

Standard Article

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Sustained, Low-Intensity Exercise Achieved by a Dynamic Feeding System Decreases Body Fat in Ponies

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Background: Obesity in horses is increasing in prevalence and can be associated with insulin insensitivity and laminitis. Current treatment strategies for obesity include dietary restriction and exercise. However, whether exercise alone is effective for decreasing body fat is uncertain.

Hypothesis: Our hypothesis was that twice daily use of a dynamic feeding system for 3 months would induce sustained, low-intensity exercise thereby decreasing adiposity and improving insulin sensitivity (SI).

Animals: Eight, university-owned, mixed-breed, adult ponies with body condition scores (BCS) $\geq 5/9$ were used.

Methods: Two treatments (“feeder on” or “feeder off”) were administered for a 3-month period by a randomized, cross-over design ($n = 4/\text{treatment}$). An interim equilibration period of 6 weeks at pasture separated the 2 study phases. Measurements of body mass (body weight, BCS, cresty neck score [CrNS], and morphometry), body fat (determined before and after the “feeder on” treatment only), triglycerides, and insulin sensitivity (SI; combined glucose-insulin test) were undertaken before and after treatments.

Results: The dynamic feeding system induced a 3.7-fold increase in the daily distance travelled ($n = 6$), compared to with a stationary feeder, which significantly decreased mean BCS (6.53 ± 0.94 to 5.38 ± 1.71), CrNS (2.56 ± 1.12 to 1.63 ± 1.06) and body fat (by 4.95%). An improvement in SI did not occur in all ponies.

Conclusions and Clinical Importance: A dynamic feeding system can be used to induce sustained (daily), low-intensity exercise that promotes weight loss in ponies. However, this exercise may not be sufficient to substantially improve SI.

Key words: Equine metabolic syndrome; Horse; Insulin; Obesity.

The prevalence of obesity in horses has been reported to be as high as 50%.^{1–3} Pasture improvement and the abundance of well-marketed complete horse feeds have the potential to increase caloric intake, whereas overbreeding (overstocking) and smaller property sizes have decreased the space available for unstructured exercise.^{4,5} As is the case in other species, increased adiposity has led to a rise in conditions that can be associated with obesity or regional adiposity in horses, including equine metabolic syndrome (EMS), reproductive abnormalities, and osteochondrosis.^{6–9}

Refractoriness to insulin by insulin-sensitive tissues has been associated with EMS and can lead to persistent hyperinsulinemia.⁹ In addition, the consumption of diets containing large amounts of nonstructural carbohydrates (NSC) can result in higher postprandial insulin

Abbreviations:

AUC	area under the curve
BCS	body condition score
BW	body weight
Cmax	maximum concentration
CGIT	combined glucose-insulin test
CrNS	cresty neck score
D ₂ O	deuterium oxide
EMS	equine metabolic syndrome
NSC	nonstructural carbohydrate
PP	positive phase
SI	insulin sensitivity
TBW	total body water

secretion in insulin-dysregulated ponies, compared to normal ponies.¹⁰ Although the complex relationship among regional adiposity, obesity, and insulin dysregulation requires further investigation, hyperinsulinemia has been shown to be associated with an increased laminitis risk.^{11–13} Preventing development of this incapacitating foot disease is a key concern in the management of insulin-dysregulated horses.

The current strategies for managing obesity and EMS and preventing insulin-associated, pasture-associated laminitis, or both are limited and principally rely on caloric restriction and exercise.^{14,15} Although dietary restriction has been shown to be efficacious for weight loss,^{16,17} available data on whether or not exercise is effective in decreasing obesity and improving insulin sensitivity (SI) are relatively limited.^{18–22} The few available reports are somewhat contradictory because of the different nature of the exercise programs used (or observed), but a strong positive association between consistent exercise and improvement in metabolic function was not apparent.^{18,21}

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We have demonstrated previously that horses will use a dynamic feeding system designed to induce prolonged, low-intensity exercise in an unsupervised manner (i.e., requiring regular walking in order to continually access a forage ration).²³ Thus, our hypotheses were that twice daily use of a dynamic feeding system for 3 months would induce sustained, low-intensity exercise, which would decrease adiposity and improve SI in ponies.

Materials and Methods

Dynamic Feeder

During operation, the custom-made dynamic feeder is only accessible from 1 side at a time, with 2 sliding doors that open alternately on each side of the feeder to allow access to an internal hayrack for a predetermined period of time (5 minutes cycle for the current study). At the end of this period, an electronic timer triggers closure of 1 sliding door while simultaneously opening the door on the opposite side (Fig 1A). Thus, the animal is required to walk to the other side of the feeder in order to continue to access the forage. A dividing fence can be used to increase the distance walked by the animal in between feeding periods (Fig 1B).

Animals

Eight, university-owned, mixed-breed ponies (12.1 ± 3.7 years; 7 male, 1 female) with body condition scores (BCS) $\geq 5/9$ ²⁴ were used. None of the ponies had used a dynamic feeding system before and all were normal (except for BCS) on physical examination. Ponies received a forage-based diet of lucerne hay (2% body weight [BW] as fed; NSC content, 10.1% dry matter) and a vitamin and mineral supplement.^a The daily ration was divided into 2 equal meals and administered at 0700 and 1530 each day. Water intake was unrestricted. Ponies were housed in flat, pasture-free paddocks with access to shade and shelter for the duration of the study. Ponies could contact each other over the fences for mutual grooming, except for the section of fence where the feeder was placed, because this fence was higher to avoid contact during feeding. Routine prophylactic care including vaccinations, parasite

control, farriery, and dental work was maintained for each pony as part of a herd health program. Ethical approval for the study was granted by the University Animal Ethics Committees (SVS/043/14/MORRIS; 140000217).

Study Design

Ponies received 2 treatments (“feeder on” or “feeder off”) administered by a randomized, crossover design for a 3-month period (i.e., 4 ponies [2 pairs] in each group). The treatment periods were separated by a 6-week rest period designed to allow ponies to return to their prestudy BW and BCS. During this equilibration phase, the ponies were fed the same diet as during the treatment periods, but also had free access to pasture. The space allocation for each pony was similar and consistent across treatment phases. All ponies were subject to assessments of body mass, adiposity, and SI (as outlined below) before and after each treatment. Total percent body fat was determined before and after the “feeder on” treatment phase only because of financial constraints.

The distance travelled each day by the ponies was assessed with a lightweight, global positioning system tracking device.^b The distance travelled in a 12-hour period (0600–1800) was measured 3 times at consistent intervals during each treatment phase for 6 ponies (the mare and gelding pairing was not tracked because of behavioral issues), and the mean daytime distance calculated. Behavioral responses to the feeding system were assessed by use of remote cameras^c (with real-time data transfer) and live observations.

Before each phase, ponies were acclimated to the dynamic feeding system for a period of 2 weeks and taught to use the feeder by the investigators during this period. During acclimation, the investigators monitored behavioral responses to the feeder and ensured appropriate pairs of ponies were selected. Ponies were matched for size and behavior to ensure optimal, safe use of the feeding system and minimize aggressive behavior in relation to feeding. The ponies were graded on feeder use as either A- or B-rated users, based on behavioral observations. Qualitative assessment of feeder use enabled a more accurate assessment in relation to the effect of the dynamic feeder (given that the distance travelled was related to willingness to use the feeder, pony size, and fitness). Ponies rated an A ($n = 5$) exercised consistently when there was food in the

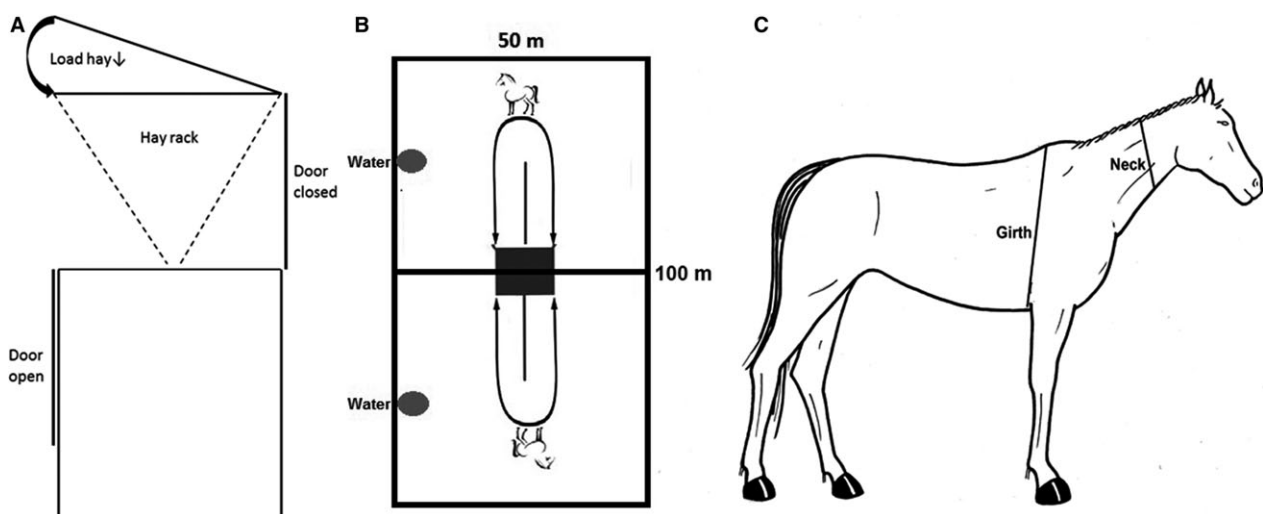


Fig 1. (A) The dynamic feeder allows access to a hayrack from alternate sides via an automatic sliding door system. (B) The distance that ponies walk to access alternating sides of the feeder during operation can be increased with the use of a fence. (C) Circumferential measurements of the neck and heart girth were measured by 2 operators at a standardized location (Artwork courtesy of M Schutze).

feeder with committed traversing of the fence line, deviated minimally from the travelled path, adopted a faster pace when exercising, did not wait on 1 side of the feeder and were difficult to distract from the task. Ponies rated a B ($n = 3$) made good use of the feeder in the first hour but periodically waited on 1 side afterward, occasionally deviated from the walking path (to roll or water), appeared to forget how to use the feeder and could be distracted from feeder use by human or more dominant pony interference (e.g. squealing, ears back).

Morphometric Measurements

Body weight was determined with a large animal weighing scale (Ruddweigh^d). Body condition²⁴ and cresty neck (CrNS)²⁵ scores were assessed independently by 1 experienced operator (blinded) and by 1 study investigator (MdL; nonblinded) and the average scores calculated.^{24,25} Heart girth and neck circumference were measured at a set anatomical location (Fig 1C) by 2 operators (as above), according to a standardized protocol and the mean measurement obtained. Concordance between the 2 operators was excellent for all morphometric measurements (Lin's $\rho_c > 0.9$).

Hormone Analysis

Fasting triglyceride concentration was determined by enzymatic determination (AU680^e) in serum samples collected at 0800 immediately before and immediately after each phase. A combined glucose-insulin tolerance test (CGIT) also was performed immediately before and after each treatment phase at 0800 after an overnight fast according to standard protocols.²⁶ Briefly, the evening before each test an indwelling catheter was placed aseptically in a jugular vein and covered, with patency maintained with heparinized saline. At 0800 the next day, glucose (150 mg/kg BW) was administered as a bolus followed by insulin (0.1 IU/kg BW). Blood glucose concentration was measured immediately on whole blood with a glucometer^f validated for use in horses by the investigators (data not shown) at 0, 1, 5, 15, 25, 35, and 45 minutes and then every 15 minutes up to 2.5 h. Plasma samples were placed immediately on ice for 10 minutes before centrifugation (10 minutes, 1500 × g), separated into 1 mL aliquots, and rapidly frozen and stored at -80°C. Serum samples were allowed to clot for 30 minutes at ambient temperature before processing and storage as above. Serum insulin concentration was determined retrospectively by a commercial diagnostic laboratory with a validated chemiluminescent assay (Immulin 2000^g) in samples (5 mL) obtained at 0, 45, and 75 minutes of the CGIT.²⁷

Body Fat Determination

The percentage body fat was determined by a deuterium oxide (D₂O) dilution method according to a protocol adapted for horses.²⁸ Briefly, syringes containing D₂O (0.12 g/kg BW) were weighed, the D₂O was administered via an indwelling catheter, and then the syringes were reweighed to calculate the exact mass of D₂O administered. Plasma samples (10 mL; chilled sodium heparin tubes) were obtained before and 4 hours after D₂O administration by venipuncture from the opposite jugular vein and the sample placed immediately on ice. Food and water were withheld during the test.

Deuterium enrichment in the plasma samples obtained pre- and post-D₂O administration was determined by gas isotope ratio mass spectrometry. The dilution space (D) was determined according to the following equation: $D = \frac{\text{Dose}_{[g]} \times \text{Pb}}{a} \times \frac{(\text{Ea} - \text{Eb})}{(\text{Ep} - \text{Eb})}$ where Pb is the baseline plasma, a is the molar mass of the stock deuterium solution, and Ea, Eb, and Ep are the isotopic enrichments (units) of the dose, baseline, and postdose plasma, respectively.²⁸ Total

body water (TBW) was calculated by means of a 4% correction factor: $\text{TBW} = \frac{D}{1.04}$ and the final fat-free mass determined by incorporating a hydration factor of 73%.²⁸

Statistical Analyses

All data were normally distributed (Shapiro-Wilk test) and analyzed parametrically. Before and after treatment phase measurements of BW, morphometry, triglyceride concentration, and CGIT parameters were compared with 2-way, repeated measures ANOVA. One-way measures (percentage BW and fat reduction and distance travelled) were compared by a paired t -test. The relationship between triglyceride concentration and body condition score fitted a single rectangular, 2-parameter hyperbola by the equation $f = a \cdot x / (b + x)$. Concordance between operator measurements was assessed by Lin's concordance coefficient. Analyses of the CGIT data included: area under the insulin and glucose-time concentration curves (AUC); maximum glucose concentration (C_{max}); positive phase duration for glucose (PP; i.e. the time taken for blood glucose concentration to return to baseline); and glucose clearance (Cl) during the PP which was calculated as follows: $\text{Cl} = (G_{\text{Cmax}} - G_{\text{basal}}) / (\text{PP duration} - 1)$. The AUC was calculated by the trapezoidal rule. Data were analyzed by SigmaPlot^h and are reported as mean ± SD. Significance was set at $P < .05$.

Results

Use of the Dynamic Feeder

All ponies remained healthy and free from lameness for the duration of the study and no change to pony pairs was required. The ponies learned to use the dynamic feeding system very quickly (within 48 hour), although 2 ponies took up to 5 days to use it consistently. Behavioral issues arose between the mare and gelding pairing (e.g. squealing, ears back), but impediment to feeder use was minimized by an individual housing configuration and a higher fence alongside the feeder (Fig 1B). Ponies using the dynamic feeder walked (some trotted initially) for approximately 2 hour twice daily. Overall, the average daily distance travelled by the ponies was 3.7-fold greater ($P = .01$) when fed from the dynamic feeder, compared to when they were fed from the stationary feeder (Fig 2A).

Body Morphometrics and Adiposity

Using the dynamic feeder for 3 months decreased mean BCS (6.53 ± 0.94 to 5.38 ± 1.71 ; $P = .01$), and CrNS (2.56 ± 1.12 to 1.63 ± 1.06 , $P = .03$), compared to no change after using the stationary feeder (Fig 2B, C). The dynamic feeding system also caused a decrease ($P = .01$) in body fat percentage ($4.95 \pm 3.82\%$; range 1.1–10.8%). Serum triglyceride concentration demonstrated a significant hyperbolic relationship with BCS before the study (Fig 3A). This curvilinear relationship is consistent with the potential for saturable triglyceride removal processes at the extremes of adiposity.²⁹ Triglyceride concentration was not altered by either the stationary or dynamic feeder (Fig 3B).

Neither feeder had an effect on heart girth or neck circumference (Table 1). The mean decrease in BW was

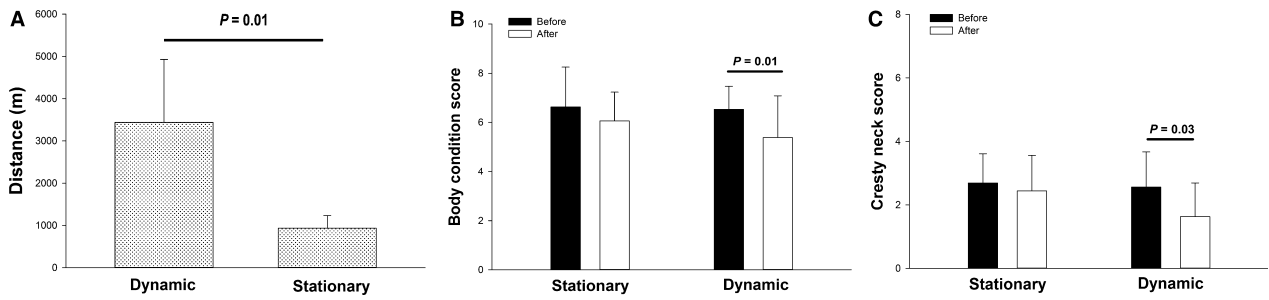


Fig 2. (A) The ponies travelled farther when using the dynamic feeder, compared to a stationary feeder (n = 6). Body condition (B) and cresty neck (C) scores were significantly decreased after 3 months of sustained, low-intensity exercise in ponies (n = 8). However, use of a standard, stationary hay feed for 3 months did not decrease either body condition (B) or cresty neck (C) scores.

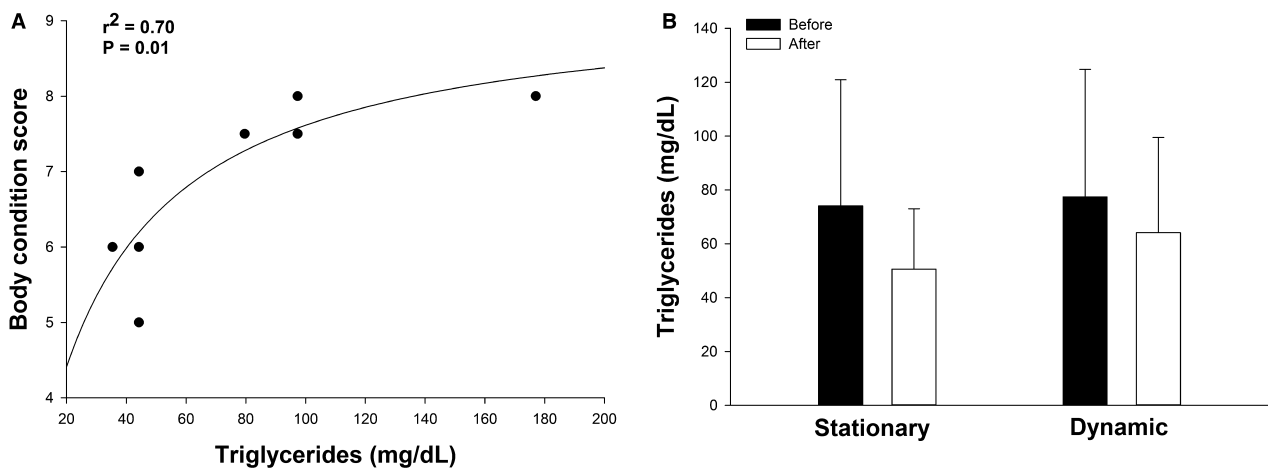


Fig 3. (A) Basal serum triglyceride concentration had a significant hyperbolic relationship with body condition score in ponies (n = 8). (B) Sustained low-intensity exercise did not result in a decrease in mean (\pm SD) serum triglyceride concentration, despite a decrease in body condition score. Feeding from a stationary feeder that did not induce exercise also did not alter serum triglyceride concentration.

Table 1. Mean \pm SD for BW and circumferential measurements of the heart girth and neck taken in 8 ponies before and after use of a dynamic or stationary feeder.

	BW (kg)	Girth (cm)	Neck (cm)
Stationary			
Before	255 \pm 88.3	147 \pm 16.4	83.6 \pm 9.33
After	254 \pm 90.5	146 \pm 17.6	80.8 \pm 8.27
Dynamic			
Before	254 \pm 89.7	148 \pm 19.6	81.4 \pm 8.32
After	246 \pm 87.7	146 \pm 18.3	82.1 \pm 8.2

BW, Body weight.

not significant after dynamic feeder use (Table 1). Similarly, the change in BW (Fig 4) after use of the dynamic feeder did not differ compared to by a stationary feeder ($-3.1 \pm 5.1\%$ and $-0.62 \pm 2.15\%$, respectively, $P = .07$).

Insulin Sensitivity

No markers of SI (G_{Cmax} , PP duration, Clearance, $AUC_{Glucose}$, or $AUC_{Insulin}$) were improved by the

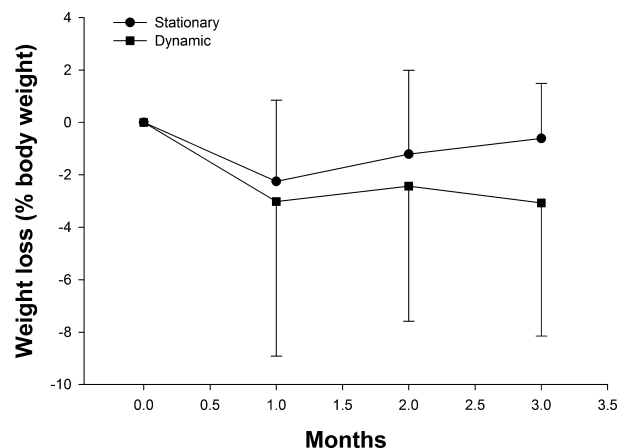


Fig 4. The mean (\pm SD) percentage change in body weight was recorded after use of a dynamic feeder that induced sustained low-intensity exercise for 3 months and compared to use of a stationary feeder.

dynamic feeder for 3 months, compared to a stationary feeder. However, if SI parameters were examined for the A-rated users only, PP duration ($P = .046$) and

AUC_{insulin} ($P = .045$) were marginally improved after using the dynamic feeder (Table 2). By comparison, there was no difference before and after either dynamic or stationary feeder use for the B-rated users (Table 2).

Discussion

Persistent low-intensity exercise (walking) was achieved in the current study by use of a novel, dynamic feeding system that significantly increased the daily distance travelled by ponies, compared to using a standard hay feeder. This consistent exercise over a 3-month period decreased fat percentage and improved body condition, consistent with the hypothesis that increased exercise decreases adiposity. However, the dynamic feeding system did not result in an improvement in SI (i.e., AUC_{insulin} and PP duration) in all ponies.

The ponies had no difficulty learning to use the feeding system after some initial training. However, behavioral responses to the feeding system were not consistent. The side-by-side design of the feeder ensured sufficient competition between paired ponies to promote consistent use of the feeder, and their physical separation at the feeder largely prevented dominance aggression from interfering with feeding. Despite this arrangement, 3 ponies were not sufficiently appetite-driven to use the feeder consistently for the entire 2-hour period. As a result, improvements in SI were either not apparent, or were less marked, in these individuals. Subjectively, willingness to use the feeder improved over the 3-month period in 2 of the poorer responding ponies. The reason for this increased compliance is unknown although an improvement in exercise tolerance may have contributed. Alterations to the feeder design may be able to address these behaviors, for example, by modifying the time allowed for feeding or using a movement sensor to trigger alternate door opening. The use of the feeder also can be adapted to suit individual requirements, such as increasing the amount of time spent accessing a forage ration (with smaller, more frequent meals). The ponies foraged for approximately 4 hours per day (2×2 hours) and

although no stereotypies were noted in the current study, adverse effects, such as gastric ulceration or behavioral abnormalities, could develop with restricted foraging. To address this concern, the time spent foraging (i.e., using the feeder) each day could be increased by altering the feeding regime.

The decrease in body fat and improvement in BCS observed in our study support the concept that exercise can be used to decrease obesity in horses. Previous studies on the impact of exercise on obesity have yielded conflicting results.^{18,21} One prior study found no association between exercise and risk of obesity.²¹ However, the horses and ponies in that survey completed only 4–6 hours of low-intensity exercise on average per week, compared with the 3–4 hours per day in the current study. A different study found that exercise of low then high intensity for 8 weeks decreased BW and fat mass.¹⁸ The decrease in fat mass in that study was substantially higher than in our study (21–34% vs 5%), yet as with our study there was no apparent improvement in heart girth and neck measurements. The reason why the morphometric measurements failed to reflect the decrease in fat percentage is unknown, but may be related to the time course of the study, given that a decrease in neck and heart girth circumference occurred after a 6-month weight loss program in client-owned horses,¹⁷ or may indicate that initial fat loss occurs from specific sites.¹⁶

Despite using different methodologies for assessing insulin dynamics, a previous study also found no improvements in SI,¹⁸ which may indicate that exercise is not a good approach to improving SI in horses, as it is in other species.^{30,31} However, a different study demonstrated that postexercise spikes in plasma insulin concentration were less marked after 14 days of low-intensity exercise.³² In our study, the improved insulin parameters recorded in ponies that used the feeder consistently appear to indicate that exercise has some beneficial effect on SI. In humans, it is not the intensity of the exercise that is most important for improving SI, but the overall amount of exercise undertaken,³³ which is consistent with the improved SI in ponies that were more willing to exercise consistently until the feeder was empty.

Table 2. Combined glucose-insulin test results (mean \pm SD) for 8 ponies before and after using a dynamic or stationary feeder. Ponies were rated on feeder use as either A ($n = 5$) or B ($n = 3$).

	AUC_G	G_{Cmax} (mM)	PP (min)	Clearance (PP)	AUC_I
Stationary					
A before	749 \pm 185	12.7 \pm 1.3	62.2 \pm 38	0.21 \pm 0.16	4285 \pm 4753
A after	796 \pm 143	13.8 \pm 1.1	58.8 \pm 29	0.21 \pm 0.18	5600 \pm 6059
B before	776 \pm 49	13.2 \pm 1.7	49.8 \pm 9.2	0.17 \pm 0.05	2278 \pm 1060
B after	898 \pm 52	14.3 \pm 2.7	76.8 \pm 35	0.14 \pm 0.07	5854 \pm 7105
Dynamic					
A before	803 \pm 167	13.2 \pm 1.4	^a 69.8 \pm 36	0.17 \pm 0.14	^b 6791 \pm 5716
A after	746 \pm 104	12.9 \pm 3.1	55.8 \pm 34	0.19 \pm 0.11	4279 \pm 4357
B before	873 \pm 84	14.5 \pm 2.7	72.2 \pm 39	0.16 \pm 0.09	5959 \pm 7009
B after	996 \pm 108	14.6 \pm 0.9	101 \pm 19	0.1 \pm 0.03	7501 \pm 7976

AUC , area under curve; G , glucose; C_{max} , maximum glucose concentration; PP, positive phase; before and after comparisons within treatment and group: ^a $P = .05$; ^b $P = .04$; comparisons of before values between and within treatments (i.e., A vs A before and A vs B before) were all $P > .05$.

Exercise may improve skeletal muscle insulin signaling in horses, at least in the immediate postexercise period.^{19,34} In addition, studies in humans have indicated that the persistence of improved glucose disposal and insulin sensitivity after exercise is variable and often wanes within 16–18 hours.^{30,35} The CGITs were performed approximately 24 hours after the last feeding session in our study, which means that any transient improvements in SI in the immediate postexercise period would not have been detected. However, longer term improvements in SI have been identified after physical activity^{36,37} and potentially, different types or longer periods of exercise or both may be required to substantially improve markers of insulin and glucose metabolism in horses in the longer term. In addition, CGIT data showed some inherent variability in our study, which is likely a function of small sample size, but also may be due to the labile nature of insulin and previous reports that the glucose parameters of the CGIT lack repeatability in horses.²⁶ Alternatively, tests used for measuring SI in our study (CGIT) and a previous study¹⁸ (frequently sampled IV glucose tolerance test) may not have been optimal for detecting early changes in insulin responsiveness, given that they do not include an assessment of the enteroinsular axis.¹⁰

The persistence of any beneficial effects of feeder use was not assessed in our study. The ponies returned to prestudy BW within 6 weeks of ceasing feeder use after a return to pasture access and continued hay supplementation. This outcome suggests that maintaining weight loss induced by the feeding system would require its continuous use. Conversely, the effect of continuous feeder use on BW and fat mass is unknown, and studies to determine whether longer term use of the dynamic feeder can induce additional benefit, or alternatively lead to adaptation and a plateau in BW, are required.

Previous studies have demonstrated that dietary restriction is effective at decreasing body mass and improving insulin parameters.^{16,38,39} Although our study did not restrict feed intake below 2% of BW (as may be recommended to achieve weight loss^{17,27}), the ponies did not have the ability to increase their feed intake, which may have contributed to their decrease in body fat and body condition during dynamic feeder use. In humans, a reduction in energy intake was superior to 12 weeks of aerobic exercise for improving SI.⁴⁰ Taken together, these data may indicate that a combination of dietary restriction and sustained low-intensity exercise is the optimal approach to weight loss in horses.

The feeding pattern of horses in the wild is based on natural roaming behavior.⁴¹ This process of “browse and move” while seeking forage results in frequent consumption of small amounts of roughage while traveling considerable distances.⁴² Domestic horses frequently lack enough space to emulate this feeding pattern and may not have any access to natural pasture. Alterations in the feeding and housing of domestic horses may contribute to behavioral, digestive, and metabolic diseases.^{43–46} Whether the use of a dynamic feeding system that induces structured, unsupervised exercise in ponies

housed in small paddocks would be beneficial for other applications beyond weight loss and EMS is unknown.

Overall, we determined that a dynamic feeding system can be used to induce sustained, low-intensity exercise that promotes weight loss in ponies. Furthermore, for ponies that commit to using the feeder and are willing to travel >3 km per day, some improvement in SI also may occur. However, it appears that exercise alone may not be sufficient to achieve substantial metabolic reform in animals with increased adiposity and that a combination of dietary restriction and exercise may constitute the optimal approach to weight loss.

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Conflict of Interest Declaration: Authors declare no conflict of interest.

Off-label Antimicrobial Declaration: Authors declare no off-label use of antimicrobials.

Footnotes

- ^a Barastoc horse block, Ridley Corporation, Melbourne Victoria, Australia
- ^b Wintec G-Rays 2, Berlin, Germany
- ^c Hero, Go Pro Inc, San Mateo, CA
- ^d Gallagher, Melbourne, Vic, Australia
- ^e Beckman Coulter, Lane Cove, NSW, Australia
- ^f Accu-Check, Roche Diagnostics, Castle Hills, NSW, Australia
- ^g Siemens, Bayswater, Vic, Australia
- ^h SigmaPlot v. 12.5, Systat Software Inc, San Jose, CA

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