Nova Acta Leopoldina NF *112*, Nr. 382, 21–26 (2011)

Maternal "Junk Food" Diet and Post-Natal Development

Stéphanie Bayol and Neil Stickland (London, UK)

With 2 Tables

Abstract

Eating habits of Western societies have changed in the last few decades. People consume greater proportions of "away from home" foods and snacks which are rich in energy, saturated fat, sugar and salt but lack the micronutrients found in wholesome foods. These "junk food" diets are generally blamed for the current obesity epidemic, but the effects of exposure to such diets from fetal life through maternal nutrition in pregnancy and lactation are poorly characterised. We have developed an animal model to examine this issue in rats and data show that offspring exposed to a "junk food" diet from fetal life are susceptible to aggravated obesity and related disorders by the end of adolescence. This work highlights the maternal diet as a contributing factor to obesity in offspring and emphasizes that healthy eating habits ought to be encouraged starting at the fetal stage of life.

Zusammenfassung

Die Essgewohnheiten haben sich in den westlichen Gesellschaften in den letzten Jahrzehnten verändert. Viele Menschen konsumieren eine größere Menge an nicht selbst zu Hause bereiteten Nahrungsmitteln, die reich an Energie, gesättigten Fettsäuren, Zucker und Salz sind, aber denen es an Spurenelementen, wie in gesunden Nahrungsmitteln vorhanden, mangelt. Die Ernährung mit ungesunder Fertigkost ist dafür bekannt, der Auslöser der derzeitigen Adipositasepidemie zu sein. Die Auswirkungen einer solchen „junk food diet" bei einer Belastung durch die maternale Ernährung in der Schwangerschaft und während der Laktation auf den Feten sind jedoch bisher nicht ausreichend beschrieben. Wir haben ein Tiermodell entwickelt, um die Auswirkungen am Beispiel der Ratte zu untersuchen, und die Daten zeigen, dass der Nachwuchs der einer ungesunden Fertignahrung bereits während der Fetalzeit ausgesetzt war, anfällig für Übergewicht und verwandte Störungen am Ende der Adoleszenzzeit war. Diese Arbeit hebt hervor, dass die maternale Ernährung Einfluss auf ein potenzielles Übergewicht des Nachwuchses hat, und betont, dass man zu gesunden Ernährungsgewohnheiten bereits von der Fetalzeit an raten sollte.

1. Introduction

Obesity rates have risen sharply in Western countries over the last few decades, and the World Health Organization predicts that the number of obese adults worldwide will grow from 400 million in 2005 to over 700 million by 2015. Children are also affected at increasingly earlier ages with around 20 million children under the age of 5 classified as overweight in 2005.

Obesity generally occurs when energy intake exceeds energy expenditure, but evidence suggests that the recent obesity epidemic may not be fuelled only by people leading more sedentary lifestyles (Westerterp and Speakman 2008). Food energy supplies have increased in Western countries over the past few decades and these directly correlate with increased BMI (Silventoinen et al. 2004). Concurrently, eating habits have changed and Western nations consume greater proportions of "away from home foods", salty snacks and fizzy drinks which are rich in energy, fat, sugar and salt (Guthrie et al. 2002, Nielsen et al. 2002). Energy

dense diets with added fat and sugar are often lacking of vitamins and micronutrients found in unrefined wholesome foods, but their palatability and low cost encourage consumers' consumption (Andrieu et al. 2006, Maillot et al. 2007, Levine et al. 2003, Glanz et al. 1998). Consequently, energy dense diets with low nutritional value and added fat, sugar and salt are often qualified as "junk foods" and are believed to contribute to the obesity epidemic (Anderson and Patterson 2005).

More recent evidence from both human and animal studies indicates that maternal obesity and nutrition in pregnancy and lactation also contribute to the development of obesity and the metabolic syndrome in offspring (Armitage et al. 2008). However, the influence of a maternal "junk food" diet rich in energy, fat, sugar and salt on the offspring is not fully characterised.

We have developed an animal model based on the "supermarket" (Sclafani and Springer 1976) and "cafeteria" (Rothwell and Stock 1978) diets to examine this issue in rats and focused our attention on appetite and food preferences, skeletal muscle development and function, glycaemia, insulinemia, lipidemia and adiposity as well as non-alcoholic fatty liver disease in progeny. This animal model is particularly relevant to the human Western diet since obesity-related disorders are attributed to complex interactions between various nutritional factors consumed in excess including refined sugars, oils and salt as opposed to excessive intake of a single dietary component such as saturated fat alone (Cordain et al. 2005). Our data published to date is summarised below.

2. Experimental Design

In all studies, pregnant dams and offspring were fed either a balanced rodent chow diet alone (C) or with "junk food" items (J), namely biscuits, sweets, full fat cheese, potato crisps, cakes etc, all given *ad libitum*, during pregnancy, lactation and/or post-weaning as described in detail in a previous publication (Bayol et al. 2007). Pups were kept with their own mothers throughout lactation to reflect human situations. Litters were selected such that the number of pups born in each litter was statistically the same across all nutritional groups to control for litter sizes during both gestation and lactation, and prevent uncontrolled maternal physiological adaptations caused by removal of un-identical numbers of pups at birth across the groups. At weaning, six offspring per litter (three males plus three females) were selected to cover the whole range of birth weights and take into account intra-litter variations in the statistical design. Offspring were either culled at weaning (21 days post-partum) or at 10 weeks post-partum, which corresponds to about the end of adolescence in rats (Quinn 2005). Group names consist of either 2 (weaning) or 3 letters (10 weeks), with each letter (either C or J) corresponding to the diet given during gestation, lactation and post-weaning, respectively. Data was analysed by hierarchical two-way ANOVA to take into account litter effects and intra-litter variations.

3. Appetite and Food Preferences

By the end of adolescence, offspring fed the "junk food" diet from fetal life (JJJ) consumed approximately 22.5 % more energy daily than offspring born to chow fed mothers and given

free access to "junk food" only after weaning (CCJ) (Tab. 1). The increased energy intake exclusively came from the "junk food" source and was characterised by a selective exacerbated intake of fat (including saturated fat), sucrose and sodium while protein consumption was comparable among all offspring weaned on the "junk food" diet (Tab. 1). The exacerbated hyperphagia was accompanied by a 15 % and 18 % increase in body mass in JJJ males and females, respectively, compared with the CCJ group and BMIs were also increased. The data showed that a maternal "junk food" diet in pregnancy and lactation promoted exacerbated hyperphagia, a greater taste for "junk food" and obesity in progeny. Offspring born to "junk food" fed mothers switched to chow at weaning (JJC) reduced their daily energy intake for the first two weeks from weaning before their appetite returned to control (CCC) level by post-partum week 10, suggesting that the exacerbated hyperphagia observed in JJJ offspring may be triggered by the hedonic aspect of appetite regulation rather than hunger as previously discussed (Bayol et al. 2007).

Tab. 1 Nutrient intake. Average daily nutrient intake consumed by dams during pregnancy and lactation and by offspring (males and females) during the 10th week post-partum. C and J indicate chow and "junk food" diets, respectively, during gestation, lactation and/or post weaning. Different letters indicate statistically significant differences ($P < 0.05$). Adapted from Bayol et al. 2007.

	Pregnancy		Lactation			Week 10 post-partum					
	C	J	CC	JC	JJ	CCC	CCJ	JCC	JCJ	JJC	JJJ
Energy (KJ)	413.9a	645.4b	1217.1a	1072.8b	1448.9c	399.9a	723.3b	400.6a	657.2b	399.4a	885.9c
Fat (g)	1.2a	13.2b	3.4a	3.0b	26.5c	1.2a	18.3b	1.1a	16.2b	1.1a	25.1c
Sucrose (g)	1.6a	7.3b	4.6a	4.1b	13.4c	1.6a	7.7b	1.5a	6.9b	1.5a	9.5c
Sodium (g)	0.09a	0.16b	0.26a	0.23b	0.36c	0.09a	0.18b	0.08a	0.17b	0.08a	0.23c
Protein (g)	6.1a	3.9b	17.9a	15.8b	11.2c	6.1a	4.5b	5.9a	4.0b	5.9a	5.1b

4. Skeletal Muscle Development and Function

Weanling pups born to mothers fed the "junk food" diet in pregnancy alone or during both pregnancy and lactation exhibited semitendinosus muscle atrophy (reduced whole muscle cross sectional area) with fibre hypoplasia and fewer nuclear counts per cross sectional area. This was accompanied by increased intramuscular fat in the JJ group as well as increased expression of peroxisome proliferator-activated receptor (PPAR)-γ mRNA (Bayol et al. 2005).

This data showed that a maternal "junk food" diet impaired skeletal muscle development in weanling offspring, thus we decided to test whether this would translate into impaired muscle function at the end of adolescence. A small study revealed that offspring born to mothers fed the "junk food" diet in pregnancy and lactation exhibited reduced specific twitch and tetanic tensions in the plantar group of muscles (gastrocnemius, plantaris and soleus) following electrical stimulation *ex-vivo*, regardless of the post-weaning diet (Bayol et al. 2009).

5. Serum Biochemistry and Abdominal Adiposity

Elevated serum glucose, insulin, triglyceride and cholesterol are associated with insulin resistance, type 2 diabetes and cardiovascular disease. Our data showed that male offspring fed the "junk food" diet from fetal life (JJJ group) exhibited increased serum insulin with normal glycaemia while females were hyperglycaemic with normal insulin levels. Serum triglycerides and cholesterol were raised in both male and female progeny from the JJJ group while glycemia, insulinemia and lipidemia were not affected in CCJ or JJC groups. This showed that offspring exposed to the "junk food" diet from fetal life on exhibited impaired serum glycaemia, insulinemia and lipidemia and were therefore at greater risk of cardiovascular disease and type 2 diabetes by the end of adolescence. Abdominal adiposity is also strongly associated with the metabolic syndrome (Phillips and Prins 2008). As a measure of abdominal adiposity, we studied the perirenal fat pad; a major abdominal fat present both in male and female rats (Rokling-Andersen et al. 2009, Belzung et al. 1993). Table 2 shows that all offspring fed the "junk food" diet at some stage in the study exhibited increased perirenal fat mass relative to body weight which was characterised by adipocyte hypertrophy while their numbers were only increased in offspring fed "junk food" during the post-weaning period. Abdominal adiposity was markedly enhanced in JJJ offspring compared with all other groups and was greater in female than male progeny across all nutritional groups. Gene expression analyses (mRNA) revealed sex differences in the molecular metabolic adaptation to diet-induced adiposity in JJJ offspring, which could be explained by the sex differences in serum insulin and glucose described above. Females showed a marked up-regulation of mRNA expression for insulin-like growth factor-1, insulin receptor substrate (IRS)-1, vascular endothelial growth factor (VEGF)-A, PPAR-γ , leptin, adiponectin, adipsin, lipoprotein lipase (LPL), glucose transporters (Glut)-1 and -3 indicating greater adipocyte proliferation and differentiation, as well as increased uptake of glucose and dietary lipids in abdominal adipose tissue compared with female offspring never given access to "junk food" (CCC). Male JJJ offspring up-regulated IRS-1, VEGF-A, Glut-4 and LPL mRNAs compared with the CCC group (Bayol et al. 2008). Data unpublished to date revealed that the increased abdominal adiposity was accompanied by aggravated signs of non-alcoholic fatty liver disease and hepatic oxidative stress in JJJ offspring with sex differences in the molecular hepatic adaptation to diet-induced obesity.

Tab. 2 Abdominal adiposity. Adiposity parameters in 10 week old male (M) and female (F) offspring fed a "junk food" diet at various stages of development and growth. C and J indicate chow and "junk food" diets, respectively, during gestation, lactation and/or post weaning. Different letters indicate statistically significant differences ($P<0.05$). Adapted from Bayol et al. 2008.

	Perirenal fat mass (g)		% perirenal fat mass to body mass		Average mature adipocyte area (μm²)		Adipocyte density × perirenal fat pad mass	
	M	F	M	F	M	F	M	F
CCC	5.3a	2.8a	1.4a	1.2a	3638.3a	2998.6a	456.3a	285.1a
CCJ	9.9b	8.0b	2.4b	3.0b	4725.8b	4539.2b	739.8b	643.7b
JJC	6.9c	3.8a	1.9c	1.7c	4385.6b	3787.3b	542.4a	331.9a
JJJ	15.2d	13.7c	3.2d	4.5d	9388.8c	8494.7c	684.8b	638.4b

6. Conclusions

The rapid rise in obesity rates among Western countries is attributed to changes in dietary habits with increased intake of foods prepared away from home, snacks and "junk foods" which are dense in energy, fat, sugar and salt. Our studies revealed that exposure to such "junk food" diets from fetal life through maternal nutrition in pregnancy and lactation leads to exacerbated hyperphagia, obesity, abdominal adiposity as well as hyperglycaemia, hyperinsulinemia and hyperlipidemia by the end of adolescence. Therefore, a maternal "junk food" diet puts progeny at greater risk of cardiovascular diseases and type 2 diabetes early in adult life compared with offspring born to mothers fed a balanced diet. These studies highlight the importance of a healthy maternal diet in pregnancy and lactation for the prevention of obesity in future generations.

References

Anderson, J. W., and Patterson, K.: Snack foods: comparing nutrition values of excellent choices and "junk foods". J. Amer. Coll. Nutr. *24*, 155–156; discussion 156–157 (2005)

Andrieu, E., Darmon, N., and Drewnowski, A.: Low-cost diets: more energy, fewer nutrients. Eur. J. Clin. Nutr. *60*, 434–436 (2006)

Armitage, J. A., Poston, L., and Taylor, P. D.: Developmental origins of obesity and the metabolic syndrome: the role of maternal obesity. Front. Horm. Res. *36*, 73–84 (2008)

Bayol, S. A., Farrington S. J., and Stickland N. C.: A maternal "junk food" diet in pregnancy and lactation promotes an exacerbated taste for 'junk food' and a greater propensity for obesity in rat offspring. Br. J. Nutr. *98*, 843–851 (2007)

Bayol, S. A., Macharia, R., Farrington, S. J., Simbi, B. H., and Stickland, N. C.: Evidence that a maternal "junk food" diet during pregnancy and lactation can reduce muscle force in offspring. Eur. J. Nutr. *48*, 62–65 (2009)

Bayol, S. A., Simbi, B. H., Bertrand, J. A., and Stickland, N. C.: Offspring from mothers fed a "junk food" diet in pregnancy and lactation exhibit exacerbated adiposity that is more pronounced in females. J. Physiol. *586*, 3219–3230 (2008)

Bayol, S. A., Simbi, B. H., and Stickland, N. C.: A maternal cafeteria diet during gestation and lactation promotes adiposity and impairs skeletal muscle development and metabolism in rat offspring at weaning. J. Physiol. *567*, 951–961 (2005)

Belzung, F., Raclot, T., and Groscolas, R.: Fish oil n-3 fatty acids selectively limit the hypertrophy of abdominal fat depots in growing rats fed high-fat diets. Amer. J. Physiol. *264*, R1111–1118 (1993)

Cordain, L., Eaton, S. B., Sebastian, A., Mann, N., Lindeberg, S., Watkins, B. A., O'Keefe, J. H., and Brand-Miller, J.: Origins and evolution of the Western diet: health implications for the 21st century. Amer. J. Clin. Nutr. *81*, 341–354 (2005)

Glanz, K., Basil, M., Maibach, E., Goldberg, J., and Snyder, D.: Why Americans eat what they do: taste, nutrition, cost, convenience, and weight control concerns as influences on food consumption. J. Amer. Diet. Assoc. *98*, 1118–1126 (1998)

Guthrie, J. F., Lin, B. H., and Frazao, E.: Role of food prepared away from home in the American diet, 1977–1978 versus 1994–1996: changes and consequences. J. Nutr. Edu. Behav. *34*, 140–150 (2002)

Levine, A. S., Kotz, C. M., and Gosnell, B. A.: Sugars and fats: the neurobiology of preference. J. Nutr. *133*, 831S–834S (2003)

Maillot, M., Darmon, N., Vieux, F., and Drewnowski, A.: Low energy density and high nutritional quality are each associated with higher diet costs in French adults. Amer. J. Clin. Nutr. *86*, 690–696 (2007)

Nielsen, S. J., Siega-Riz, A. M., and Popkin, B. M.: Trends in energy intake in U.S. between 1977 and 1996: similar shifts seen across age groups. Obes. Res. *10*, 370–378 (2002)

Phillips, L. K., and Prins, J. B.: The link between abdominal obesity and the metabolic syndrome. Curr. Hypertens. Rep. *10*, 156–164 (2008)

Quinn, R.: Comparing rat's to human's age: how old is my rat in people years? Nutrition *21*, 775–777 (2005)

Rokling-Andersen, M. H., Rustan, A. C., Wensaas, A. J., Kaalhus, O., Wergedahl, H., Rost, T. H., Jensen, J., Graff, B. A., Caesar, R., and Drevon, C. A.: Marine n-3 fatty acids promote size reduction of visceral adipose depots, without altering body weight and composition, in male Wistar rats fed a high-fat diet. Br. J. Nutr. *102*, 995–1006 (2009)

Rothwell, N. J., and Stock, M. J.: A paradox in the control of energy intake in the rat. Nature *273*, 146–147 (1978)

Sclafani, A., and Springer, D.: Dietary obesity in adult rats: similarities to hypothalamic and human obesity syndromes. Physiol. Behav. *17*, 461–471 (1976)

Silventoinen, K., Sans, S., Tolonen, H., Monterde, D., Kuulasmaa, K., Kesteloot, H., and Tuomilehto, J.: Trends in obesity and energy supply in the WHO MONICA Project. Int. J. Obes. Relat. Metab. Disord. *28*, 710–718 (2004)

Westerterp, K. R., and Speakman, J. R.: Physical activity energy expenditure has not declined since the 1980s and matches energy expenditures of wild mammals. Int. J. Obes. (London) *32*, 1256–1263 (2008)

Dr. Stéphanie Bayol, Ph.D.
Department of Verterinary Basic Sciences
The Royal Veterinary College
Royal College Street, London 2
NW1 OTU
United Kingdom
Phone: +44 20 74685248
Fax: +44 20 73882342
E-Mail: sbayol@rvc.ac.uk