinfusion when compared with Con and cattle supplemented with Cr-nicotinic acid complex.

The overall (~60 to 150 min) I:G revealed no differences between treatment means ($P = 0.27$; Table 3). However, the I:G postinfusion (0 to 150 min) was lower for Con steers when compared to the Cr-supplemented steers ($P = 0.03$). These differences in I:G stem from the fact that there were no treatment differences in glucose concentrations but a numerically greater increase in insulin concentrations in Cr-supplemented steers. These results almost mimic the linear increase in I:G with increasing Cr supplementation reported by Kegley et al. (2000). Typically, these increases in I:G would indicate reduced insulin sensitivity. However, Bunting et al. (1994), Kegley et al. (1997b), and Sumner et al. (2007) have all suggested that some Cr supplementation increased insulin sensitivity. Yet, other data in ruminants contradict this statement (NRC, 1997). Bunting et al. (2000) proposed a model that specified that Cr as Cr-propionate had a greater effect on increasing insulin secretion than on insulin sensitivity. Supporting this proposed model is previous data that demonstrated that supplementing Cr-chloride increases insulin secretion from perfused rat pancreas (Striffler et al., 1993).

Average NEFA concentrations were less in Cr-supplemented steers preinfusion and postinfusion (0.231 ± 0.018 and 0.172 ± 0.009 mmol/L, respectively) vs. Con

![Figure 2](image-url) **Figure 2.** The effect of Cr supplementation on the change in insulin concentrations during a glucose tolerance test (GTT). Crossbred steers ($n = 20$; initial BW 235 ± 4 kg) were separated into 2 treatments receiving a diet that added 0 (Con; $n = 10$) or 0.2 mg/kg of Cr (KemTRACE chromium propionate 0.04%, Kemin Industries, Des Moines, IA; $n = 10$) to the diet on a DM basis for 53 d. Blood samples were collected at –60, –45, –30, –15, 0, 7.5, 15, 30, 45, 60, 90, 120, and 150 min, relative to GTT (0.5 g of glucose/kg of BW). Serum was isolated and analyzed for insulin concentrations. Concentrations of serum insulin did not differ between treatments preinfusion ($P = 0.58$). Insulin concentrations increased postinfusion ($P < 0.01$), with Cr-supplemented steers producing numerically greater concentrations compared with Con steers. Mean insulin concentrations tended ($P = 0.06$) to be greater for Cr-supplemented steers vs. Con steers postinfusion. Data are presented as the least squares means ± SE of the mean ($n = 10$ steers/treatment mean).

![Figure 3](image-url) **Figure 3.** The effect of Cr supplementation on the change in NEFA concentrations during a glucose tolerance test (GTT). Crossbred steers ($n = 20$; initial BW 235 ± 4 kg) were separated into 2 treatments receiving a diet that added 0 (Con; $n = 10$) or 0.2 mg/kg of Cr (KemTRACE chromium propionate 0.04%, Kemin Industries, Des Moines, IA; $n = 10$) to the diet on a DM basis for 53 d. Blood samples were collected at –60, –45, –30, –15, 0, 7.5, 15, 30, 45, 60, 90, 120, and 150 min, relative to GTT (0.5 g of glucose/kg of BW). Serum was isolated and analyzed for NEFA concentrations. Mean concentrations of NEFA were lower preinfusion and postinfusion (0.231 ± 0.018 and 0.172 ± 0.009 mmol/L, respectively) vs. Con
steers (0.296 ± 0.018 and 0.216 ± 0.009 mmol/L, respectively; \( P \leq 0.01 \); Figure 3). Nonesterified fatty acid concentrations peaked in both treatment groups at 0 min and then declined rapidly to 30 min postinfusion. Similar to the current study, Kitchalong et al. (1995), Gentry et al. (1999), and Sumner et al. (2007) have reported decreases in mean NEFA concentrations when supplementing chromium (Cr-tripicolinate, Cr-tripicolinate, and Cr-pro- pionate, respectively). These results would suggest that Cr-supplemented animals have enough available energy to meet all demands and need to mobilize fewer stored adipocytes. In contrast, Kegley et al. (2000) reported no difference in NEFA concentrations when supplementing Cr-L-methionine and Bunting et al. (1994) reported no difference in NEFA concentrations when supplying Cr-tripicolinate to growing Holstein calves. Although not every study has yielded a similar outcome, the results of previous Cr research.

**Insulin Sensitivity Test**

No time \( \times \) treatment interaction was detected preinfusion or post insulin infusion for any blood metabolite measured (\( P > 0.40 \)). Glucose concentrations preinfusion were not different between treatments (\( P = 0.38 \); Figure 4). Overall, the Cr-supplemented steers had greater glucose concentrations postinfusion when compared with Con steers (75.5 ± 1.85 vs. 65.8 ± 1.67 mg/dL). This would suggest that the Cr-supplemented steers were less sensitive to the insulin bolus or there might have been a saturation effect of glucose within the insulin-sensitive tissues of the Cr-treated steers. Chromium-supplemented steers also tended (\( P = 0.10 \)) to return to baseline glucose concentrations quicker. When supplementing Cr-tripicolinate, Bunting et al. (1994) and Kitchalong et al. (1995) found no difference in mean glucose concentrations preinfusion or postinfusion in steers or lambs, respectively. Kegley et al. (2000) reported that steers supplemented with Cr-L-methionine had decreased glucose concentrations preinfusion and postinfusion. Before infusion, Con cattle had less plasma glucose concentrations than cattle supplemented with CrCl\(_3\) or Cr-nicotinic acid complex (Kegley et al., 1997b). A time \( \times \) treatment interaction was noted postinfusion, with CrCl\(_3\)-supplemented cattle producing greater glucose concentrations from 15 to 180 min compared with Con cattle, whereas cattle receiving Cr-nicotinic acid complex had reduced glucose concentrations from 45 to 180 min compared with Con cattle (Kegley et al., 1997b).

From 15 to 30 min postinfusion, glucose concentrations decreased at the same rate in both treatments (\( P = 0.88 \); Table 4), but from 30 to 45 min postinfusion the glucose concentrations in the Cr-supplemented steers tended (\( P = 0.06 \)) to decrease at a faster rate than that of the Con steers (3.38 vs. 1.14 ± 0.845%/min). This tendency for an increase in \( k \) would suggest that Cr-supplemented steers were more sensitive to the insulin bolus than Con steers. Beginning at 45 min postinfusion, glucose concentrations in both treatments increased (\( P = 0.05 \)) until 150 min postinfusion. Glucose half-life measured from

![Figure 4. The effect of Cr supplementation on the change in glucose concentrations during an insulin sensitivity test (IST). Crossbred steers (n = 20; initial BW 235 ± 4 kg) were separated into 2 treatments receiving a diet that added 0 (Con; n = 10) or 0.2 mg/kg of Cr (KemTRACE chromium propionate 0.04%, Kemin Industries, Des Moines, IA; n = 10) to the diet on a DM basis for 53 d. Blood samples were collected at –60, –45, –30, –15, 0, 7.5, 15, 30, 45, 60, 90, 120, and 150 min, relative to IST (0.1 IU of bovine insulin/kg of BW). Serum was isolated and analyzed for glucose concentrations. Mean glucose concentrations were not different between treatments preinfusion (\( P = 0.38 \)). Chromium-supplemented steers produced greater glucose concentrations postinfusion (\( P = 0.01 \)) when compared with Con steers. The greatest numerical difference was at 15 min postinfusion. Data are presented as the least squares means ± SE of the mean (n = 10 steers/treatment mean).](http://example.com/figure4.png)

<table>
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<th>Item</th>
<th>Chromium inclusion level, mg/kg(^1)</th>
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<th>0.2</th>
<th>SEM(^2)</th>
<th>P-value</th>
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<tr>
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<td>2.20</td>
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<td></td>
<td></td>
<td>30 to 45 min</td>
<td>1.14</td>
<td>3.38</td>
<td>0.845</td>
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<tr>
<td>Glucose half-life, min</td>
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<td>15 to 30 min</td>
<td>28.9</td>
<td>41.8</td>
<td>16.92</td>
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<tr>
<td></td>
<td></td>
<td>30 to 45 min</td>
<td>22.8</td>
<td>31.0</td>
<td>12.82</td>
</tr>
<tr>
<td>Serum insulin (ng/mL):serum glucose (mg/dL)</td>
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<td>–60 to 150 min</td>
<td>0.0254</td>
<td>0.0232</td>
<td>0.00212</td>
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<tr>
<td></td>
<td></td>
<td>0 to 150 min</td>
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<td>0.0316</td>
<td>0.00306</td>
</tr>
</tbody>
</table>

\(^1\)DM basis.

\(^2\)SE of treatment means (n = 10 steers/treatment mean).
Figure 5. The effect of Cr supplementation on the change in insulin concentrations during an insulin sensitivity test (IST). Crossbred steers (n = 20; initial BW 235 ± 4 kg) were separated into 2 treatments receiving a diet that added 0 (Con; n = 10) or 0.2 mg/kg of Cr (KemTRACE chromium propionate 0.04%, Kemin Industries, Des Moines, IA; n = 10) to the diet on a DM basis for 53 d. Blood samples were collected at –60, –45, –30, –15, 0, 7.5, 15, 30, 45, 60, 90, 120, and 150 min, relative to IST (0.1 IU of bovine insulin/kg of BW). Serum was isolated and analyzed for insulin concentrations. Concentrations of serum insulin did not differ between treatments preinfusion or postinfusion (P > 0.30). Insulin concentrations increased and peaked at 7.5 min postinfusion (P < 0.01). Data are presented as the least squares means ± SE of the mean (n = 10 steers/treatment mean).

Figure 6. The effect of Cr supplementation on the change in NEFA concentrations during an insulin sensitivity test (IST). Crossbred steers (n = 20; initial BW 235 ± 4 kg) were separated into 2 treatments receiving a diet that added 0 (Con; n = 10) or 0.2 mg/kg of Cr (KemTRACE chromium propionate 0.04%, Kemin Industries, Des Moines, IA; n = 10) to the diet on a DM basis for 53 d. Blood samples were collected at –60, –45, –30, –15, 0, 7.5, 15, 30, 45, 60, 90, 120, and 150 min, relative to IST (0.1 IU of bovine insulin/kg of BW). Serum was isolated and analyzed for NEFA concentrations. Mean concentrations of NEFA were lower preinfusion and postinfusion for cattle supplemented with Cr compared with Con steers (P = 0.01). Data are presented as the least squares means ± SE of the mean (n = 10 steers/treatment mean).

15 to 30 and 30 to 45 min postinfusion were not different between treatments (P > 0.55). When supplementing Cr-tripicolinate, Kitchalong et al. (1995) and Bunting et al. (1994) reported no differences in k or T½ in sheep or steers, respectively, but Bunting et al. (1994) reported improvements in k and T½ in heifers supplemented with Cr-tripicolinate. Kegley et al. (2000) discovered an increase in k from 5 to 10 min postinfusion in Cr-supplemented cattle, but no differences were found from 10 to 15 or 15 to 30 min postinfusion. Chromium-L-methionine tended to decrease the T½ of steers from 5 to 10 and 10 to 15 min postinfusion (Kegley et al., 2000).

There was no difference in insulin concentrations between treatments preinfusion or postinfusion (P = 0.33 and P = 0.62, respectively; Figure 5). However, insulin concentrations dramatically increased from 0 to 7.5 min postinfusion (P < 0.01). Insulin concentrations returned to baseline concentrations by 60 min postinfusion in both treatment groups. There were no differences in mean insulin concentrations preinfusion and post insulin infusion in cattle and sheep supplemented with Cr-tripicolinate, and insulin concentrations returned to baseline concentrations by 90-min postinfusion (Bunting et al., 1994; Kitchalong et al., 1995). Supplemental CrCl₃ and Cr-nicotinic acid complex had no effect on insulin concentrations preinfusion or postinfusion (Kegley et al., 1997b). Kegley et al. (2000) reported no differences between treatments preinfusion, but postinfusion a time × treatment interaction revealed that steers supplemented with Cr-L-methionine had greater insulin concentrations at 5 and 15 min. Other than Kegley et al. (2000), Cr supplementation has consistently not affected insulin concentrations preinfusion and post insulin infusion.

Insulin to glucose ratios from –60 to 150 and 0 to 150 min relative to insulin infusion did not differ between treatments (P > 0.40; Table 4). Previous studies have reported that supplemental Cr-tripicolinate had no effect on I:G (Bunting et al., 1994; Kitchalong et al., 1995). However, chromium-L-methionine has been reported to cause an increase in I:G at 5 and 15 min postinfusion but not at any other time points (Kegley et al., 2000). Kegley et al. (1997b) suggested that Cr-supplemented cattle were either more sensitive to insulin or insulin had a longer-lasting effect.

Nonesterified fatty acid concentrations were greater for Con steers preinfusion and postinfusion (0.32 ± 0.015 and 0.39 ± 0.017 mmol/L, respectively), when compared with the Cr-supplemented steers (0.25 ± 0.015 and 0.33 ± 0.017 mmol/L, respectively; P = 0.01; Figure 6). Nonesterified fatty acid concentrations were least at 15-min and 30-min postinfusion. After 30 min, NEFA concentrations drastically increased in both treatment groups (P < 0.01) with Con steers appearing to increase at a faster rate to 45 min postinfusion. Nonesterified fatty acid concentrations peaked at 60 min postinfusion and then slowly declined. Data reported by Kitchalong et al. (1995) support the current study that Cr supplementation causes decreases in circulating NEFA concentrations, but data by Bunting et al. (1994) does not support current findings as they did not observe any significant differences in NEFA concentrations between treatments. Kitchalong et al. (1995) and the current study would suggest that Cr-
supplemented animals have less need to mobilize stored lipids to meet their normal energy requirements.

Conclusions

Currently, Cr propionate is the only Cr source permitted for supplementation to cattle diets in the United States and appears to be a bioavailable source of chromium, altering glucose, insulin, and especially lipid metabolism of steers fed during a 53-d receiving period. In the present study, Cr supplementation did not affect glucose clearance rate after GTT, but Cr supplementation tended to increase serum insulin concentrations. After IST, Cr supplementation increased glucose concentrations but tended to increase the glucose clearance rate. Nonesterified fatty acids displayed the most consistent results, being greater both preinfusion and postinfusion during GTT and IST in nonsupplemented steers. Collectively, our data suggest that steers supplemented with Cr may have less dependence on lipid metabolism for energy or the sensitivity of adipose tissue to antilipolytic signals was reduced. These effects of tissue metabolism could potentially have a positive impact on marbling capabilities of beef cattle, but more research is needed in this area.

LITERATURE CITED


