Equine obesity: current perspectives

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Abbreviations

BCS	Body condition score
BWT	Body weight
ID	Insulin dysregulation
PPID	Pituitary *pars intermedia* dysfunction
SIRS	Systemic inflammatory response syndrome
EMS	Equine metabolic syndrome
TOFI	Thin on the outside, fat on the inside
NSC	Non-structural carbohydrate

Figures

Foreword

Equine obesity is now so common that is has become accepted by many as the norm [1]. Rates of obesity may be as high as 70% in some populations and obesity is often associated with morbidities that may ultimately result in mortality. Obesity is a common feature in animals diagnosed with equine metabolic syndrome, a conflation of metabolic disturbances including insulin dysregulation, which may lead to laminitis. Obesity is a risk factor for insulin dysregulation and is therefore implicated in laminitis risk. In addition to laminitis, morbidities associated with obesity include orthopaedic disease, hyperlipaemia, hyperthermia, infertility and poor performance. Over time, perception of what constitutes a healthy body condition in horses has shifted, with the result that potentially harmful excess adiposity may not be recognised by owners or those working in the equine industry [1]. In addition, increasing numbers of equines are kept as companions rather than athletes and live relatively inactive lifestyles favouring the development of obesity. Finally, owners of leisure horses often think their horses are working hard when, in reality, commonly their exertions have minimal or limited impact on their energy requirements.

Despite increasing awareness within the veterinary profession and equine industry of the impact of obesity on equine welfare, little progress seems to have been made in tackling it. This document was commissioned in order to provide veterinary surgeons with up to date information on equine obesity and to equip them to tackle it within their own practices. Recommendations were developed using an informal two-round Delphi process, considering published and unpublished research relating to equine obesity using a round table forum and online discussion. Where research evidence was conflicting or absent, collective expert opinion based on the clinical experience of the group was applied. The opinions expressed are the consensus of views expressed by the authors. Where agreement was not reached opposing views are presented such that readers can understand the arguments fully. The document is focused on the management of horses and ponies; whilst much of the information herein is applicable to donkeys it is important to recognise that the metabolism and management of donkeys are different and further research is required before specific recommendations can be made. The expert group was organised by *UK-Vet Equine* with sponsorship from Baileys Horse Feeds.

Defining adiposity, obesity and equine metabolic syndrome

Fat deposition is a normal physiological response to positive energy balance; however, the deposition of excess lipid and the expansion of adipose tissue results in metabolic disturbances. The terms physiological and pathological adiposity are used to attempt to make the distinction between normal and abnormal fat deposition. One cannot determine in an individual patient when adiposity becomes pathological and it is likely that there is variation determined both by genetic and environmental factors. The pathological processes that may develop with excess adiposity include inflammation, oxidative stress, stimulation of the hypothalamic-pituitary-adrenal axis, disturbances of cortisol and lipid metabolism and vascular dysfunction.

Obesity is the excessive (pathological) accumulation of fat to the point at which there is a negative health impact on the individual. Obesity may be generalised (Figure 1) or focal (regional), external (palpable subcutaneous depots) or internal (covert accumulations of adipose tissue within and around organs and muscle). Obesity may be difficult to identify if deposits are focal, particularly if they are internal rather than subcutaneous.

Horses with a body condition score (BCS) of $\geq$ 7/9 are considered to be obese [2,3] as fat is likely to accounting for greater than 20% of body weight (BWT). In very obese horses, fat mass may even

exceed 40% of BWT. Whilst a definition of obesity as BCS $\geq$ 7/9 is crude, it is widely used. Using a 5 point scale, the authors consider horses with a BCS > 3/5 as obese. However, the authors consider that the 9 point scale [4] is more appropriate due to its more extensive validation (Appendix 1).

Horses with a BCS of 5/9 are considered to be in healthy body condition. However, season should be considered when assessing appropriate body condition, given the fluctuations in body condition that naturally occur. The authors consider that horses should ideally be a BCS of 5 tending to 6 toward the end of summer and 5 tending to 4 at the end of winter i.e. owners should aim for corrective weight loss over the winter.

Equine Metabolic Syndrome (EMS) describes the presence of insulin dysregulation (ID) with or without other metabolic alterations associated with an increased risk of laminitis. Obesity is common in equines with EMS, but is no longer considered a defining feature. Strictly, EMS can only be diagnosed by demonstrating ID in the form of hyperinsulinaemia or abnormal insulin responses to oral or intravenous carbohydrate (simple sugars/starch) challenges. However, the diagnosis is often presumed if there is concurrent obesity and laminitis and the laminitis cannot be explained by other causes such as pituitary *pars intermedia* dysfunction (PPID), systemic inflammatory response syndrome (SIRS) , marked overfeeding of cereals or excessive weight bearing. Not all obese equines become insulin dysregulated, hence not all obese equines develop equine metabolic syndrome; however, other adverse effects of obesity on health may still ensue. Whilst by definition all equines with EMS are at an increased risk of laminitis, they will not all go on to develop clinical laminitis; genetics, environment and management are all likely to influence the potential for development of clinical disease.

Equines with EMS typically exhibit generalised or regional adiposity. Some may not appear to be obese; however, it is the opinion of some of the authors that many of these animals have adipose deposits that go unrecognised unless ultrasonography or evaluation of total body fat content by deuterium oxide dilution are performed to identify visceral or retroperitoneal fat deposits. Reports of the presence of EMS in the absence of internal as well as external obesity are lacking. The acronym *TOFI* is easily understood by horse owners and is applied to horses with a lean EMS phenotype that appear *Thin on the Outside but Fat on the Inside*. An alternate hypothesis is that obesity is not a primary cause of EMS, but instead, may be a marker of an underlying metabolic predisposition that, depending on other environmental factors (e.g., diet, level of physical activity), drives adipose tissue accretion and development of obesity (Figure 2) [5] . This has an important implication for treatment as it would suggest that the underlying metabolic dysfunction is likely to persist even with effective dietary management and weight loss. If this is the case then some native animals, regardless of how well their weight is managed, will always be at risk of laminitis if they are placed on rich pasture or receive a diet with high levels of soluble sugars/starch. Anecdotally, older ponies seem to tend toward deposition of intraperitoneal and retroperitoneal fat. Thus, obesity and insulin dysregulation may be overlooked in older leaner equids and equine metabolic syndrome (EMS) may be mistaken for PPID if appropriate investigations are not performed.

The authors consider that laminitis and EMS frequently go unrecognised in breeds that are susceptible to obesity. Clinical signs of acute laminitis are often attributed to other causes of foot pain or lameness and signs of chronic disease such as irregular horn grown are often missed or attributed to nutritional changes [6]. The presence of irregular growth rings which typically diverge toward the heel (Figure 3) is extremely common in native ponies and likely indicates prior episodes of laminitis [7] which may have been associated with pain even if this was not noted by the owner. Episodes of mild or sub-clinical laminitis are likely to render the affected animal more susceptible to more severe laminitis in the future.

Key Points:

- The accumulation of body fat is a normal physiological response to positive energy balance, but if it is excessive it may result in inflammation, oxidative stress, stimulation of the hypothalamic-pituitary-adrenal axis, disturbances of cortisol and lipid metabolism and vascular dysfunction
- Obesity refers to the accumulation of fat to the point at which there is a negative health impact on the individual. This includes impaired athletic and reproductive performance, susceptibility to some forms of colic, thermal stress, excessive loading of the joints and feet etc.
- Obesity may be generalised or focal (regional), external or internal. Internal fat deposits may not be detected unless appropriate ultrasonography or deuterium oxide dilution are performed.
- Equines with a body condition score (BCS) of ≥ 7/9 are considered to be obese as this typically equates to over 20% of their body mass being fat.
- Not all obese equines become insulin dysregulated hence they do not all develop equine metabolic syndrome.
- Equine Metabolic Syndrome (EMS) describes the presence of insulin dysregulation with or without obesity or other metabolic alterations that increase the risk of laminitis.
- Irregular and divergent hoof growth rings are often attributed to periods of stress or dietary change when they are actually due to previous laminitis.

Prevalence of equine obesity in the UK

In a survey conducted in 2005, 45% of pleasure riding horses in Scotland were considered to be obese [8]. A questionnaire-based study estimated 54% obesity in horses belonging to non-professional owners in the East Midlands in 2008 when a correction was applied for owners under-estimating the condition of their animals [9]. In another questionnaire based survey across the UK, owner determined prevalence of obesity was 31%; Draught, Cob, Welsh and native pony breeds and those described as good doers were more likely to be obese [10]. In the summer of 2011, 35% of horses living predominantly outdoors in North Somerset were considered obese [11]. Native breeds (particularly Cobs), older horses and horses that had sustained an injury were more likely to be obese. The prevalence of obesity was higher at the end of summer (35%) than at the end of winter (27%). In the same population 33% had a cresty neck score >3/5 [13]. A more recent study, which looked specifically at ponies aged ≥ 7 years within 50 miles of The Royal Veterinary College, found 72% were overweight or obese [12].

Horses used for pleasure, rather than competition riding, were more likely to be obese in one study [14]. However, the prevalence of obesity in competition horses also appears to be high. A study of 331 horses and ponies competing at a national unaffiliated championship found 41% were considered to be overweight (BCS > 5/9) and 21% were obese (BCS ≥ 7/9) with show and dressage horses being the most likely to be overweight [15]. A recent survey of 539 horse owners confirmed that owners have a poor ability to visually identify overweight animals and that perceptions of ideal weight for animals participating in showing classes was perceived to be significantly greater than for other equestrian disciplines {Morrison:2017gx}.

Key points

- Rates of obesity are likely to be 30-50% in the equine population and may be as high as 70% in native pony breeds.
- Obesity is common even in horses that are used for leisure-based competition.
- There is often disparity between what owners perceive to be a healthy body condition and what is actually healthy. Owners are typically poor at identifying overweight horses.

Consequences of obesity

Obesity has been demonstrated to have a number of negative consequences on health:

- Increased risk of laminitis [10]
- Poorer prognosis for recovery from laminitis (Menzies-Gow, unpublished data)
- Increased risk of hyperlipaemia
- Impairment of normal thermoregulation [16]
- Altered oestrous cycles and decreased fertility [17]
- Increased pro-inflammatory cytokine production characteristic of inflam-aging [18]
- Greater risk of osteochondrosis desicans in foals born to obese mare [19]
- Undesirable behavioural traits [20]
- Increased blood pressure

And may be associated with:

- Increased risk of orthopaedic disease through increased loading
- Preputial and mammary oedema and dermatitis
- Ventral oedema possibly as a consequence of compromised lymphatic drainage
- Strangulating small intestinal lesions caused by pedunculated mesenteric lipomas
- Greater susceptibility to hypertriglyceridaemia and hyperglycaemia when faced with other critical illness
- Inappropriate lactation possibly via effects on thermoregulation and prolactin production
- Subfertility in mares and stallions
- Reduced growth rates in foals caused by excessive mammary adiposity and reduced milk production
- Respiratory compromise [21]. Relative to total body mass the mass of the respiratory tract may decrease as much as 15% [2].
- Pharyngeal collapse
- Poor performance [22].

Identifying and quantifying obesity

Gold standard methods for evaluating total body fat mass such as carcass dissection, deuterium oxide (D_2O) dilution and bioelectrical impedance analysis are currently not practical for use in the clinical setting. D_2O dilution is straightforward and would be a valuable technique for clinical cases should measurement of D_2O become more widely available. Currently available algorithms for the evaluation of total body fat based on ultrasound-generated images of superficially accessible adipose depots are unreliable and should not be used [23].

Obesity is generally estimated using calculations from objective morphometric measurements or by subjective body condition assessment. Whilst is does not quantify obesity *per se,* measurement of body weight is the most robust practical means of monitoring responses to diet. Portable

weighbridges are extremely useful and are being used increasingly by ambulatory vets (Figure 4). They must be calibrated regularly to ensure their accuracy; a simple method being weighing a known volume of water . Weigh tapes provide a substitute for assessing weight but have not been validated for obese horses and take no account of focal adiposity; they are not recommended for the assessment and monitoring of obesity therefore. Changes in girth will lag behind changes in body weight.

Body Condition Score

Different body condition scoring schemes have been proposed with the 1-9 scale modified by Kohnke et al. in 1992 [4] from the original in 1983 [24] being the most widely accepted and studied. The original was specifically developed for assessing Quarterhorses with the focus being on those that may be underweight. At the top of the body condition scoring scale there is less discrimination of body fat content, but horses of BCS ≥7/9 are considered to be obese. There has been a tendency towards using simpler 1-5 or even 1-4 scales modified from the system reported by Carroll and Huntingdon [25]; however, they are not as well validated and when half points are introduced the potential benefit of simplicity is lost. If this scale is used, horses with a BCS greater than 3/5 are considered to be obese. Regardless of the system of scoring used owners will underestimate body condition [8,9,26].

Body condition score is less precise when used to assess UK native breeds [21], which are mostly overweight, and is very slow to change in response to reductions in body weight [27]. Morphometric measurements typically change before body condition score [7] and are therefore more useful in the assessment and monitoring of obesity.

Morphometric measurements

Crest neck score [28] and crest depth [29,30] provide estimates of nuchal fat deposition, and insulin resistance has been associated with neck crest adiposity in some studies [31,32]. However, the neck crest fat (Figure 5) is functionally discrete, heavily influenced by breed and develops and depletes more slowly than other fat deposits [13,33]. Furthermore, changes in nuchal crest adiposity reflect longer-term management trends, may be affected be season and may not correlate with generalised obesity [13]. Once a nuchal crest develops, it is unlikely to disappear as the extracellular matrix and fibrous tissue will remain even if the adipose deposits are depleted markedly (R Morgan, unpublished data). Measures of neck size are also less helpful in assessing the short-term management of obesity and responses to management changes.

In constrast, belly girth (Figure 6) provides the most sensitive indicator of generalised fat loss in response to management change and is arguably the single most useful measure for monitoring; heart girth (Figure 7) and rump width? may also used (Figure 8) [27,34].

In the future, a combination of objective measurements may prove to be easier and more robust to apply than the BCS system for owners, such as the body condition index that is derived using the heart girth, belly girth, neck circumference and animal height (REF) ; but more work is required for validation.

Ultrasonography

Ultrasonography is a sensitive means of assessing ventro-abdominal retroperitoneal fat deposition [35] [36]. Ultrasonographic measurement of fat thickness on the ventral midline immediately caudal to the xiphisternum and around 10 cm either side of the linea alba (Figure 9) should be performed in

animals that are apparently lean but are insulin resistant and/or laminitic to identify TOFI individuals. This adipose reserve is one of the first to be mobilised during weight loss and conversely, one of the earliest depots to expand during weight gain (ref). For animals allowed to follow seasonal patterns of summer weight gain and winter weight loss, season should be considered at the time of depot evaluation.

Ultrasonographic assessment of rump fat depth has been advocated [31], but in other studies there was no association between this measure and D_2O derived measures of total body fat [23,37].

Laboratory tests

There are no laboratory tests that will indicate reliably when adiposity starts becomes damaging to health; however, diagnostic testing can be very useful as an adjunct to clinical observations.

Although serum leptin concentration correlates well with adipose tissue mass, there is little correlation with insulin dysregulation and laminitis risk, making its value over clinical assessment limited [38,39] and it is not currently offered commercially in the UK. Adiponectin production typically decreases with increasing adiposity, though this is breed and diet dependent [40], and low total adiponectin concentration is associated with risk of laminitis [41-43] such that adiponectin is a potentially useful marker of pathological adiposity. Of the tests that are offered in the UK, to date only an immunoturbidometric assay for total adiponectin has been shown to be reliable and to correlate with laminitis risk, other methods generate inconsistent results [43].

Measures of insulin dynamics do not give an indication of obesity *per se* but are a useful means of assessing the risk of laminitis, which may be associated with obesity and metabolic dysfunction. Detailed discussion of the diagnosis of EMS is beyond the scope of this article and has been summarised recently [44,45]. Given that results should be interpreted in light of recent feeding, laboratory method used, and the test-specific reference range, the use of a specialist equine laboratory is recommended. Insulin concentrations can be measured in serum but may be influenced by pain or stress (such as occurs in laminitis), by recent ingestion of feedstuffs high in non-structural carbohydrates and (paradoxically) by fasting, potentially confounding results. Recommendations regarding measurement of basal insulin with respect to feeding have evolved and have come full circle such that it is now advised that insulin is measured in the normal state (without fasting) provided feeds with a high non-structural carbohydrate level have not been fed in the preceding 5 hours. Basal insulin concentrations provide an indication of insulin dysregulation if they are increased; however, the test has low sensitivity, so a normal result does not rule-out insulin dysregulation. Tests of insulin responses to oral glucose provide a more sensitive means of identifying insulin dysregulation and are therefore recommended if basal testing is equivocal?. The high-dose oral sugar test (or karo challenge) is simple to perform and can overcome issues of palatability which can occur when glucose or dextrose powder are used as the sugar challenge. Horses should be ideally be fasted for 3-12 hours (though this is not imperative), administered 45ml Karo sugar per 100kg BWT by mouth using a dosing syringe and then have 2 blood samples collected at 10-15-minute intervals between 60 and 90 minutes after the sugar was administered {Jocelyn:2018hk}. Results of the oral sugar test may vary considerably, for example when repeated quickly in the same animal. For example, a result of around 50uIU/ml on initial testing could differ by up to +/- 30uIU/ml on repeat testing although more modest variation is more common. When the test is used for monitoring purposes it is important that the conditions of testing are consistent to minimise variation and only large changes in results should be considered clinically relevant

Pituitary *pas intermedia* dysfunction (PPID) is a risk factor for laminitis and may occur concurrently with obesity. Obesity and EMS can be overlooked when PPID is diagnosed and it is important that insulin dysregulation is identified and managed in addition to providing therapy for pituitary dysfunction. Even aged, healthy horses tend to have a greater insulin response to diets rich in starch (REF) Effective management of insulin dysregulation will have a more direct effect on reducing laminitis risk than alterations in pituitary function. Horses previously diagnosed with PPID that have normal ACTH concentrations in response to treatment may continue to suffer from recurrent laminitis if concurrent insulin dysregulation is not controlled (Rainbow Equine Lab, unpublished data). Obesity will increase the activity of the hypothalamo-pituitary-adrenal axis and increase adrenocorticotropic hormone (ACTH) concentration in horses that do not have PPID [46] so there is a danger that obesity-related laminitis is mistaken for PPID. More conservative guidelines for the diagnosis of PPID have been recommended recently [47] and obese horses with mild increases in ACTH concentration should be appraised critically before they are treated with pergolide. Application of the thyroptropin releasing hormone stimulation test and titration of the dose of pergolide in response to diagnostic testing aids in differentiating horses with PPID from those with obesity and EMS.

Key Points:

- Body condition scoring has merit but is a crude, subjective means of assessing obesity.
- Equine practices should look to utilise portable weighbridges to monitor body weight accurately.
- Belly girth provides a sensitive indicator of generalised fat loss in response to management change; heart girth and rump width may also be monitored.
- Ultrasonographic assessment of retroperitoneal fat on the ventral midline should be performed in animals that are apparently lean but are insulin dysregulated and/or laminitic.
- Measures of insulin dysregulation do not give an indication of obesity but are used to identify equine metabolic syndrome and laminitis risk with which it may be associated.
- Measurement of adiponectin using an immunoturbidometric method is a useful means of assessing adipose dysregulation and laminitis risk.
- Obesity should not be overlooked in animals suspected of having PPID and obesity may complicate diagnosis by increasing pituitary activity.

Gathering data and setting targets

Knowledge of what is currently fed and what is possible under the individual circumstances will facilitate implementation of a weight loss programme but most plans will follow a very similar format. Success often hinges on understanding the behaviour and the attitude of the owner in order that they can be supported most appropriately in order to implement effective and lasting change. Gathering data and ensuring that clients engage takes time, so it is often more appropriate to arrange a follow-up appointment with a vet or other suitably qualified person to ensure it is done effectively. Getting the client to complete a questionnaire ahead of the consultation expedites the process (Appendix 1). In small animal practice, veterinary nurses usually oversee weight management clinics who usually have more time and patience that make them better suited to running weight loss programmes than vets. In addition, studies performed in small animals have indicated that vet psychology and attitudes of vets to obesity are as great a barrier to effective weight loss as owner attitudes [48]. Owners need to understand what they are trying to achieve; in the management of obesity in man, success rates are higher if the patient understands and has ownership of their weight loss programme [49].

In controlled environments, bodyweight reductions of 1% per week accompanied by increases in insulin sensitivity are achieved consistently [27,50] [34]. In a study of client owned animals in the UK, mean weight loss after 23 ± 21 weeks was 43 ± 39.3 kg, which corresponded to 8.9 ± 6.7% of bodyweight [50]. Only one horse failed to lose weight but the rates of loss were considerably lower than in animals kept in controlled conditions. Thus, a reduction in BW of 0.5-1.0% per week is a realistic target. Very rapid weight loss was associated with more rapid subsequent weight gain in one study {Bruynsteen:2015il} so there may be merit in more conservative and sustainable approaches to dietary restriction. However, the rate of weight loss in overweight cats and dogs slows over time [51], and those that are most obese are less likely to complete their programme [52] so it is important that targets are reviewed regularly and management adjusted accordingly. Further work is required to determine whether or not the same is true in horses.

Key Points

- Collecting the necessary information to ensure compliance with weight loss programmes is time consuming and may be better performed on a follow-up visit.
- Asking clients to complete a questionnaire ahead of the consultation is advantageous.
- Vet nurses may be better suited to coordinating weight loss programmes than veterinary surgeons.
- A target of 0.5-1% reduction in BW per week is appropriate for most horses.
- Targets and progress should be written down and given to the owner.
- Once targets are reached plans for ongoing management and monitoring need to be implemented.

Nutrition and management of the obese equine

Programmes of weight loss have to be tailored to the patient and have to consider what is achievable for the owner. In some horses, discontinuation of overfeeding and provision of more appropriate feed sources may be sufficient to induce weight loss. Veterinary involvement frequently follows diagnosis of EMS, which in turn often occurs after laminitis has developed. In these patients, weight loss programmes ought to be more aggressive as there is an increased risk of future laminitis, there is an additional desire to limit hyperinsulinaemia and exercise cannot be included as part of the management programme. If weight loss programmes are being implemented prior to the development of laminitis or other morbidities, then there is more time and there may be less necessity to remove horses from pasture and control every aspect of the diet.

Access to pasture is always desirable as it allows expression of normal behaviour; however, when pasture access is maintained it is very difficult to estimate intake (Text box 1) and there is a tendency to underestimate overall feed/calorie intake. Restricting access serves to increase their intake over a short period [57]. Therefore, even short periods of turnout can severely undermine programmes of weight loss as they may contribute all the energy that is required for daily maintenance with the additional hay that is fed only serving to provide extra calories. When conditions are favourable, non-structural carbohydrate levels in grass can exceed 30%, comparable to levels in many cereal-based proprietary feeds. It is therefore advantageous to eliminate access to pasture during the initial period of weight loss in an obese animal. If pasture turn-out is permitted, then consideration should be given to the nature of the pasture (Text box 2). Sand or wood-chip areas of turn-out would be preferred as complete control over the diet is retained (Figure 10). Hungry horses need to be monitored to ensure they do not ingest large quantities of bedding or other material, such as straw, hemp or wood shavings. Wood shaving intakes of up to 3.5kg daily have been recorded in some ponies on restricted hay intakes {Curtis:2011dd. Ingestion of small amounts of straw is unlikely to be problematic;

however, ingestion of large quantities or ingestion of large quantities of other dry material may lead to gastrointestinal impaction and the use of rubber matting without bedding should be considered.

Grazing muzzles can be an effective means of reducing pasture intake, although their effectiveness varies with design and between horses [56,58]; reductions in dry matter intake from 30% to 83% have been reported [56,58,59]. The muzzle should be the appropriate size so it fits well and should be carefully introduced to enable the horse to acclimatise. Grazing muzzles must be used with care and an owner guide and video is available from the National Equine Welfare Council http://www.newc.co.uk/advice/horse-and-donkey-care/grazing-muzzles-2/. Some people perceive grazing muzzles to be cruel, which can be a barrier to their use particularly on livery yards; education is therefore important if their use is contemplated.

Where pasture access is restricted by strip grazing (electric fences), or limiting pasture area, attention should be given to ensuring freedom from potentially toxic weed or boundary plant species (e.g. ragwort, yew, cypress, ivy) which hungry animals may consume. Overly short sward lengths can promote soil ingestion and may result in inappropriate abrasion of the incisors and sand impactions. Where electric fencing is used, more frequent moving of fences to open small areas of fresh graze is preferred to weekly additions of larger areas in order to maintain more consistent intakes. A practical means of assessing changes in pasture intake in response to management change is to assess faecal output. This often needs to decrease by approximately half in order for there to be weight loss if the horse had previously had unrestricted access to pasture.

Hay should comprise the bulk of the ration in any horse that is obese. Quality varies and whilst forage analysis is cheap when performed through feed companies (approximately £30) and is widely available, it is rarely performed in practice. The DM and nutrient content of hay varies and will depend on the grass species present, time of cut and how the hay is cured. In the absence of forage analysis, grass based hay should be assumed to be 90% dry matter and to be low in protein. Soaking hay markedly decreases the DM and mineral content of hay and has a variable impact on water soluble carbohydrate (WSC) intake and protein content [60-63]. While the feeding of soaked hay may aid in decreasing WSC contents, soaking hay DM can lead to a greater restriction of dietary energy provision than was originally intended [Argo et al 2014]. Similarly, when forage is fed at the levels required for weight loss, protein levels may already be insufficient [27]. Therefore, a low calorie protein, vitamin and mineral balancer should always be included in the diet of animals offered soaked hays.

A typical practical starting recommendation for a horse undertaking little or no exercise that requires more aggressive weight loss restriction would be to feed a mature grass based hay at 1.5% BW as fed dry (assuming 90% DM) or 1.8% (pre soaked weight?) as fed if being fed after having been soaked (assuming 20% loss of DM with soaking) to promote weight loss (Figure 11). However, it should be remembered that the effects of soaking are variable (Text box 3) and any estimate is simply a starting point and will have to be adjusted according to the patient's response. Within any population that is managed in the same manner, there will be large variation in body condition between individuals and there is similar variation in responses to dietary restriction. Some animals exhibit "weight loss resistance" and may require repeated re-evaluation and further reduction in their feed intake [56]. Feed intakes of 1% BM as daily DM intake are considered the minimum desirable level.

Owners are often concerned that restriction of forage intake increases the risk of gastrointestinal disease. Whilst gastric disease will be induced by cycles of fasting the level of restriction required for weight loss did not result in gastric disease in one study with ponies [64]. Fasting overnight is not associated with gastric disease [65].It is sensible to extend the amount of time eating as much as possible by giving multiple small meals, small weave haynets, double haynets, hanging multiple nuts, or hanging nets away from a wall [66].

Given that the dry matter and nutritional composition of haylage is variable, it should not be used as part of the diet in an obese horse unless it is analysed and the ration calculated accordingly, as feeding some haylages will result in a marked hyperinsulinaemic response. Cereals, oils and treats such as carrots and apples should be eliminated from the diet.

Text box 1. Estimating pasture forage intake

Currently, it is not practical to determine the nutrient contribution of pasture to a mixed diet and only very rough estimates can be made:

- Grass intake of ponies can approach 5% of BW as dry matter (DM) when they have 24 h access [53].
- Ponies can consume 1% of their bodyweight as pasture DM within 3 hours [53,56]
- Grass intake by horses is typically lower at ~2-2.5% BW/day on a DM basis [54,55].
- The contribution of pasture to the daily DM intake can be estimated by subtracting the amount of supplemental feeds/forage provided from a given daily DM intake level (e.g. 4% of BW for ponies out at grass for >16-18 h/day; 2-3% BW for horses).
- An alternative approach is to estimate intake as a function of time at pasture – for horses 0.4% BW as DM per 3 h of turnout up to a maximum of 1% BW when turned out during the day and stabled at night. For ponies these rates and maximum values may double.

These estimates assume good quality pastures. If there is limited herbage, intake may be reduced (but sugar content may be higher, see text box on pasture management). If there are lawns and troughs then intakes depend on whether individuals graze the rough areas. Intakes will also be affected by season.

Text box 2. Pasture management and Hay Production

Access to pasture that is high in NSC has undesirable short and long-term effects. Short-term, hyperinsulinaemia may result increasing laminitis risk and long-term the high calorie content will frustrate attempts at weight loss. It is unknown exactly how the NSC content of the grass and rate of ingestion influence laminitis risk and it is therefore prudent that laminitics do not have access to high quality grazing, even for short periods. If turn-out is to be permitted, then factors that affect the sugar content of grass should be considered:

Text box 3. Hay Soaking

The WSC content of UK hays is highly variable and if the WSC content is unknown then the hay should be soaked. The effect of soaking can be as variable as the initial W content and in one study in which hay produced commercially in the UK was soaked for 16 hours at 8°C the reduction ranged from 6-54% in with a mean of 27% [63]. By contrast, in another study soaking for 14 .5 ± 2.1 hours resulted in a mean reduction of 50.1% NSC with little variation between samples [67]. Water temperature can have a marked effect and soaking in water of 16°C for 1 hour has a similar effect on sugar content as soaking at 8°C for 16 hours; in colder weather the use of warm water should be encouraged [60]. Whilst soaking should be recommended, it is impossible to determine the effect it will have (short of

repeating forage analysis post-soaking). Therefore, the response in the individual horse should be monitored closely. In addition to reducing WC content, soaking hay will also reduce the DM, vitamin and mineral content of hay [61-63,68], hence the need for a vitamin and mineral balancer.

Key points:

- Weight loss programmes should be tailored to the patient and progress needs to be re-assessed every 4-6 weeks.
- Pasture access is the major factor in the development of obesity and has to be restricted or ideally eliminated in order to effect weight loss.
- Areas of non-grass turn-out are very useful.
- Grazing muzzles can be useful means of restricting pasture intake as part of a weight management programme
- Faecal output is a useful indicator of pasture intake and often needs to halve for there to be weight loss.
- As a practical guide to promote significant weight loss, mature grass hay should be fed at 1.5% BW if being fed dry or 1.8% if being fed post soaking.
- If the sugar content of hay is not known then it should be soaked for at least 6 hours in cold water or 1 hour in warm (16°C) water.
- When feeding a hay restricted diet a low calorie protein, vitamin and mineral balancer should also be fed especially if the hay is being fed post soaking.

Exercise

The effect of exercise on ID in horses is inconsistent between studies. In some studies, relatively short periods of exercise (20-30 minutes) appear to increase insulin sensitivity even in the absence of weight loss [69] and overweight ponies which were exercised for six weeks whilst on a controlled diet had improved insulin sensitivity [70]. Weight loss will result in some undesirable muscle loss in addition to the desired fat loss; regular exercise may help to limit loss of muscle and may have an anti-inflammatory effect .

It has been recommended that half-hour sessions of exercise, which raise heart rate to over 150 beats per minute (which typically requires canter work), should be performed 5 days per week assuming they will not have other detrimental effects on the animal's health by exacerbating laminitis or lameness (McGowan, personal communication). However, some recent work has shown a beneficial effect on tissue insulin sensitivity of adding, to a dietary restriction protocol, exercise of a lower intensity (5 times a week : 5 min walk, 15 min trot (2.0–3.5m/s, according to size) and 5 min walk (Bamford et al 2018) The exercise that is generally undertaken in overweight horses is frequently inadequate and may be unlikely to have significant effect on ID or obesity especially when not combined with energy restriction. Exercise is no substitute for an appropriate diet and moderate exercise in the absence of dietary restriction or turn-out to stimulate exercise has no effect [71,72]. Given that the effects of exercise on insulin sensitivity are short-lived [73], exercise should be regular in horses that have insulin dysregulation, and should be continued after the desired level of weight loss has been achieved. Studies of weight loss which compared dogs that exercise with dogs which are unable to exercise due to orthopaedic disease found no significant differences in the rate of weight loss when the dogs with orthopaedic disease were subject to an extra 5% reduction in energy (A. German, unpublished data).

Key points:

- Exercise is no substitute for dietary restriction.
- Exercise may be beneficial in increasing insulin sensitivity, reducing inflammation and limiting muscle loss.

Rugging

There is a misconception among horse owners that horses require rugs in all but the finest of weather. Rugs may be necessary in warm and hot-blooded breeds in bad weather, but most native breeds are designed to withstand inclement weather. The use of rugs limits energy losses and they should therefore be avoided where possible. Loss of weight during colder winter weather is normal, and should be encouraged where horses have gained weight through the summer.

Monitoring

- Re-assesment should be performed every 4-6 weeks. Ideally, the animal would be re-examined and weighed but a telephone conversation may suffice. Ideally, clients should keep weekly records of morphometric measurements such as heart and belly girth.
- If the target rate of weight loss is not achieved after 4-6 weeks, then compliance should be questioned and the horse's diet and management reviewed. If there are no issues of compliance, then the amount fed should be reduced by 0.25% of bodyweight.
- Even with identical management, there will be marked variation in rates of weight loss between individuals and some horses will exhibit marked "weight loss resistance" [34].
- Reduction in the amount fed to less than 1% of bodyweight as DM of fresh dry mature grass hay (estimated as 1.1% as fed weight) is not recommended.
- Up to 50% of the hay ration can be replaced by straw, to reduce calorie intake further whilst maintaining fibre intake.
- Straw should be introduced gradually to help avoid gastrointestinal complications (and needs to be of high hygienic quality with the seed heads shaken free before feeding). If weight loss is not achieved having reduced feed to 1% of bodyweight as DM of low sugar (<10-12% WSC) forage, and there are no doubts over compliance, then treatment with levothyroxine might be considered.

In the management of type 2 diabetes mellitus in people, the degree of weight loss correlates with the number of contacts with the healthcare provider [74]. It has also been suggested that follow-up contacts are as important in further educating the patient and re-enforcing the importance the managing obesity as they are in assessing progress and modifying the diet and management plan [49]. Regular reassessments should, therefore, be scheduled from the outset or there is a risk that they will not happen. Owners are unlikely to see visible changes in BCS in the early diet period but where interventions are effective, clear differences in belly girth should be recorded. Weekly monitoring of belly girth and potentially other measurements (see above) by the owners is a useful aid to optimising compliance.

Once the target weight is achieved, it is important that monitoring is continued or experience from other species indicates that diet and management changes will not be maintained in a large proportion of cases and many will return to an obese state. Equines that have lost weight may still exhibit insulin dysregulation and, if they do, should continue to be fed low sugar (<10-12% NSC DM basis) feeds that will limit hyperinsulinaemia. A high fibre, low cereal diet will be healthier so any return to feeding

cereals after weight has been lost should be discouraged. Any subsequent gain in weight, however transient, may be associated with decreased insulin sensitivity and therefore increased laminitis risk.

Key points:

- Regular follow-ups are essential.
- If there is insufficient progress, management should be reviewed. If there are no issues with compliance, the amount of hay fed should be reduced by 0.25% BWT every 4-6 weeks.
- The amount fed should not drop below 1% BW DM (1.2% DM if being soaked).
- Straw can be used to comprise up to 50% of the ration. The straw should be clean, shaken to remove any seed heads and introduced gradually.
- If there is genuine "weight loss resistance", pharmaceutical treatment might be considered.
- Once target weights are achieved, dietary management and monitoring must continue to prevent obesity from recurring.
- A return to appropriate body condition does not guarantee improved insulin sensitivity and absence of laminitis risk.

The psychology of weight loss

The increasing prevalence of obesity in horses parallel trends in humans and other domestic animals. In humans, the prevelance of obesity has quadrupled in the last 25 years, to around 30%, and there are expected to be 11 million more obese adults in the UK by 2030 [75]. This trend is reflected in our pets with around 50% of dogs in the UK being overweight or obese [76].

Obesity in pets has been considered as a model for obesity in children [77], making obesity is a genuine one health issue. These similarities between children and pets, likely reflect as both have their lifestyle and diet determined by a parent or owner. There are associations between obesity in owners and their pets [78] as there are between parents and children. In both children and pets the suggestion that obesity is related to poor nutrition and increasingly inactive lifestyles has been challenged. In children, fat mass may be a cause of inactivity rather than an effect [79]. Other factors in the child obesity epidemic include genetics ("thrifty genes"), weight set-point, low metabolism, a food-rich environment, the cost of healthy, low-energy food and poor food choices [80]. Some of these factors, particularly genetics, low metabolism and the food-rich environment will also apply to horses.

An addiction model of obesity in both children and pets has recently been proposed in which it has been suggested that a major factor in obesity is the desire for parents or owners to obtain affection from their children or pets with treats and excessive meal sizes [80]. It is conceivable that a similar psychological bond develops between horses and their owners as the time horse and owner spend together often centres on the feeding routine. However, not all experts are agreed that the addiction model is valid in people (Alex, ref) or in pets (A. German, personal communication). Furthermore, in horses which typically live out at pasture, ingestion of pasture is likely to be the predominant factor in the development of obesity [11].

Restriction of feed can be associated with negative behaviours from pets or children and loss of the affection that normally accompanies feeding may prevent the parent from continuing with feed reduction [80]. Dogs learn quickly how to get extra food, and how to respond if they do not get it, providing support for the theory that pets can evade feed withdrawal in a similar manner to children

[81-83]. Horses no doubt do the same. Withdrawal symptoms typically last for a few days and may recur for 2-3 days after each reduction in portion size [80]. Weighing of food (Figure 11) has been demonstrated to reduce "withdrawal indecision" whereby parents or owners will add extra to portions having convinced themselves that they are not providing enough [84].

A number of strategies used to cope with feed restriction in children [80] might be applied to horses. The horse should not be exposed to trigger factors for eating such as stress, boredom, the sight of food or other stimuli associated with feeding. Distractions from the desire to be eat should be provided, for example exercise, environmental stimulation and interaction with humans or other horses. Horses that are denied food when other horses in the group are being fed will exhibit behaviours that are indicative of stress (P. Harris, unpublished data) and it is therefore important that they are given something to eat, for example a small amount of low calorie chaff or balancer.

Practical measures used in children [80] that could be modified for horses would include the use of smaller plates (or bowls/nets), smaller serving scoops (Figure 12) and preventing the horse in question from being able to see, hear or smell the feed room or other horses eating. Applying these measures may be challenging, and potentially impossible, in some management settings particularly when individual owners are not able to control management practices on the yard. An additional challenge in the management of equine obesity is compliance of others on the yard, particularly on livery yards where there are multiple people involved with the care of individual animals and many other others that take it upon themselves to become involved.

Key points:

- Owners need to be prepared for the fact that weight loss will take time.
- Owner attitudes to food may be important in managing equine obesity, obesity in people and their pets are linked
- Owners require support to overcome the negative psychological effects that may accompany restricting their horse's feed, particularly when they do not receive the support of their peers.
- Food should be always be weighed prior to feeding.

Medical treatments for obesity

Pharmaceuticals should not be an excuse for poor compliance with weight loss protocols and should only be used when there is insulin dysregulation and/or a history of laminitis or other confounding factors. Some authors felt the use of pharmaceuticals could not be justified in addressing obesity/EMS under any circumstances as diet and management should be sufficient to induce weight loss. The authors were concerned that veterinary surgeons are overprescribing pharmaceuticals for the management of obesity and EMS [85] at the expense of ensuring compliance with management changes and concerned that there can be a tendency for owners to rely on pharmaceutical treatment and to neglect the dietary and management interventions.

Levothyroxine

Levothryoxine has been demonstrated to be an effective means of inducing weight loss and increasing insulin sensitivity in small numbers of normal horses [90-92]. However, clinical trials in obese horses have not been performed and there is no evidence that the weight loss is due to reduction in total body fat mass. The induction of a hyperthyroid state has been demonstrated to be safe in small numbers of horses [93,94], but further, larger studies are required to be confident of its safety and efficacy before its wide scale use can be recommended and some authors counselled against its use

at all. Levothyroxine administration has been reported as an adjunct to dietary management in horses that cannot be exercised [95] and has also been used in horses with "weight loss resistance" and in severe cases of laminitis associated with insulin dysregulation that were not responding despite conventional management (ref). However, objective and published clinical outcome data is lacking in the horse. Concerns have been expressed over the potential for an increase in activity, hunger and metabolic rate that may stimulate cortisol release, offsetting any potential benefit. However, clinicians using levothyroxine in the UK and the United Sates do not report such effects and report a subjective impression of benefit. Controlled studies with more objective measures of outcome are required. Recommendations for the use of levothyroxine are derived from extensive clinical experience in the United States where a 3- to 6-month duration of treatment at a dosage of 0.1 mg/kg PO SID is recommended. Treatment is continued until target body weight is reached at which point the dose is decreased by 50% to 0.05 mg/kg for 2 weeks before being reduced by 50% again to 0.025 mg/kg for a further 2 weeks prior to discontinuing treatment [96].

There is no equine licensed medicine for use in the horse containing levothyroxine, and therefore can only be used under the prescribing cascade. Canine palatable tablets marketed in the UK contain natural meat flavouring (SPC) and therefore are not appropriate since animal by-products are prohibited from being fed to horses in the UK. When indicated, veterinary surgeons can consider alternative steps in the prescribing cascade including the use of human formulations or, where appropriate, extemporaneous preparations (specials) but should be able to justify their selection and obtained informed owner consent[a]. Levothyroxine is permitted in food producing animals, but is a controlled medicine in competition animals.

Metformin

Metformin is used widely in the treatment of type II diabetes in people and has therefore been proposed for the management of equine metabolic syndrome in horses. In people, metformin is rarely used as a monotherapy. The authors do not consider that metformin is indicated for the management of animals that are simply obese and question its efficacy in equines that have EMS.

The efficacy of metformin in EMS is disputed as very little of it is systemically available in horses [86,87] and its use does not appear to be associated with detectable improvements in insulin sensitivity [88]. Metformin might be of benefit for EMS through actions at an intestinal or hepatic level and influences on the enteroinsular axis; metformin has been demonstrated to impair glucose absorption and reduce the rise in insulin which occurs following ingestion of glucose in non-obese horses [89]. This may be of benefit in reducing glucose absorption and in limiting post prandial hyperinsulinaemia, which is a factor in the development of laminitis. However, effects are likely to be limited to a few hours after administration and there is no robust evidence of improved outcomes, compliance or body weight in treated animals. If metformin is administered TID (suggested dose rate 15-30 mg/kg BID or TID) the clinical benefit over a 24-hour period is unknown. Furthermore, if the diet is suitably low in WSC there should be no need for the administration of metformin. If diet is not controlled, metformin will have negligible effect. If there were an indication for metformin, then it would be an hour before feeding or pasture turn-out on the assumption that it will limit hyperinsulinaemia for 2 or 3 hours after administration, although research is required to confirm this application. The use of metformin may lead to the dangerous assumption by the owner that pasture intake does not need to be limited.

Metformin is not licensed for use in horses in the UK and is used in accordance with the cascade. Human tablets may be used but ensuring large numbers of tablets are eaten can be problematic in some cases and the tablets have rarely been associated with oral ulceration (Mark Bowen, unpublished observations). Extemporaneous preparations of metformin powder or palatable pastes

are available in the UK as “special” preparations and their use under the prescribing cascade must be justified on an individual animal basis. Written consent should be obtained whenever using medicines not licensed for use in the target species. Metformin is a controlled medicine and should not be used in competition animals. It cannot be used in animals intended for human consumption and if used the horse should be permanently excluded from the human food chain by proper endorsement of the horse passport.

Other treatments

Pergolide is used widely for the treatment of PPID, which may accompany obesity. Despite a recent questionnaire survey of equine veterinary surgeons indicating that 20% used pergolide for the management of EMS [85], there is no indication for its use in the management of obesity or EMS in the absence of PPID. Whilst it had been suggested that pergolide might have an insulin sensitising effect, a recent investigation determined that dopamine agonists do not increase insulin sensitivity [97]. Various nutraceuticals have been suggested to be of benefit in the management of obesity and particularly EMS, but there is insufficient scientific evidence to justify their use.

Key points

- The use of medical treatments should be a last resort and should only be necessary in a small number of obese horses, if any.
- There is insufficient evidence of the merits of pharmaceutical treatment in the management of obesity and EMS.
- Metformin reduces glucose absorption and insulin responses and may thereby reduce laminitis risk. However, effects are short-lived and metformin is not indicated in the management of obesity.
- Levothyroxine is effective in inducing weight loss and increasing insulin sensitivity in healthy horses, but does so by inducing a state of hyperthyroidism and should only be used as a last resort with consideration of possible adverse effects.
- If levothyroxine is used then close monitoring and dietary restriction are essential and the dose should be tapered prior to discontinuing treatment.

Future directions

The panel identified a number of stakeholders who will need to be included in efforts to reduce levels of obesity in the UK equine population.

1. The breed societies for those breeds that are at increased risk of obesity and EMS i.e. all UK native cold-blooded breeds. These societies need to be pro-active in informing their owners of the risks associated with keeping their breeds in modern management systems and in providing information on preventing and managing obesity.
2. The showing council. Showing has celebrated the obese horse for decades and has contributed to the distortion of the perception of how horses should look. Many show horses are perpetually at high risk of laminitis and many show evidence of chronic laminar disease. Radical change needs to be implemented so that obese horses are not successful in the show ring and fit athletic horses are celebrated. Horses with evidence of prior laminitis ought to be penalised.
3. Horse owners and yard owners need to be educated on:
    a. Their perception of what constitutes a healthy body condition
    b. How little most equines need to be fed in order to maintain a healthy body condition

    c. The normal cycle of weight gain and weight loss over a calendar year
    d. The negative consequences of obesity on equine welfare
4. Livery yard owners need to be supportive of owners who want to maintain their horses in a healthy body condition. All livery yards where there are native types should have areas of non-grass turn-out to enable effective management of equine obesity. Yard owners frequently dictate how and where horses are grazed and often this is not in the animal's best interest. Yard owners can also blamed unfairly for owners' poor compliance and it is often helpful if vets engage directly with yard owners.
5. The pony club who need to be educating the next generation of horse owners to effect real change in the next generation.
6. The British Equine Veterinary Association who could pay a role in co-ordinating educational partnerships with equestrian organisations.
7. Individual veterinary surgeons who should be proactive in assisting clients in recognising obesity and advising on implementation of effective weight management programs.

Appendices

1. Figure 2. A 9-point system for body condition scoring horses.
2. Sample questionnaire from the University of Edinburgh for the investigation of endocrinopathic laminitis.
3. Template for a weight loss monitoring chart

Footnotes

[a] BEVA provide free client information leaflets, that are recommended when using medicines under the cascade that are not licensed for use in the horse (beva.org.uk/cascade).

References

1. OWERS, R. and CHUBBOCK, S. (2012) Fight the fat! *Equine Vet J* **45**, 5–5.

2. Dugdale, A.H., Curtis, G.C., Harris, P.A. and Argo, C.M. (2011) Assessment of body fat in the pony: Part I. Relationships between the anatomical distribution of adipose tissue, body composition and body condition. *Equine Vet J* **43**, 552–561.

3. Dugdale, A.H.A., Grove-White, D., Curtis, G.C., Harris, P.A. and Argo, C.M. (2012) Body condition scoring as a predictor of body fat in horses and ponies. *Vet J*.

4. Kohnke, J. (1992) *Feeding and Nutrition: the Making of a Champion*, Birubi Pacific, Australia.

5. Mccue, M.E., Geor, R.J., Science, N.S.J.O.E.V.2015 Equine metabolic syndrome: a complex disease influenced by genetics and the environment. *Elsevier*

6. Potter, S.J., Bamford, N.J., Harris, P.A. and Bailey, S.R. (2017) Incidence of laminitis and survey of dietary and management practices in pleasure horses and ponies in south-eastern Australia. *Aust Vet J* **95**, 370–374.

7. Karikoski, N.P., McGowan, C.M., Singer, E.R., Asplin, K.E., Tulamo, R.M. and Patterson-Kane, J.C. (2015) Pathology of Natural Cases of Equine Endocrinopathic Laminitis Associated With Hyperinsulinemia. *Vet Pathol* **52**, 945–956.

8. Wyse, C.A., McNie, K.A., Tannahill, V.J., Tannahil, V.J., Murray, J.K. and Love, S. (2008) Prevalence of obesity in riding horses in Scotland. *Vet Rec* **162**, 590–591.

9. Stephenson, H.M., Green, M.J. and Freeman, S.L. (2011) Prevalence of obesity in a population of horses in the UK. *Veterinary Record* **168**, 131.

10. ROBIN, C.A., Ireland, J.L., Wylie, C.E., COLLINS, S.N., Verheyen, K.L.P. and Newton, J.R. (2014) Prevalence of and risk factors for equine obesity in Great Britain based on owner-reported body condition scores. *Equine Vet J* **47**, 196–201.

11. Giles, S.L., Rands, S.A., Nicol, C.J. and P, H.A. (2013) Equine obesity: prevalence and risk factors in domestic-herd living populations.

12. Menzies-Gow, N.J., Harris, P.A. and Elliott, J. (2017) Prospective cohort study evaluating risk factors for the development of pasture-associated laminitis in the United Kingdom. *Equine Vet J* **49**, 300–306.

13. Giles, S.L., Nicol, C.J., Rands, S.A. and Harris, P.A. (2015) Assessing the seasonal prevalence and risk factors for nuchal crest adiposity in domestic horses and ponies using the Cresty Neck Score. *BMC Vet Res* **11**, 13.

14. ROBIN, C.A., Ireland, J.L., Wylie, C.E., COLLINS, S.N., K. L. P. Verheyen and Newton, J.R. (2015) Prevalence of and risk factors for equine obesity in Great Britain based on owner-reported body condition scores. *Equine Vet J* **47**, 196–201.

15. Harker, I.J., Harris, P.A. and Barfoot, C.F. (2011) The body condition score of leisure horses competing at an unaffiliated championship in the UK. *J Equine Vet Sci* **31**, 253–254.

16. Cymbaluk, N.F. and Christison, G.I. (1990) Environmental effects on thermoregulation and nutrition of horses. *Veterinary Clinics of NA: Equine Practice* **6**, 355–372.

17. Vick, M.M., Sessions, D.R., Murphy, B.A., Kennedy, E.L., Reedy, S.E. and Fitzgerald, B.P. (2006) Obesity is associated with altered metabolic and reproductive activity in the mare: effects of metformin on insulin sensitivity and reproductive cyclicity. *Reprod. Fertil. Dev.* **18**, 609–617.

18. Adams, A.A., Katepalli, M.P., Kohler, K., Reedy, S.E., Stilz, J.P., Vick, M.M., Fitzgerald, B.P., Lawrence, L.M. and Horohov, D.W. (2009) Effect of body condition, body weight and adiposity on inflammatory cytokine responses in old horses. *Vet Immunol Immunopathol* **127**, 286–294.

19. Robles, M., Nouveau, E., Gautier, C., Mendoza, L., Dubois, C., Dahirel, M., Lagofun, B., Aubrière, M.-C., Lejeune, J.P., Caudron, I., Guenon, I., Viguié, C., Wimel, L., Bouraima-Lelong, H., Serteyn, D., Couturier-Tarrade, A. and Chavatte-Palmer, P. (2018) Maternal obesity increases insulin resistance, low-grade inflammation and osteochondrosis lesions in foals and yearlings until 18 months of age. *PLoS ONE* **13**, e0190309–25.

20. Buckley, P., Morton, J.M., Buckley, D.J. and Coleman, G.T. (2013) Misbehaviour in Pony Club horses: incidence and risk factors. *Equine Vet J* **45**, 9–14.

21. Mcgregor-Argo, C. (2009) Appraising the portly pony: Body condition and adiposity. *Vet J* **179**, 158–160.

22. Kearns, C.F., Mckeever, K.H., Kumagai, K. and Abe, T. (2002) Fat-free mass is related to one-mile race performance in elite standardbred horses. *Vet J* **163**, 260–266.

23. Argo, C.M., Dugdale, A.H., Morrison, P.K., Curtis, G.C. and Grove-White, D. Evaluating body composition living horses: Where are we up to? In: *Farm Animal Imaging III*, Eds: C. Maltin, C. Craigie and L. Bunger, Copenhagen. pp 14–19.

24. Henneke, D.R., Potter, G.D., Kreider, J.L. and Yeates, B.F. (1983) Relationship between condition score, physical measurements and body fat percentage in mares. *Equine Vet J* **15**, 371–372.

25. Carroll, C.L. and Huntington, P.J. (1988) Body condition scoring and weight estimation of horses. *Equine Vet J* **20**, 41–45.

26. Ireland, J.L., Clegg, P.D., McGowan, C.M., Mckane, S.A., Chandler, K.J. and L, P.G. (2012) Comparison of owner-reported health problems with veterinary assessment of geriatric horses in the United Kingdom. *Equine Vet J* **44**, 94–100.

27. Dugdale, A.H., Curtis, G.C., Cripps, P., Harris, P.A. and ARGO, C.M. (2010) Effect of dietary restriction on body condition, composition and welfare of overweight and obese pony mares. *Equine Vet J* **42**, 600–610.

28. Carter, R.A., Geor, R.J., Burton Staniar, W., Cubitt, T.A. and Harris, P.A. (2009) Apparent adiposity assessed by standardised scoring systems and morphometric measurements in horses and ponies. *Vet J* **179**, 204–210.

29. Morrison, P.K., Bing, C., Harris, P.A., Maltin, C.A., Grove-White, D. and Argo, C.M. (2014) Preliminary investigation into a potential role for myostatin and its receptor (ActRIIB) in lean and obese horses and ponies. *PLoS ONE* **9**, e112621.

30. Znamirowska, A. (2005) Prediction of horse carcass composition using linear measurements. *MESC* **69**, 567–570.

31. Bailey, S.R., Habershon-Butcher, J.L., Ransom, K.J., Elliott, J. and Menzies-Gow, N.J. (2008) Hypertension and insulin resistance in a mixed-breed population of ponies predisposed to laminitis. **69**, 122–129.

32. Frank, N., Elliott, S.B., Brandt, L.E. and Keisler, D.H. (2006) Physical characteristics, blood hormone concentrations, and plasma lipid concentrations in obese horses with insulin resistance. *J Am Vet Med Assoc* **228**, 1383–1390.

33. Dugdale, A.H.A., Curtis, G.C., Cripps, P.J., Harris, P.A. and Argo, C.M. (2011) Effects of season and body condition on appetite, body mass and body composition in ad libitum fed pony mares. *Vet J* **190**, 329–337.

34. Argo, C.M., Curtis, G.C., Grove-White, D., Dugdale, A.H.A., Barfoot, C.F. and Harris, P.A. (2012) Weight loss resistance: A further consideration for the nutritional management of obese Equidae. *Vet J* **194**, 179–188.

35. Siegers, E.W., de Ruijter-Villani, M., van Doorn, D.A., Stout, T.A.E. and Roelfsema, E. (2017) Ultrasonographic measurements of localized fat accumulation in Shetland pony mares fed a normal v. a high energy diet for 2 years. *Animal* **206**, 1–9.

36. Morrison, P.K., Harris, P.A., Maltin, C.A., Grove-White, D. and Argo, C.M. (2017) EQUIFAT: A novel scoring system for the semi-quantitative evaluation of regional adipose tissues in Equidae. *PLoS ONE* **12**, e0173753.

37. Westervelt, R.G., Stouffer, J.R. and Hintz, H.F. (1976) Estimating fatness in horses and ponies. *Journal of animal …*.

38. Buff, P.R., Dodds, A.C., Morrison, C.D., Whitley, N.C., McFadin, E.L., Daniel, J.A., Djiane, J. and Keisler, D.H. (2002) Leptin in horses: tissue localization and relationship between peripheral concentrations of leptin and body condition. *J Anim Sci* **80**, 2942–2948.

39. Bamford, N.J., Potter, S.J., Harris, P.A. and Bailey, S.R. (2016) Effect of increased adiposity on insulin sensitivity and adipokine concentrations in horses and ponies fed a high fat diet, with or without a once daily high glycaemic meal. *Equine Vet J* **48**, 368–373.

40. Bamford, N.J., Potter, S.J., Baskerville, C.L., Harris, P.A. and Bailey, S.R. (2016) Effect of increased adiposity on insulin sensitivity and adipokine concentrations in different equine breeds adapted to cereal-rich or fat-rich meals. *Vet J* **214**, 14–20.

41. Schultz, N., Geor, R., Manfredi, J. and Mccue, M.E. (2014) Factors associated with leptin and adiponectin concentrations in a large across breed cohort of horses and ponies. *J Vet Intern Med* **28**, 1114.

42. Wray, H., Elliott, J., Bailey, S.R., Harris, P.A. and Menzies-Gow, N.J. (2013) Plasma concentrations of inflammatory markers in previously laminitic ponies. *Equine Vet J* **45**, 546–551.

43. Menzies-Gow, N.J., Knowles, E.J., Rogers, I. and Rendle, D.I. (2018) Validity and application of immunoturbidimetric and enzyme-linked immunosorbent assays for the measurement of adiponectin concentration in ponies. *Equine Vet J*.

44. Frank, N. and Tadros, E.M. (2014) Insulin dysregulation. *Equine Vet J* **46**, 103–112.

45. BERTIN, F.R. and De Laat, M.A. (2017) The diagnosis of equine insulin dysregulation. *Equine Vet J*.

46. Morgan, R.A., Beck, K.R., Nixon, M., Homer, N.Z.M., Crawford, A.A., Melchers, D., Houtman, R.X., Meijer, O.C., Stomby, A., Anderson, A.J., Upreti, R., Stimson, R.H., Olsson, T., Michoel, T., Cohain, A., Ruusalepp, A., Schadt, E.E., rkegren, J.L.M.B.X., Andrew, R., Kenyon, C.J., Hadoke, P.W.F., Odermatt, A., Keen, J.A. and Walker, B.R. (2017) Carbonyl reductase 1 catalyzes 20β-reduction of glucocorticoids, modulating receptor activation and metabolic complications of obesity. *Scientific Reports* 1–11.

47. Frank, N. (2017) EEG PPID. 1–12.

48. Rolph, N.C., Noble, P.-J.M. and German, A.J. (2014) How often do primary care veterinarians record the overweight status of dogs? *J Nutr Sci* **3**, e58.

49. Wycherley, T.P., Mohr, P., Noakes, M., Clifton, P.M. and Brinkworth, G.D. (2012) Self-reported facilitators of, and impediments to maintenance of healthy lifestyle behaviours following a supervised research-based lifestyle intervention programme in patients with type 2 diabetes. *Diabet. Med.* **29**, 632–639.

50. Morgan, R.A., Keen, J.A. and McGowan, C.M. (2015) Treatment of Equine Metabolic Syndrome: a clinical case series. *Equine Vet J*.

51. German, A.J. (2016) Weight management in obese pets: the tailoring concept and how it can improve results. *Acta Vet Scand* **58**, 57.

52. German, A.J., Titcomb, J.M., Holden, S.L., Queau, Y., Morris, P.J. and Biourge, V. (2015) Cohort Study of the Success of Controlled Weight Loss Programs for Obese Dogs. *J Vet Int Med* **29**, 1547–1555.

53. Longland, A., Ince, J. and Harris, A.P. (2011) Estimation of pasture intake by ponies from liveweight change during six weeks at pasture. *J Equine Vet Sci* **31**, 275–276.

54. Edouard, N., Fleurance, G., Dumont, B., Baumont, R. and Duncan, P. (2009) Does sward height affect feeding patch choice and voluntary intake in horses? *App Anim Behav Sci* **119**, 219–228.

55. Cuddeford, D. (2013) Equine applied and clinical nutrition. In: *Factors affecting feed intake*, Eds: R.J. Geor and P.A. Harris, Saunders Elselvier, London. pp 64–79.

56. Longland, A.C., Barfoot, C. and Harris, P.A. (2016) Effects of Grazing Muzzles on Intakes of Dry Matter and Water-Soluble Carbohydrates by Ponies Grazing Spring, Summer, and Autumn Swards, as well as Autumn Swards of Different Heights. *J Equine Vet Sci* **40**, 26–33.

57. Ince, J., Longland, A., Newbold, J. and Harris, A.P. (2011) Changes in proportions of dry matter intakes by ponies with access to pasture and haylage for 3 and 20 hours per day respectively, for six weeks. *Joirnal of Equine Veterinary Science* **31**, 283.

58. Longland, A.C., Barfoot, C. and Harris, P.A. (2016) Efficacy of Wearing Grazing Muzzles for 10 Hours per Day on Controlling Bodyweight in Pastured Ponies. *J Equine Vet Sci* **45**, 22–27.

59. Glunk, E.C., Sheaffer, C.C., Hathaway, M.R. and Martinson, K.L. (2014) Interaction of Grazing Muzzle Use and Grass Species on Forage Intake of Horses. *J Equine Vet Sci* **34**, 930–933.

60. Longland, A.C., Barfoot, C. and Harris, P.A. (2014) Effect of period, water temperature and agitation on loss of water-soluble carbohydrates and protein from grass hay: implications for equine feeding management. *Veterinary Record* **174**, 68–68.

61. Moore-Colyer, M.J.S., Lumbis, K., Longland, A. and Harris, P. (2014) The effect of five different wetting treatments on the nutrient content and microbial concentration in hay for horses. *PLoS ONE* **9**, e114079.

62. Argo, C.M., Dugdale, A.H.A. and McGowan, C.M. (2015) Considerations for the use of restricted, soaked grass hay diets to promote weight loss in the management of equine metabolic syndrome and obesity. *Vet J* **206**, 170–177.

63. Longland, A.C., Barfoot, C. and Harris, P.A. (2011) Effects of soaking on the water-soluble carbohydrate and crude protein content of hay. *Veterinary Record* **168**, 618–618.

64. Bruynsteen, L., Moons, C.P.H., Janssens, G.P.J., Harris, P.A., Vandevelde, K., Lefère, L., Duchateau, L. and Hesta, M. (2015) Level of energy restriction alters body condition score and morphometric profile in obese Shetland ponies. *Vet J* **206**, 61–66.

65. Husted, L., Sanchez, L.C., Baptiste, K.E. and Olsen, S.N. (2010) Effect of a feed/fast protocol on pH in the proximal equine stomach. *Equine Vet J* **41**, 658–662.

66. Ellis, A.D., Redgate, S., Zinchenko, S., Owen, H., Barfoot, C. and Harris, P. (2015) The effect of presenting forage in multi-layered haynets and at multiple sites on night time budgets of stabled horses. *App Anim Behav Sci* **171**, 108–116.

67. Mack, S.J., Dugdale, A.H., Argo, C.M., Morgan, R.A. and McGowan, C.M. (2014) Impact of water-soaking on the nutrient composition of UK hays. *Veterinary Record* **174**, 452–452.

68. McGowan, C.M., Dugdale, A.H., L, P.G. and ARGO, C.M. (2013) Dietary restriction in combination with a nutraceutical supplement for the management of equine metabolic syndrome in horses. *Vet J* **196**, 153–159.

69. Powell, D.M., Reedy, S.E., Sessions, D.R. and Fitzgerald, B.P. (2002) Effect of short-term exercise training on insulin sensitivity in obese and lean mares. *Equine Vet J Suppl* **34**, 81–84.

70. Freestone, J.F., Beadle, R., Shoemaker, K., Bessin, R.T., Wolfsheimer, K.J. and Church, C. (1992) Improved insulin sensitivity in hyperinsulinaemic ponies through physical conditioning and controlled feed intake. *Equine Vet J* **24**, 187–190.

71. Carter, R.A., McCutcheon, L.J., Valle, E., Meilahn, E.N. and Geor, R.J. (2010) Effects of exercise training on adiposity, insulin sensitivity, and plasma hormone and lipid concentrations in overweight or obese, insulin-resistant horses. **71**, 314–321.

72. Turner, S.P., Hess, T.M., Treiber, K., Mello, E.B., Souza, B.G. and Almeida, F.Q. (2011) Comparison of Insulin Sensitivity of Horses Adapted to Different Exercise Intensities. *J Equine Vet Sci* **31**, 645–649.

73. de Graaf-Roelfsema, E., Keizer, H.A., van Breda, E., Wijnberg, I.D. and Der Kolk, Van, J.H. (2012) Effects of intensified training and subsequent reduced training on glucose metabolism rate and peripheral insulin sensitivity in Standardbreds. **73**, 1386–1393.

74. Norris, S.L., Lau, J., Smith, S.J., Schmid, C.H. and Engelgau, M.M. (2002) Self-management education for adults with type 2 diabetes: a meta-analysis of the effect on glycemic control. *Diabetes Care* **25**, 1159–1171.

75. Wang, C., McPherson, K., Marsh, T., Gortmaker, S. and Brown, M. (2011) Health and economic burden of the projected obesity trends in the USA and the UK. *Lancet* **378**, 815–825.

76. Courcier, E.A., Thomson, R.M., Mellor, D.J. and Yam, P.S. (2010) An epidemiological study of environmental factors associated with canine obesity. *J Small Anim Pract* **51**, 362–367.

77. German, A.J. (2015) Style over substance: What can parenting styles tell us about ownership styles and obesity in companion animals? *Br. J. Nutr.* **113 Suppl**, S72–7.

78. Holmes, K.L., Morris, P.J., Abdulla, Z., Hackett, R. and Rawlings, J.M. (2007) Risk factors associated with excess body weight in dogs in the UK. *J Anim Physiol Anim Nutr (Berl)* **91**, 166–167.

79. Metcalf, B.S., Jeffery, A.N., Hosking, J., Voss, L.D., Sattar, N. and Wilkin, T.J. (2009) Objectively measured physical activity and its association with adiponectin and other novel metabolic markers: a longitudinal study in children (EarlyBird 38). *Diabetes Care* **32**, 468–473.

80. Pretlow, R.A. and Corbee, R.J. (2016) Similarities between obesity in pets and children: the addiction model. *Br. J. Nutr.* **116**, 944–949.

81. Carballo, F., Freidin, E., Putrino, N., Shimabukuro, C., Casanave, E. and Bentosela, M. (2015) Dog“s discrimination of human selfish and generous attitudes: the role of individual recognition, experience, and experimenters” gender. *PLoS ONE* **10**, e0116314.

82. Fugazza, C., Pogány, Á. and Miklósi, Á. (2016) Do as I … Did! Long-term memory of imitative actions in dogs (Canis familiaris). *Anim Cogn* **19**, 263–269.

83. Jakovcevic, A., Elgier, A.M., Mustaca, A.E. and Bentosela, M. (2013) Frustration behaviors in domestic dogs. *J Appl Anim Welf Sci* **16**, 19–34.

84. Pretlow, R.A., Stock, C.M., Allison, S. and Roeger, L. (2015) Treatment of child/adolescent obesity using the addiction model: a smartphone app pilot study. *Child Obes* **11**, 248–259.

85. Menzies-Gow, N. (2012) The diagnosis and treatment of Equine Metabolic Syndrome by first opinion equine veterinarians in the United Kingdom. pp 1–1.

86. Tinworth, K.D., Edwards, S., Noble, G.K., Harris, P.A., Sillence, M.N. and Hackett, L.P. (2010) Pharmacokinetics of metformin after enteral administration in insulin-resistant ponies. **71**, 1201–1206.

87. Hustace, J.L., Firshman, A.M. and Mata, J.E. (2009) Pharmacokinetics and bioavailability of metformin in horses. **70**, 665–668.

88. Tinworth, K.D., Boston, R.C., Harris, P.A., Sillence, M.N., Raidal, S.L. and Noble, G.K. (2012) The effect of oral metformin on insulin sensitivity in insulin-resistant ponies. *Vet J* **191**, 79–84.

89. Rendle, D.I., Rutledge, F., Hughes, K.J., Heller, J. and Durham, A.E. (2013) Effects of metformin hydrochloride on blood glucose and insulin responses to oral dextrose in horses. *Equine Vet J* **45**, 751–754.

90. Frank, N., Sommardahl, C.S., Eiler, H., Webb, L.L., Denhart, J.W. and Boston, R.C. (2005) Effects of oral administration of levothyroxine sodium on concentrations of plasma lipids, concentration and composition of very-low-density lipoproteins, and glucose dynamics in healthy adult mares. **66**, 1032–1038.

91. Tóth, F., Frank, N., Geor, R.J. and Boston, R.C. (2010) Effects of pretreatment with dexamethasone or levothyroxine sodium on endotoxin-induced alterations in glucose and insulin dynamics in horses. **71**, 60–68.

92. Frank, N., Elliott, S.B. and Boston, R.C. (2008) Effects of long-term oral administration of levothyroxine sodium on glucose dynamics in healthy adult horses. *Am. J. Vet. Res.* **69**, 76–81.

93. Sommardahl, C.S., Frank, N., Elliott, S.B., Webb, L.L., Refsal, K.R., Denhart, J.W. and Thompson, D.L. (2005) Effects of oral administration of levothyroxine sodium on serum concentrations of thyroid gland hormones and responses to injections of thyrotropin-releasing hormone in healthy adult mares. **66**, 1025–1031.

94. Frank, N., Buchanan, B.R. and Elliott, S.B. (2008) Effects of long-term oral administration of levothyroxine sodium on serum thyroid hormone concentrations, clinicopathologic variables, and echocardiographic measurements in healthy adult horses. **69**, 68–75.

95. Durham, A.E. (2017) Therapeutics for Equine Endocrine Disorders. *Vet Clin North Am Equine Pract* **33**, 127–139.

96. Frank, N. (2006) Insulin resistance in horses. *Proc 52nd Annu AAEP Conv*.

97. Valencia, N.A., Thompson, D.L., Jr, Oberhaus, E.L. and Gilley, R.M. (2013) Long-term treatment of insulin insensitive mares with cabergoline: Effects on insulin sensitivity, insulin response to glucose infusion, and prolactin response to sulpiride. *J Equine Vet Sci* **33**, 359.