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SPONTANEOUSLY ARISING DISEASE: REVIEW ARTICLE

The Financial Costs, Behaviour and Psychology of Obesity: A One Health Analysis

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Summary

People who are overweight or have obesity are estimated to comprise 30% of the global population and up to 59% of companion dogs and cats are estimated to be above their optimal body weight. The prevalence of human and companion obesity is increasing. The direct and indirect costs of obesity and associated comorbidities are significant for human and veterinary healthcare.

There are numerous similarities between obesity in people and companion animals, likely related to the shared environmental and lifestyle elements of this multifactorial disease. While the study of human obesity is relatively robust, research conducted in pets is generally limited to small studies, studies with cross-sectional designs or reports that have yet to be replicated. Greater understanding of human obesity may elucidate some of the factors driving the more recent rise in pet obesity. In particular, there are overlapping features of obesity in children and pets that are, in part, related to dependency on their 'parents' for care and feeding. When feeding is used in a coercive and controlling fashion, it may lead to undesirable feeding behaviour and increase the risk for obesity. A 'responsive parenting' intervention teaches parents to respond appropriately to hunger−satiety cues and to recognize and respond to others' distress. Such interventions may impact on childhood overweight and obesity and have the potential to be adapted for use with companion animals.

Social behaviour towards people with obesity or owners of pets with obesity is often driven by beliefs about the cause of the obesity. Educating healthcare professionals and the public about the multifactorial nature of this complex disease process is a fundamental step in reducing the bias and stigma associated with obesity. Children living in low-income households have particularly high rates of obesity and as household income falls, rates of obesity also rise in pets and their owners. There are risk regulators (i.e. dynamic components of interconnected systems that influence obesity-related behaviours) and internal factors (i.e. biological determinants of obesity) that may influence the development of both childhood and pet obesity, and poverty may intersect with these variables to exacerbate obesity in low-income environments. This review discusses the costs, behaviours and psychology related to obesity in people and pets, and also proposes potential techniques that can be considered for prevention and treatment of this disease in pets. A 'One Health' approach to obesity suggests that an understanding of human obesity may elucidate some of the factors driving the more recent rise in pet obesity.

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Contents

The Financial Costs of Healthcare for Obesity in People and Pets

Obesity is often considered to be the most identified and fastest growing epidemic disease in both people and companion animals, with worldwide rates of human obesity more than doubling since 1980 (Flegal *et al*., 2002; World Health Organisation, 2016). People who are overweight or have obesity are estimated to comprise nearly 30% of the global population, or about 2.1 billion individuals, and obesity accounts for 5% of all deaths worldwide. If current trends continue, up to 50% of the estimated 8.5 billion global adult population (United Nations News Centre, 2015) will be overweight or have obesity by 2030 (McKinsey Global Institute, 2014). In the USA about 35% of adults and 17% of children 2−19 years of age have obesity (defined by a body mass index [BMI] ≥30 in adults and BMI ≥95th percentile of the Centers for Disease Control and Prevention [CDC] sex-specific BMI-for-age growth charts from 2000 for children) (Ogden *et al*., 2010). Even the youngest children have not been spared; 10% of infants and toddlers have high weight-for-length, and about 25% of 2−5 year olds are overweight or have obesity. Prevalence differs substantially by sex and among subpopulations, including race/ethnicity and socioeconomic status.

In companion animals, the inferences are similar. Of the estimated 71 million dogs and 73 million cats in the USA (Pet Food Institute, 2016), an estimated 54% of dogs and 58% of cats are overweight or have obesity (Association for Pet Obesity Prevention, 2015). Globally, multiple studies have estimated that 27–59% of pet dogs and cats are above their optimal weight (Lund *et al.*, 2005, 2006; German, 2006); a trend that appears to be increasing, especially in cats (Banfield Pet Hospital, 2012). Over the last 5 years alone, the prevalence of obesity has increased by 37% in dogs and 90% in cats (German, 2016). Factors contributing to the rise of obesity in people are complex and some have the potential to impact on companion pets, in part due to a shared lifestyle (Day, 2010).

Direct Healthcare-related Costs of Obesity

Since overweight and obesity are significant risk factors for diseases such as coronary heart disease, hypertension, stroke, type 2 diabetes, elevated cholesterol and triglycerides, cancer, osteoarthritis, sleep apnoea, hypoventilation syndrome, reproductive disease and gallstones, the secondary medical costs are significant (National Institutes of Health (2012)). It is reported that approximately 20% of all cancer cases are attributable to being overweight or having obesity (Wolin *et al.*, 2010). Childhood obesity increases the risk for obesity-associated health problems in children such as fatty liver, hypertension, hyperlipidaemia, type 2 diabetes and orthopaedic problems (Estrada *et al.*, 2014). Furthermore, children who are overweight before puberty are 60% more likely to have obesity as adults and are at an increased risk for serious comorbidities as obese adults.

In 2008, the estimated annual medical cost of human obesity in the USA was $147 billion, with individuals with obesity incurring $1,429 greater annual medical costs than people of normal weight (Finkelstein *et al.*, 2009). In another study, taking into account the diseases influenced by overweight and obesity (specifically diabetes, heart disease, stroke and cancer), the estimated increase in treatment costs will be $48–$66 billion/year in the USA and £1.9–£2 billion/year in the UK by 2030 (Wang *et al.*, 2011). A study by the McKinsey Global Institute estimated that the global impact of obesity is approximately $2.0 trillion, which, at 2.8% of worldwide gross domestic product, is almost equal to the cost of smoking and war, violence and terrorism (McKinsey Global Institute, 2014).

Workers who are overweight or have obesity are more likely to have chronic diseases and increased absenteeism. Eighty-six percent of US workers were reported to be above normal weight and to have a chronic medical condition, leading to an estimated 450 million days of work missed per year compared with healthier colleagues (Witters and Agrawal, 2011). This translates into an estimated $153 billion in lost productivity per year. If this analysis included workers who still came to work, but were less productive due to poor health because of obesity, the economic impact would increase to $1.1 trillion per year. Global implications are less clear, although lost productivity in the UK was a quarter of that in the USA and fewer UK workers were of above normal weight (Witters and Agrawal, 2011).

Obesity produces health consequences in small companion animals that are similar to those in people. In dogs, diseases associated with obesity include diabetes mellitus, osteoarthritis, urinary incontinence and neoplastic disease (Lund *et al.*, 2006). In cats, disease associations include diabetes mellitus, neoplasia, skin disease, oral cavity disease and urinary tract disease (Lund *et al.*, 2005). In addition, having increased body fat has a negative impact on respiratory function (Bach *et al.*, 2007; Mosing *et al.*, 2013), renal function and health (Tvarijonaviciute *et al.*, 2013), and metabolic function (German *et al.*, 2009, 2010; Tvarijonaviciute *et al.*, 2012a,b). Further, average lifespan is shorter in dogs that are overweight throughout their life (Kealy *et al.*, 2002) and affected dogs have a poorer quality of life (German *et al.*, 2012). Various risk factors for companion animal obesity have been described (German, 2006); for example, rapid growth predicts the likelihood of cats being overweight during adulthood (Serisier *et al.*, 2013).

In contrast to human medicine, there is a paucity of global information regarding the healthcare costs of overweight and obese pets. In a study that monitored 429 dogs and 372 cats over a period of 4 years, it was shown that owners of obese dogs spent an average of 17% more than owners of normal weight dogs, also spending 25% more on medications. Owners of obese cats spent 36% more on diagnostic services and 53% more on surgical services than owners of cats of normal weight (Banfield Applied Research and Knowledge, 2015). Overweight or obese pets suffer from an increased risk of secondary diseases, further adding to healthcare expenses (German, 2006). In 2009, one study attempted to apply costs to some of these obesity-related disease conditions and, on average, estimated that the potential median cost was $1,804/year for dogs and $1,049/year for cats (Bartlett and Van Buren, 2009). Adjusting these figures for inflation (using a 12.3% inflation rate), would give approximately $2,026/year for dogs and $1,178/year for cats today. If there are 71 million dogs in the USA, and 54% are overweight or obese, incurring an average healthcare spend of $2,000/year would equate to approximately $76.68 billion spent per year related to obesity. Similarly, if there are 73 million cats in the USA, and an estimated 58% are considered overweight or obese, an average healthcare spend of $1,100/year would equate to a further $46.5 billion spent per year related to obesity.

Indirect Costs of Obesity

In people, overweight and obesity have additional costs not directly related to physical health that can affect mood, self-esteem and possibly productivity. For example, in a study of 1,520 children using a self-perception profile, children who had obesity had lower levels of self-esteem, higher rates of sadness, loneliness and nervousness, and were more likely to partake in high-risk behaviours such as smoking and alcohol consumption (Strauss, 2000). Another study demonstrated that obesity can directly affect wages and, through affecting self-esteem, indirectly affect the wage earning potential of an individual, especially in white females (Mocan and Tekin, 2009).

A bidirectional relationship reportedly occurs between obesity and common mental health disorders, with moderating factors such as gender, level of obesity, age and socioeconomic status affecting this relationship. Obesity has been associated with depression (Luppino *et al*., 2010) and anxiety (Gariepy *et al*., 2010), both of which have associated healthcare costs. Additional factors such as stigma/reduced support, diet and exercise adherence, chronic disease, medication use, negative thoughts and low self-esteem also contribute to this relationship, with women being more at risk than men (Gatineau and Dent, 2011). Interestingly, the 'perception' of being overweight or having obesity is more predictive of potential mental disorders than 'actual' obesity in both adults and children (Gatineau and Dent, 2011).

While it is more difficult to measure these secondary effects of obesity on companion pets, their body weight could have impacts not previously considered. Companion animals who are overweight or have obesity, like their human counterparts, live shorter lives, with one study demonstrating the potential for decreased vitality, emotional disturbance and increased pain perception in dogs with obesity (German *et al*., 2012).

The Psychology of Obesity-related Behaviours: Similarities Between Obesity in Children and Companion Animals

The fact that the rise in pet obesity appears to mirror that in children is not surprising as both share similar environments. Further, childhood obesity may be an intriguing model for obesity in pets (German, 2015) as both young children and pets are dependent on their 'parents' for care and feeding. Children whose parents have obesity are more likely to develop obesity themselves (Danielzik *et al*., 2004), reflecting the conjoint influences of genetic and environmental factors (Frayling *et al*., 2007). Similarly, overweight pets also tend to have overweight owners (Holmes *et al*., 2007; Nijland *et al*., 2010), suggesting similar environmental influences on obesity, particularly the 'family food environment', a term describing family practices and attitudes about food and eating that may impact on childhood obesity risk (Campbell *et al*., 2006). Here, we describe the development of feeding preferences in infants and children, comparing this process to that seen in pets. We also discuss potential strategies for obesity prevention in companion animals based on these insights.

Development of Infant Feeding Preferences

Infants and toddlers 'family food feeding environments' influence the development of eating behaviour arising in the first years of life, when developmental plasticity is high. In the first year, infants must make the transition from the exclusive milk diet of infancy to consuming a more varied diet consisting of foods typical of the family's diet (Paul *et al*., 2009). Infants inborn preferences are for sweet and salty tastes, and they tend to reject new foods that are bitter or sour (Mennella, 2008). Familiarization is a powerful form of early learning that is central to this dietary transition (Rheingold, 1985). Although infants and toddlers are 'neophobic', tending to reject new foods, they are primed to accept the foods made available to them and they learn to like foods and flavours that become familiar (Birch, 1998). The choices parents make about feeding, have a major impact on children's diet quality, growth and subsequent lifetime risk for obesity.

Development of Young Pet Cats and Dogs Feeding Preferences

Cats are solitary feeders by nature and, given the choice, prefer to consume multiple (e.g. 12–20) small meals per day (Mugford and Thorne, 1980; Kane *et al*., 1981). In contrast, dogs eat fewer and larger meals, typically between four and eight per day (Mugford, 1977; Mugford and Thorne, 1980). Similar to people, early feeding experiences can influence later dietary preferences. For example, puppies fed a single food are reluctant to eat novel foods, while those with a varied diet are more likely to accept newer foods (Kuo, 1967). Likewise, cats can sometimes become fixated with food of a single flavour (National Research Council, 2006). Both dogs and cats that are well adjusted to a particular food demonstrate so-called 'flavour fatigue', where they select a new diet in preference to the existing one (Kuo, 1967; Mugford, 1977; Mugford and Thorne, 1980; Kane, 1989). However, when cats and dogs are in a strange environment, they become 'neophobic' and avoid new flavours (Bradshaw and Thorne, 1992), similar to the pattern seen in infants and toddlers.

Dogs tend to adjust their energy intake in response to diets of differing energy density (Janowitz and Grossman, 1949), consuming more and less when foods of low and high energy densities are offered, respectively. However, energy intake declines once energy content is diluted enough (e.g. with added dietary fibre) (Weber *et al.*, 2007), and feeding highly palatable and energy-dense diets can lead to overeating and obesity (National Research Council, 2006). This pattern is less clear in cats, with some studies reporting that cats do not regulate their weight when feeding *ad libitum* (Kanarek, 1975; Hirsch *et al.*, 1978; Castonguay *et al.*, 1987) and others reporting that they may. For example, a recent study demonstrated two different feeding phenotypes in domesticated cats (Serisier *et al.*, 2013); studied over 8 years, some cats were able to maintain their body weight despite ad-libitum feeding, while others could not and instead gradually gained weight throughout their adult years. In this study, rapid weight-gain early in life (i.e. prior to cats becoming overweight) was a key predictor of cats likely to gain weight in adult life.

Obesity-related Behaviours in Children and Their Caregivers

Cultural norms around both diet and exercise have changed over the years, and the perception of what is considered 'normal' for a child to eat at one sitting has increased. This is likely related to larger portion sizes promoted by restaurants and food companies (Young and Nestle, 2002). There has also been a generational shift towards considering a higher BMI as 'normal', which may cause individuals to recognize a weight problem at higher BMIs than before (Burke *et al.*, 2010). Not surprisingly, the increasing prevalence of obesity in people has coincided with an increase in portion sizes (Piernas and Popkin, 2011), and both children and adults often respond to larger portions of palatable food by eating more (Birch *et al.*, 2015; Wood *et al.*, 2016).

While young children can adjust the amount consumed to the energy density of food by eating less of foods that are higher in energy density (Birch and Deysher, 1985), the feeding of palatable energy-dense foods leads to overeating (Savage *et al.*, 2012). Furthermore, parents often overestimate the amounts of food children need to eat, and child feeding practices that encourage the child to 'clean the plate' can exacerbate the effects of large portions and override a child's ability to adjust his or her own energy intake in response to hunger and fullness cues (Birch *et al.*, 1987). Pressuring children to eat can have additional adverse effects, promoting disinhibited overeating, a behavioural phenotype for developing obesity (Francis *et al.*, 2007), and fostering children's dislike of specific foods they are forced to consume (Galloway *et al.*, 2006).

Indulgent parenting has also been linked to increased obesity (Olvera and Power, 2010), and parents may use food to soothe or control behaviour (Stifter *et al.*, 2011; Moding *et al.*, 2014), similar to a practice often used in dog training. For some parents, feeding may be the default response to a crying infant, although infants and young children cry for many reasons that are not hunger related. Foods are also effective rewards that can be used to manage behaviour via associative conditioning, increasing a child's liking for those foods (Birch *et al.*, 1984a,b). Learned food preferences develop as foods are repeatedly associated with emotional states generated by these social contexts of feeding. These practices may affect a child's food responsiveness or the reinforcing value of food (Birch, 1998; Rollins et al., 2014a,b).

In addition, because children tend to eat what they like and leave the rest, parents often feel the need to restrict children's access to preferred foods, which are typically high in sugar, fat, and salt, and often the same foods are used as rewards or treats (Rollins *et al.*, 2015). Using such coercive control mechanisms to restrict access to certain foods increases a child's interest in and responsiveness to his or her preferred foods, which subsequently promotes disinhibited overeating in the absence of hunger (Fisher and Birch, 1999; Rollins et al., 2014a,b). As such, the use of coercive, controlling feeding practices can have adverse effects on the development of children's eating behaviour, contributing to obesity risk and unhealthy dietary patterns.

Obesity-related Behaviours in Pets and Their Owners

Similar to humans, owner factors may also influence the likelihood of pets becoming overweight. Indeed, a number of studies have identified differences in the owner–pet relationship between owners of overweight pets and those owning pets of ideal weight. Analogous to how parents often misperceive the actual body shape of their children, owners may believe their pets to be of normal weight when they are in fact overweight or have obesity (Courcier *et al.*, 2011;

Eastland-Jones *et al.*, 2014). With regard to feeding behaviour, owners of overweight dogs more closely observe them feeding (Kienzle *et al.*, 1998), feed them more snacks and table scraps (Robertson, 1999, 2003; Allan *et al.*, 2000) and more often allow them to be present when preparing a meal (Kienzle *et al.*, 1998). Owners of cats that have obesity are also more likely to observe them feeding and to use food as a reward (Kienzle and Bergler, 2006).

The household feeding regime can also be problematic, most notably in multicat households; cats are by nature solitary feeders and would prefer to consume food in multiple small meals, yet often they are group fed according to a schedule of set meal times that suits the owner. This can cause significant stress to the cat and may lead to abnormal feeding behaviours such as overeating. Attitudes to activity also differ between the owners of overweight pets and owners of pets that are ideal weight. Owners of cats that have obesity play less with them than the owners of ideal weight cats (Kienzle and Bergler, 2006), while dogs that are overweight are significantly less likely to be walked daily, and their walks tend to be shorter (German *et al.*, 2016a,b).

A number of undesirable behaviours may also occur more frequently in overweight animals. In a recent owner survey, overweight dogs were significantly more likely to display a range of undesirable behaviours including abnormal eating behaviour (e.g. coprophagia, stealing food and food guarding), barking, growling or snapping at people (including other dogs, strangers and familiar people) and being more fearful of the outdoors (German *et al.*, 2016a). Owners were more likely to report that such unsociable behaviours adversely affected their dog's health than were owners of dogs in optimal condition.

Focusing on Early Feeding and Responsive Parenting to Prevent Childhood Obesity

One of the authors (LB) has used what is known about how parents shape children's learning about food and eating to develop a primary obesity prevention trial beginning in early infancy. The INSIGHT project (NIH R01) is a prospective, randomized controlled trial designed to evaluate whether a responsive parenting (RP) intervention prevents rapid infant weight gain and childhood obesity among first-born infants (Paul *et al.*, 2014). The RP intervention is being compared with a home safety control in a cohort of 279 infants and their parents. All participants received four home visits during the first year followed by annual clinic visits. Participating children have been followed until 3 years of age with BMI as the study's primary outcome.

The INSIGHT RP intervention provides new parents with alternatives to the coercive feeding practices described above, teaching parenting that is prompt and contingent on infant cues and developmental level. RP emphasises responsive feeding guidance, helping parents learn to identify and respond sensitively and appropriately to infant hunger–satiety cues and to recognize and respond to other distresses including the infant's need for sleep. It is based in part on studies demonstrating that responsive feeding fosters the development of infant self-soothing (Pinilla and Birch, 1993), increased sleep duration, slower growth and self-control in feeding, while coercive feeding attenuates a child's responsiveness to hunger and satiety cues, promotes eating in the absence of hunger and increases preferences for energy-dense foods and subsequent obesity risk (Savage *et al.*, 2007). In contrast, responsive feeding promotes self-regulation and shared parent–child responsibility for feeding, which reduces risk for overeating and overweight (Fisher and Birch, 2007).

Positive findings from INSIGHT demonstrate that behavioural interventions with an RP framework delivered to new mothers and their infants can affect early growth to reduce overweight and obesity during early childhood. This trial is among the few beginning during early infancy that has demonstrated significant efficacy on weight-related outcomes (Blake-Lamb *et al.*, 2016). Further, the RP intervention has demonstrated reduced rapid infant weight gain, higher levels of self-soothing and improved night sleep duration (Paul *et al.*, 2016; Savage *et al.*, 2016). Infants receiving RP had lower mean weight-for-length percentiles at 1 year than controls and were less likely to be overweight at age 1 year (Savage *et al.*, 2016) using the American Academy of Pediatrics' definition of weight-for-length ≥95th percentile for those aged <2 years (Daniels and Hassink, 2015). INSIGHT findings at age 2 years show a reduction of overweight (BMI ≥85th percentile) and obesity among those in the RP group versus control.

Focusing on Early Feeding and Responsive Ownership to Prevent Pet Obesity

The work undertaken in the INSIGHT RP intervention is clearly promising for control of childhood obesity in the future. Unfortunately, similar evidence-based interventions for companion animals are lacking. Given similarities in the care provided, it is feasible that these principles from INSIGHT could be adapted to pet dogs and cats. Such an intervention would require early engagement with new pet owners, ideally at the time of initial acquisition, and would be based on using sensitive and supporting approaches to feeding and treating as opposed to coercive feeding practices. For example, adopting a strategy that avoids a single (or even two) large meal (National Research Council, 2006) in pet cats, instead enabling food to be consumed as multiple small meals at times chosen by the cat, may decrease obesity. Of course, such a feeding regime can be challenging, especially in multicat households where different feeding phenotypes (some grazers and some overeaters) may co-exist. In such households, creating a stress-free environment is key, such that individuals can feed in isolation and consume their daily intake over multiple small meals at times determined by the cat rather than the owner. Spatial separation (i.e. providing food in different rooms for different cats) can be used to reduce stress at feeding times, while microchip-controlled electronic feeding bowls can also be employed to ensure that cats only consume the food assigned to them.

Early identification of the cat feeding phenotype (i.e. grazer versus overeater) may also help with obesity prevention. For example, cats that display the 'grazer' phenotype can feasibly be fed *ad libitum*, yet still be able to maintain their weight. In contrast, some method of portion control is likely required for cats demonstrating the 'overeater' phenotype. Interestingly, there is some suggestion that these different phenotypes can be predicted early in life, before cats are overweight (Serisier *et al.*, 2013), raising the possibility that early intervention might be feasible.

The Role of Poverty in the Development of Obesity in Humans and Pets

Children living in low-income US households have particularly high rates of obesity (Grow *et al.*, 2010; Pan *et al.*, 2013). Similar to patterns observed among US children, as household income falls, rates of obesity rise in pets and their owners (Kienzle *et al.*, 1998; Courcier *et al.*, 2010; Ogden *et al.*, 2013). Clearly, there are parallels between parent–child and owner–pet relationships; as such, individual interactions between owner and pet may mimic those between parent and child (Archer, 1997). Given this connection, one might expect that shared social environments could impact an owner and pet similarly to how they impact a parent and child (Kienzle *et al.*, 1998; Courcier *et al.*, 2011, 2012).

Factors influencing body weight change over time comprise two general categories: internal factors and risk regulators. Internal factors represent biological determinates of obesity, while risk regulators represent dynamic components of interconnected systems that influence obesity-related behaviours from the person to public policy level (Huang *et al.*, 2009). Internal factors and risk regulators do not act in isolation, but interact and influence each other in complex ways. This section of the review discusses risk regulators and internal factors that may influence the development of both childhood and pet obesity, focusing on how poverty intersects with these variables to exacerbate obesity in low-income environments.

Risk Regulators

Built Environment and Area Deprivation. The built environment refers to the manufactured surroundings that provide the settings for activity, including buildings and parks (Lee *et al.*, 2008). Area deprivation denotes an area's potential for health risk and includes the ecological concentrations of poverty and economic disinvestment (Anderson *et al.*, 1997). Individuals of low socioeconomic status (SES) are more likely to live in neighbourhoods with less greenery (Martin *et al.*, 2004; Mennis, 2006) and fewer physical fitness resources (Estabrooks *et al.*, 2003). Such adverse surroundings increase the odds that a child is overweight by 20–60% (Singh *et al.*, 2010), in part because children are less likely to engage in physical activity and parents are less likely to encourage it in these environments (Schreier and Chen, 2013). In contrast, better neighbourhood features, such as improved walkability, are associated with a decreased prevalence of obesity (Creatore *et al.*, 2016). Features of the built environment that reduce opportunities for human physical activity may also influence pet obesity by decreasing opportunities for pets to exercise outdoors. Outside time has become increasingly important for controlling pet weight, as general trends in pet care have shifted towards dogs and cats spending more time indoors (German, 2016).

Neighbourhood crime may also play a significant role in the development of childhood obesity (Hale, 1996). Children living in neighbourhoods with high crime rates report less moderate to vigorous physical activity (Gordon-Larsen *et al.*, 2000), and even the perception of crime may reduce comfort with using available physical activity amenities (Hood, 2005). Pet owners living in neighbourhoods with increased crime or the perception of increased crime may similarly respond by providing their pets with fewer or shorter opportunities for walking, which may increase obesity risk.

Local Food Environment. 'Food deserts', or a lack of healthy food options in the neighbourhood (Moore and Roux, 2006; Powell *et al.*, 2007), and 'food swamps', or the overavailability of unhealthy food options like fast food (Larson *et al.*, 2009), are more common in high-poverty neighbourhoods (White, 2007).

This geographical disparity may partially explain why low SES adults sometimes purchase poorer quality, less healthy food (Darmon and Drewnowski, 2015) for children, increasing the risk of childhood obesity. The impact that the local food environment has on pet obesity has not been well studied. For example, it is not clear whether the availability of more calorically-dense pet food products differs in higher versus lower income neighbourhoods (Linder and Freeman, 2010). In addition, one might expect that pet owners in local food environments with poorer quality food feed their pets table scraps of lower nutritional quality. However, the degree to which the feeding of table scraps influences the risk of obesity in pets is unclear (Courcier *et al.*, 2010).

Parental Influences. As previously mentioned, parental modelling of feeding behaviours (Gerards and Kremers, 2015) influences the development of childhood obesity (Schreier and Chen, 2013). Poverty has been associated with more authoritarian parenting (Conger *et al.*, 1994), and more controlling parenting has been linked to both increased snack food consumption in overweight children (Liang *et al.*, 2016) and decreased ability to regulate intake during ad-libitum consumption (Johnson and Birch, 1994). With regard to activity levels, parental support correlates positively with physical activity in children (Trost *et al.*, 2003). Low SES individuals are more likely to live sedentary lifestyles and less likely to use physical activity to lose or maintain weight (Active Living by Design, 2012). The extent to which owner support influences pet activity is not clear. However, one might expect that owners from lower SES households, with more demands on their time, poorer social support and fewer financial resources for pet care, exercise their pets less often.

Cultural Norms. As mentioned previously, there has also been a generational shift towards considering a higher BMI as 'normal', which may cause individuals to recognize a weight problem at higher BMIs than before (Burke *et al.*, 2010). This shift in perception is more pronounced in low-income households (Duncan *et al.*, 2015) and may influence pet obesity similarly to how it influences childhood obesity (German, 2016). Although data are limited, one study found that lower income pet owners were less likely to perceive pets as being overweight or obese (Courcier *et al.*, 2010).

Internal Factors

Epigenetics. Although the extent to which genetic factors are responsible for recent surges in human obesity is not fully understood, it is clear that they do influence risk (Min *et al.*, 2013). Epigenetic changes, or alterations in gene expression due to environmental fluctuations (Campion *et al.*, 2009), likely occur with the experience of poverty and may contribute to increasing obesity prevalence by modifying how risk regulators interact with biological factors. How epigenetic factors contribute to pet obesity has not been fully examined, although there is some evidence that genetic variation in pets contributes to obesity.

Hypothalamic—Pituitary—Adrenal Axis. Low SES is associated with higher levels of stress (Santiago *et al.*, 2011), and upregulation of the hypothalamic—pituitary—adrenal (HPA) axis related to chronic stress is associated with greater visceral adiposity (Adam *et al.*, 2010; Donoho *et al.*, 2011). Furthermore, studies have shown that stress is associated with higher intake of fatty foods and increased snacking (Cartwright *et al.*, 2003), and that the association between stress and obesity persists even after dietary intake is accounted for (Brunner *et al.*, 2007; Richardson *et al.*, 2015). There is no research examining the influence of chronic stress on pet neurohormones and future research should examine whether owner stress influences the HPA axis in pets. The specific role that stress may play in the development of pet obesity is described below.

Mood. Research on mood and obesity risk in children is often focused on depression. Low SES is associated with a higher prevalence of depression (Lorant *et al.*, 2002). Children of parents who are depressed are more likely to develop depression in the future (Lieb *et al.*, 2002; Weissman *et al.*, 2006) and, similar to adults, depression has been linked to worsening obesity in adolescents (Goodman and Whitaker, 2002). Moreover, children living in lower SES environments have more cognitive, behavioural, and emotional difficulties (Brown *et al.*, 2012), which have also been associated with obesity (Duarte *et al.*, 2010). The ways in which owner mood impact on pet obesity are potentially numerous. For example, owners with depressive symptoms may treat their dogs to more snacks as a coping mechanism, insofar as rewarding pets may provide a positive effect boost to the person, or the anhedonia accompanying an owner's depression may reduce exercise opportunities for the pet.

Additional Factors in the Development of Obesity in Humans and Pets

Obesity is recognized as a complex, multifactorial disease, not simply a condition caused by an imbalance of energy intake and output. In this section, we will review additional potential contributing causes of obesity in pets including erroneous perceptions of a healthy pet body condition, commercial messaging, genetic predispositions for obesity, the role of the microbiome and the impact of stress on obesity.

Erroneous Perceptions of Healthy Weight

Obesity is recognized as one of the most prevalent and important chronic diseases of pets in developed countries. Yet, in the individual pet, the disease is often unidentified, partly due to misconception by owners about what an ideal body weight looks like in their pets. Studies have shown a significant disconnect between a pet's body condition and the owner's perception of their pet's relative weight. For example, in one study experts classified 79% of pet dogs to be overweight or have obesity, while only 28% of the owners estimated their dog to be above an ideal body weight (Singh *et al.*, 2002). Another study demonstrated that close to half of the dogs deemed overweight by a veterinarian were considered to be a healthy weight or underweight by their owners (White *et al.*, 2011). Even when provided with a body condition score (BCS) chart with images to help guide their assessment of their dog, most (89%) pet owners underestimated their pet's BCS (Eastland-Jones *et al.*, 2014). A study of urban cats in France identified a similar finding, with an approximately 50% concurrence between veterinarians and owners on the number of cats having an optimal BCS, primarily due to the owners underestimation of their cat's body condition (Colliard *et al.*, 2009). Neoteny may be a factor in this phenomenon, as we breed and are attracted to juvenile features such as big eyes, roundness and playfulness (McGreevy and Nicholas, 1999). Similar to people, the lack of recognition of weight concerns in an individual pet may play a critical role in the pet obesity problem; if the typical pet owner does not see a problem, they are unlikely to seek medical help or initiate change to overcome the condition.

In addition to the owner, the veterinarian similarly might not identify weight-related concerns in their pet population (German and Morgan, 2008). Even when obesity is identified, veterinarians may be reluctant (McGreevy *et al.*, 2005) or ineffective (White *et al.*, 2011) in communicating their concerns to the owner. Furthermore, the low periodicity of veterinary visits for an otherwise healthy young animal may also contribute to an unidentified escalation in weight.

Commercial Messaging

Campaigns by food companies target children in order to influence immediate dietary choices, condition taste preferences and build brand loyalty (Lobstein *et al.*, 2015). The marketing of high-calorie foods to children increases their consumption (Committee on Food Marketing and the Diets of Children and Youth, 2006) despite labelling requirements that seek to provide information needed for parents to make informed choices. The extent to which commercial messaging of pet food is related to caloric density or nutritional content is unclear. Regardless, pet owners may struggle to make informed decisions due to the general lack of requirements to label energy density on pet foods (Linder and Freeman, 2010). Even pet foods marketed for weight management vary considerably in caloric density and have no label standards, making comparison difficult for consumers (Linder and Mueller, 2014). Veterinarians often play an important role in owner decisions about pet food (Laflamme *et al.*, 2008), particularly for overweight pets; however, the extent and influence of pet food company marketing directly to veterinarians remains largely unstudied.

Genetic Predisposition

In humans, it is well known that variations in genetic loci, hormones and their receptors are associated with obesity and increased adiposity. However, when obesity is recognized in pets, the owners are often blamed for their condition, as a common assumption is that the owner has the ultimate ability to control their energy intake (e.g. through feeding) and output (e.g. by increasing exercise) and should be able to adjust those accordingly to control weight. Interestingly, data have shown that owners of overweight dogs exert more control over feeding regimes than owners of lean dogs (Raffan *et al.*, 2015). Genetic studies are now providing insights as to why this contradiction may exist. In one study, a mutation in pro-opiomelanocortin (POMC) was associated with increased body weight, adiposity, and food motivation in Labrador and flat-coated retrievers (Raffan *et al.*, 2016). Owners of these affected dogs may make substantial efforts to manage intake; however, the genetic predisposition for that affected dog overwhelms their efforts. Data for cats also support a genetic predisposition to obesity (Haring *et al.*, 2011). Similar studies have previously been performed in people, where variants within leptin, the leptin receptor and other genes in the hypothalamic leptin–melanocortin pathway (including POMC) have been reported in obese individuals (Farooqi and O'Rahilly, 2014). Further identification of genetic predispositions for obesity in pets may help not only to change the way we view owners of obese pets, but also lead to more effective therapies.

The Microbiome

Recent studies have described associations between the gut microbiome and obesity in humans (Riva *et al.*, 2016), with purported mechanisms including the role of the microbiome in increasing energy production, regulating fatty acid tissue composition and contributing to low-grade inflammation (Cani *et al.*, 2012; Kallus and Brandt, 2012; Cox *et al.*, 2015). Future research should investigate the role of the microbiome in contributing to pet obesity, how the microbiome may be shared between owners and their pets, and how stress and poverty influence the microbiome.

Stress

While stress is an accepted cause of overeating (sometimes termed 'emotional eating') and subsequent weight gain in people and laboratory animals, the impact that stress has on cat and dog obesity has not been well studied (McMillan, 2013). Stressors can be internal or external, and responses to stressors can vary between individuals. There is one process that millions of dogs and cats experience annually: being rehomed through the sheltering systems (www.aspca.org). The potential impact of this likely stressful life event should not be ignored since in the USA, especially as shelter adoption is the most popular way to obtain a pet, as identified by the 2014 PetSmart Charities US Shelter Pet Report. Perhaps this or other stressful life events is linked to pets 'self-medicating' with food, especially in the presence of highly palatable food (Adam and Epel, 2007).

A heading

Having considered the underlying causes of obesity in pets, we finally review the potential interventions that may reduce obesity and discuss how social pressures may impact on the success of these interventions.

Neutering

A number of studies have shown that neutering is a risk factor for obesity (Lund *et al.*, 2005, 2006; Lefebvre *et al.*, 2013), therefore keeping pets entire is a potential intervention to protect against obesity. In some countries, this would be viewed as an unacceptable strategy in the face of pet overpopulation. Furthermore, in many communities there is strong social pressure to adopt rather than purchase pets, so much so that people who do purchase often feel the need to justify their reason for not adopting. Most sheltering organizations require spaying/neutering as part of the adoption process.

Reducing Intake

Reduction in caloric intake often works for weight reduction. However, there are multiple social challenges that make intake reduction particularly challenging for pet owners. Understanding and addressing these challenges is central to any solutions. Firstly, in part due to a pet's inability to self-report, society has embraced a healthy appetite as a primary indicator of good health. Transitioning to a less appetizing food may pose a true dilemma for the pet owner, as watching a pet not eat as enthusiastically as they have in the past could be concerning. The comfort of having a pet with a strong appetite might overwhelm the desire to have a pet at an ideal body weight.

Secondly, feeding and treating regimes may be a significant part of pet owner social interactions and training programmes. The human–animal bond is a much revered and cherished part of pet ownership, and having a devoted, obedient companion is coveted by many owners. Food and its delivery can be an important part of that bond. Some owners believe that the bond they share with their pet, or their ability to control their pet (via obedience), may be put at risk with caloric restriction. Fortunately, researchers are investigating this potential social barrier and have found that caloric restriction in cats did not reduce the cat's affiliative behaviour towards their owners. Continued research that alleviates these compelling social concerns is critical in getting owner compliance with certain strategies that may effect weight reduction in their pets.

Increasing Output

Increasing caloric expenditure can facilitate weight reduction. A great deal of canine exercise is conducted in public places (e.g. walks, hikes and dog parks). Unfortunately, taking dogs suffering from extreme obesity into public venues may make the owner feel self-conscious, a feeling that may be magnified if an owner of a pet with obesity is also suffering from obesity.

Reducing Bias and Stigma Associated with Obesity

Word choice and phrasing can impact how we view weight challenges and obesity. Derogatory terminology such as 'fat cat', which has been used in the veterinary scientific literature, should be avoided. Phrasing to reflect that obesity is a disease, not an attribute, should help to reduce bias and stigma; for example, instead of an obese person/pet there is a person/pet with obesity.

Educating both healthcare professionals and the public about the multifactorial nature of this complex disease process is a fundamental step in reducing the bias and stigma associated with obesity. When an overweight or obese state is recognized in a pet, there is a pervasive attitude that owner behaviour is at fault for creating this state and that the owner should be able to fix it by limiting intake and increasing exercise. However, new data support the idea that the overweight or obese state is secondary to much more than an indulgent or undisciplined owner who is unable to resist begging brown eyes (Haring *et al.*, 2011; Raffan *et al.*, 2016). Until, as professions and a society, we recognize that obesity is not necessarily easy to prevent or treat, we continue to do a disservice to those battling or managing this disease.

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