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Effects of monensin on glucose metabolism in transition dairy cows

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ABSTRACT

Eight multiparous periparturient Holstein cows fitted with ruminal cannula were used in a split plot design to evaluate the effects of monensin on plasma glucose metabolism. Diets were top-dressed daily with 0 mg/cow of monensin (control) or 300 mg/cow of monensin (MON) both pre- and postpartum. Plasma glucose kinetic parameters on d -13 ± 2.0 and 19 ± 1.6 relative to parturition were determined by using stable isotopes. Na-1-$^{13}C_3$-Propionate (labeled propionate) was infused into the rumen to measure glucose synthesis originating from ruminal propionate, and U-^{13}C-glucose (labeled glucose) was injected into the jugular vein to determine total glucose kinetics. A sampling period of 480 min following labeled glucose injection was implemented. A compartmental analysis was employed to determine steady state glucose kinetic parameters. To develop a steady state glucose model, the Windows version of SAAM software (WinSAAM) was used. A 4-compartment model was adequate to comprehensively describe plasma glucose metabolism. The main model compartments consisted of propionate and plasma glucose. The time frame of the 480-min sampling period post-tracer glucose infusion allowed accurate quantification of glucose metabolism. The model estimated that glucose input from sources other than ruminal propionate decreased with MON, from 2.26 to 1.09 g/min postpartum. Gluconeogenesis, expressed as the propionate contribution to the plasma glucose pool, increased in cows fed MON (22 vs. 31%), whereas glucose oxidation, expressed as the glucose disposal rate, significantly decreased (1.67 vs. 0.92 g/min). In conclusion, MON may improve the energy status of transition cows by (1) improving the efficiency of propionate to produce glucose and (2) decreasing glucose oxidation in body tissues.
Key words: monensin, transition cow, glucose metabolism, compartmental analysis

INTRODUCTION

The most crucial period for dairy cows is the physiological period from late pregnancy to the onset of lactation, when the demand for energy increases to meet the requirements for the fetus and milk production (Bell, 1995). For a cow to meet the increased demands of lactation, energy may be mobilized from stores such as adipose tissue. Increases in the mobilization of adipose tissue will increase the concentration of fatty acids in the blood levels, thus predisposing cows to metabolic disorders such as ketosis and fatty liver (Duffield et al., 1998; Ospina et al., 2010). Greater glucose supply may increase insulin, which in turn helps to decrease body fat mobilization and circulating fatty acids (Christensen et al., 1997; Rabelo et al., 2005). Energy supply could be increased by various feeding strategies, including feeding more fermentable sources of carbohydrates, administering propylene glycol prepartum, and feeding glycerol (Grummer, 1995) and monensin (McCarthy et al., 2015b,c). Feeding more fermentable carbohydrates prepartum may increase the capacity for VFA absorption by the rumen epithelium (Bannink et al., 2011), acclimate the microbial population to lactation diets, and reduce lipolysis by increasing glucogenic precursors to the liver (Grummer, 1995). In transition cows, propylene glycol enhances energy status by increasing plasma glucose and insulin and decreasing fatty acids and BHB (Nielsen and Ingvartsen, 2004). Monensin improves the energy status of the transition cow by altering VFA production toward more propionate production (McGuffey et al., 2001). An enhanced production of propionate in the rumen can increase glucose availability to the host through gluconeogenesis. Glucose derived from propionate produced in the rumen constitutes a major portion (24–61%) of total energy production (Young, 1977; Bergman, 1990). However, it is debatable as to whether an increase in propionate production may reflect a proportional increase in the contribution of propionate to the plasma glucose pool (Young, 1977). In early lactation, propionate removal by the liver has been shown to increase by 69% (Reynolds et al., 2003). McCarthy et al. (2015c) reported that the liver capacity to convert propionate to glucose ranges

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between 85 and 126% of prepartum values on d 1 and 21 after parturition. An increased hepatic propionate metabolism in early lactation may increase (McCarthy et al., 2015c) or may not affect (Larsen and Kristensen, 2009a,b) hepatic gluconeogenesis. McCarthy et al. (2015b) demonstrated increased propensity of the liver to convert propionate to glucose in cows in early lactation through an increase in the ratio of glucose to CO_2 when monensin was fed during early lactation.

Various methods have been proposed to study glucose metabolism, such as in vivo measurements of splanchnic metabolism (Kristensen and Harmon, 2004), in vitro methods with biopsied liver slices (McCarthy et al., 2015b,c), and kinetic analysis of glucose metabolism (Arieli et al., 2001). Kinetic research of glucose has involved dilution studies with the use of radioisotopes, mainly ^{14}C, ^{3}H, (Leng and Brett, 1966; Van Maanen et al., 1978), or ^{13}C stable isotopes (Breves et al., 1993; Arieli et al., 2001; Martin et al., 2001). All of the above kinetic studies were conducted with sheep, steers, or lactating cows, except for Arieli et al. (2001), which was with transition dairy cows. Although many studies have evaluated VFA metabolism in the rumen and gluconeogenesis (Van Maanen et al., 1978; Armentano and Young, 1983; Nolan et al., 2014), only the studies by Van Maanen et al. (1978) and Armentano and Young (1983) examined the effect of monensin on propionate and glucose metabolism using compartmental analysis in steers. Arieli et al. (2001) studied glucose metabolism of transition cows provided monensin prepartum, employing compartmental analysis by a simulation model to describe glucose kinetic parameters. In that study (Arieli et al., 2001), fractional catabolic rate and glucose disposal rate (**GDR**) were reduced, with an increase in the plasma glucose pool, indicating an improvement in the energetic status of transition cows with monensin. Currently, information is lacking in the literature concerning the effects of monensin fed through the transition period on the kinetic parameters of gluconeogenesis.

Our study was conducted to investigate and quantify the effects of monensin administration fed continuously through the transition period on pre- and postpartum glucose kinetics. We hypothesized that monensin inclusion in the diet would increase fractional conversion of substrates to glucose and the effects would depend upon the reproductive stage of the cow.

MATERIALS AND METHODS

Experimental Design and Treatment Allocation

Eight rumen-cannulated multiparous periparturient Holstein cows were used in a split plot design to measure the effects of monensin on metabolism of plasma glucose during the transition period (i.e., prepartum vs. postpartum). The main emphasis was to determine the kinetic parameters of glucose and the production rate of propionate during the periparturient period in dairy cows. Cows were randomly assigned to treatments on d 30 relative to expected parturition with randomization restricted to balancing for previous 305-d lactation mature equivalent milk production and BCS. Cows were also blocked according to the expected calving date. The 2 treatments were 0 (control; **CON**) or 300 mg of monensin/cow per day (**MON**; Elanco Animal Health, Greenfield, IN). Four cows (n = 4) were assigned to each treatment. Cow in the design was the whole plot, treatment was a whole plot factor, and reproductive stage (prepartum or postpartum) was used as the subplot factor.

All procedures associated with the experimental protocol were in accordance with the Pennsylvania State University Institutional Animal Care and Use Committee.

Feeding and Management of Cows

Cows were dried off on d 60 before expected parturition and moved to a ventilated tiestall facility where they were housed until d 56 postpartum. Approximately on d 1 before calving, cows were moved with their feed to the maternity barn; within 1 d after calving they returned to the tiestall facility. Cows had free access to water at all times. All cows were individually fed ad libitum a TMR and switched to a lactation TMR (Table 1) after parturition. They were fed once a day at approximately 0800 h.

For the treatment cows, monensin was incorporated into a pellet containing 170.5 g of distiller's grain as the carrier. The daily dose of monensin was preweighed and labeled for the appropriate cow and date, and top-dressed beginning on d 30 before the expected calving date. To adapt cows to monensin, 85 g/d was fed for the first 3 d of monensin supplementation.

Blood Sampling

Blood samples for plasma and serum were collected via venipuncture of the coccygeal vein into evacuated tubes (Becton Dickinson and Co., Rutherford, NJ). Blood was sampled approximately 2 h postfeeding on the same day of each week starting 4 wk before calving through 8 wk, postcalving. Blood (~7 mL) for plasma glucose determination was collected in tubes containing sodium heparin and 4% sodium fluoride. All other tubes for other plasma and serum analyses contained only sodium heparin. All blood samples were placed in