Fat balance and ageing: results from the Québec Family Study

Angelo Tremblay*, Vicky Drapeau, Eric Doucet, Natalie Alméras, Jean-Pierre Després and Claude Bouchard

Physical Activity Sciences Laboratory and Lipid Research Center, Laval University, Ste-Foy, Québec, Canada, G1K 7P4

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The aim of the present study was to evaluate changes in participation in physical activity and in fat and alcohol intake associated with ageing. This issue was examined in adults (*n* 207) who were tested between 1978 and 1982 and re-tested 12 years later. These adults were 42·3 (SD 4·9) years of age at baseline. Their children (*n* 122) were tested over the same follow-up period. They were, on average, 12·5 (SD 1·9) years at entry into the study. A decrease in the proportion of daily energy intake as fat and an increase in participation in vigorous physical activities were observed over the 12-year period in both groups. The proportion of dietary energy as alcohol remained stable in adults whereas it increased markedly in children. Correlation analyses between baseline and follow-up levels were significant for dietary fat and alcohol intake in adults. In children, the levels of these variables in the growing years did not predict the levels attained 12 years later. Even though the adults displayed changes in fat balance generally following current public health recommendations, a substantial increase in skinfold thicknesses was observed in these subjects during follow-up. This observation suggests that there is a strong effect of age-related factors on fat balance.

Energy intake: Adiposity: Physical activity

Fat balance, i.e. the equilibrium between dietary lipid intake and lipid oxidation, is the component of macronutrient balance which best predicts variations in energy balance (Schutz *et al.* 1989; White *et al.* 1997). This is probably explained by the lower potential of fat to inhibit subsequent food intake (Blundell *et al.* 1993; Lawton *et al.* 1993; Rolls *et al.* 1994) and to promote its own oxidation (Flatt *et al.* 1985) compared with protein and carbohydrate.

Variations in fat balance depend on genetic and environmental factors determining lipid intake and lipid oxidation. It has been demonstrated that the composition of the fuel mix oxidized under standardized conditions (Bouchard *et al.* 1989) and the relative contribution of lipid to daily energy intake (Pérusse *et al.* 1988) are partly biologically inherited. Among environmental factors, dietary fat intake has the greatest potential to provoke deviations in fat and energy balance. Indeed, a high-fat diet is associated with a substantial increase in daily energy intake (Lissner *et al.* 1987; Tremblay *et al.* 1989) and body fatness (Lissner *et al.* 1987; Tremblay *et al.* 1989; Tucker & Kano, 1992; Nelson & Tucker, 1996). On the other hand, recent data also tend to show that this effect of dietary fat plays a minor role in variations in adiposity (Larson *et al.* 1996). Experimental data demonstrate that alcohol intake also influences fat and energy balance by transiently decreasing fat oxidation (Suter *et al.* 1992) and favouring an excess energy intake (Tremblay *et al.* 1995*b*; Poppitt *et al.* 1996). Exercise is another factor which can modify fat balance. Its impact on body weight and body fat has been the topic of many studies which generally show that an increase in exercise volume is associated with a greater body-fat loss (Ballor & Kessey, 1991). Recent results obtained in our laboratory revealed that increasing exercise intensity favours additional negative energy balance and fat loss. For a given energy cost of physical activities, an increase in exercise intensity is related to an accentuation of the following effects: decrease in subcutaneous fat (Tremblay *et al.* 1990, 1994), increase in the skeletal muscle lipid oxidation potential (Tremblay *et al.* 1994), increase in post-exercise energy expenditure and fat oxidation rate (Yoshioka *et al.* 1996). The idea that increasing exercise intensity favours an increase in post-exercise energy expenditure has also been recently demonstrated by using whole-body indirect calorimetry

Abbreviations: QFS, Québec Family Study.

***Corresponding author:** Dr Angelo Tremblay, fax +1 418 656 3020, email ATREMB@FSE.ULAVAL.CA

(Treuth *et al.* 1996). Taken together, these observations suggest that a high-fat and alcohol intake regimen plus a low participation in vigorous physical activities are partly responsible for the increase in body fatness observed over time in many individuals.

Population studies, also, have documented the potential effect of fat balance-related factors on long-term changes in adiposity. For instance, the progressive increase in the prevalence of obesity while dietary lipid intake is stable or is slightly decreasing (National Health and Nutrition Examination Survey III, 1995) suggests that fat intake does not play a major role in the recent increase of adiposity in many countries. Prentice & Jebb (1995) have pointed out that there is a lack of detailed information about long-term changes in factors influencing fat and energy balance. In their study, they excluded daily energy intake and fat consumption but implicated the number of cars and duration of television viewing, with the concomitant reduction in physical activity and energy expenditure, to explain the recent increase in obesity in Great Britain. In the Québec Family Study (QFS), changes in fat and alcohol intake and participation in vigorous physical activities were measured in parents and their offspring at entry into the study and, on average, 12 years later. Baseline energy and macronutrient intakes, physical activity level and body mass and body composition characteristics were compared with those observed at the follow-up examination in parents and offspring of both sexes. The correlations between the two measurement periods were also examined.

Methods

Daily energy and macronutrient intakes, alcohol consumption, participation in vigorous physical activities, and body composition were measured in 207 adults (103 males, 104 females) and their offspring (*n* 122; sixty males, sixty-two females) who were tested in phase 1 (between 1978 and 1982) and phase 2 (between 1989 and 1994) of QFS. Subjects gave their written consent to participate in this study which received the approval of the Laval University Medical Ethics Committee.

Food intake was measured using a 3 d dietary record as previously described (Tremblay *et al.* 1983). The tables of Dubuc and Lahaie (Brault-Dubuc & Caron-Lahaie, 1978) were used to calculate daily energy, protein, lipid, carbohydrate and alcohol intakes in phase 1 of testing. These calculations were performed with the *Canadian Nutrient File* (Canada Health and Welfare, 1988) in phase 2.

The physical activity diary described by Bouchard *et al.* (1983) was used to assess participation in vigorous physical activities. The activity diary was completed during the same days as those selected to record food intake. This method classifies activities on a scale from 1 (sleep) to 9 (heavy exercise). For each 15 min period, the subject coded the dominant activity of that period. The daily physical activity level was derived by summing up the number of 15 min periods during which each activity category was performed. Since the focus of the present study was on vigorous activities which are the most likely to induce changes in adiposity (Tremblay *et al.* 1990) and energy balance (Tremblay *et al.* 1994; Treuth *et al.* 1996; Imbeault *et al.* 1997), we calculated the number of periods over 3 d during which activities coded as 8 and 9 (intensity of at least six times resting energy expenditure) were performed. Thus, the reference to vigorous activities includes activities of moderate-to-high intensity.

Subcutaneous skinfold thicknesses were measured with a Harpenden skinfold caliper at the following sites: biceps, triceps, calf, subscapular region, abdomen, and suprailiac crest. The procedures recommended by the International Biological Program (Weiner & Lourie, 1969) were followed for these measurements.

A paired *t* test was used to assess whether there were significant differences in each group of subjects for each variable. Pearson's correlations (Sokal & Rohlf, 1969) were computed to evaluate the relationship between results obtained before and after the 12-year follow-up. A repeated measures ANOVA was performed to assess sex effects on dependent variables.

Results

Table 1 shows the characteristics of the parents. As expected, body weight and skinfold thicknesses were significantly increased after 12 years. These increases were observed despite the fact that there were changes in intake and activity which are commonly thought to facilitate the control of fat balance. Indeed, parents significantly decreased the fraction of dietary energy as fat whereas they increased their participation in vigorous physical activities.

Results obtained in offspring who were about 12 years of age in 1980 are presented in Table 2. The transition between prepuberty and adulthood was accompanied by a significant increase in skinfold thicknesses. Relative fat intake was lower in phase 2 of testing in comparison with the baseline value. This effect was found in both males and females but it was statistically significant only in females. A small increase in participation in physical activities was also observed in both sexes but this effect was not significant. Not surprisingly, Table 2 also shows that the transition from prepuberty to adulthood was associated with a considerable increase in alcohol intake. Within this period, alcohol consumption increased from almost nothing to a level comparable to that measured in parents.

Correlation coefficients between baseline and 12-year follow-up values are presented in Table 3. As expected, body weight and adiposity values measured at entry were significantly correlated with those obtained 12 years later, both in offspring and adults. However, the correlation coefficients were lower in the offspring than in adults. Values of relative fat and alcohol intake at baseline were positively correlated with those measured at the second examination in adults whereas no association was found in offspring. With respect to physical activity level, correlations between pre- and post-follow-up values were low but statistically significant in parents. The correlation was also significant in children but this association was only seen in female offspring.

Table 1. Characteristics of parents before and after the 12-year follow-up period
(Mean values and standard deviations)

	Age (years)		Body wt (kg)		Sum of six skinfolds (mm)		Energy intake (kJ/d)		Protein intake (% energy)		Lipid intake (% energy)		Carbohydrate intake (% energy)		Alcohol intake (% energy)		Physical activity (n 8+9)†	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Males (n 103)																		
Before	43·6	5·0	74·6	11·4	71·7	28·7	11151	2472	14·6	2·9	35·0	5·9	43·7	7·3	6·7	7·5	1·3	2·1
After	55·8**	5·4	77·0**	12·2	87·0**	29·1	10562*	2295	15·6**	2·3	33·4*	6·3	45·4*	6·9	5·6	6·7	4·1**	7·6
Δ	+12·2	1·9	+2·4	5·9	+15·3	19·4	−589	2895	+1·0	3·5	−1·6	6·6	+1·7	7·1	−1·1	8·1	+2·8	7·5
Females (n 104)																		
Before	41·1	4·4	58·0	8·6	93·8	32·6	7760	1600	15·0	3·1	35·5	5·5	46·4	6·8	3·1	5·3	0·7	1·9
After	53·3**	4·9	62·9**	10·3	129·6**	42·5	8037	1570	16·2**	3·0	33·1**	5·3	46·9	6·0	3·9	5·1	2·9**	5·5
Δ	+12·2	1·9	+4·9	5·8	+35·8	29·6	+277	1954	+1·2	3·3	−2·4	6·6	+0·5	7·3	+0·8	5·4	+2·2	5·5

Mean values were significantly different from those before follow-up: $^{*}P \leq 0{\cdot}05$, $^{**}P \leq 0{\cdot}01$.
† Sum of activity periods coded 8 and 9 (moderate-to-high intensity), see p. 414.

Table 2. Characteristics of offspring before and after the 12-year follow-up period
(Mean values and standard deviations)

	Age (years)		Body wt (kg)		Sum of six skinfolds (mm)		Energy intake (kJ/d)		Protein intake (% energy)		Lipid intake (% energy)		Carbohydrate intake (% energy)		Alcohol intake (% energy)		Physical activity (n 8+9)†	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Males (n 60)																		
Before	12·6	1·9	43·2	12·0	45·8	19·9	9928	2318	13·7	2·8	34·2	5·1	51·1	6·1	0·0	0·1	4·7	3·9
After	24·1**	2·8	72·5**	11·5	66·8**	31·9	12465**	2171	14·5*	2·4	33·7	6·0	46·0**	7·3	5·8**	7·7	6·0	7·3
Δ	+11·5	1·6	+29·3	10·9	+21·0	21·5	+2537	2983	+0·8	2·9	−1·5	7·1	−5·1	7·5	+5·8	7·7	+1·3	8·0
Females (n 62)																		
Before	12·5	2·1	41·1	9·8	59·6	21·4	7934	1793	14·2	2·6	36·0	4·9	49·6	6·2	0·2	1·0	3·6	5·2
After	24·5**	3·1	57·9**	7·1	86·6**	30·2	8769**	1584	15·3*	2·6	33·8*	5·6	47·5*	5·7	3·5**	4·6	4·1	6·2
Δ	+12·0	1·7	+16·8	10·7	+27·0	26·9	+835	2098	+1·1	3·5	−2·2	7·6	−2·1	7·9	+3·3	4·8	+0·5	6·9

Mean values were significantly different from those before follow-up: $^{*}P \leq 0{\cdot}05$, $^{**}P \leq 0{\cdot}01$.
† Sum of activity periods coded 8 and 9 (moderate-to-high intensity), see p. 414.

Table 3. Correlations between values collected before and after the 12-year follow-up period

	Body weight	Sum of six skinfolds	Energy intake	Protein intake	Lipid intake	Carbohydrate intake	Alcohol intake	Physical activity
Parents								
Group (*n* 207)	0·90**	0·77**	0·52**	0·35**	0·36**	0·45**	0·41**	0·20**
Males (*n* 103)	0·88**	0·78**	0·27**	0·30**	0·42**	0·51**	0·36**	0·20*
Females (*n* 104)	0·82**	0·72**	0·24*	0·39**	0·28**	0·35**	0·47**	0·18
Offspring								
Group (*n* 122)	0·42**	0·66**	0·41**	0·23**	0·07	0·25**	−0·06	0·20*
Males (*n* 60)	0·57**	0·74**	0·14	0·35**	0·20	0·39**	0·07	0·08
Females (*n* 62)	0·25*	0·50**	0·23	0·09	−0·07	0·13	−0·08	0·29*

$^*P \leq 0·05$, $^{**}P \leq 0·01$.

Sex differences in changes in body composition and fat balance were observed over the 12-year follow-up period. Adult women displayed a significantly greater increase in body weight and the sum of six skinfolds than adult men ($P < 0·01$). Accordingly, the increase in reported energy intake and percentage of energy intake as alcohol in women were significantly different from the changes in the variables noted in adult men ($P \leq 0·05$). As expected, male offspring increased their body weight and energy intake to a greater extent than females ($P < 0·01$). Male offspring increased their energy intake as alcohol more than their female counterparts and this was compensated by a decrease in carbohydrate intake (% energy) ($P \leq 0·05$). No sex difference was observed for changes in participation in vigorous physical activity.

Fig. 1 presents an estimate of the mean energy equivalent of changes over time in participation in physical activity as well as in fat and alcohol intake. In adults, the cumulative effect of changes in physical activity and fat intake was about 600 kJ/d. The energy equivalent of changes in alcohol intake was trivial in adults whereas it compensated for changes in activity participation and fat intake in children.

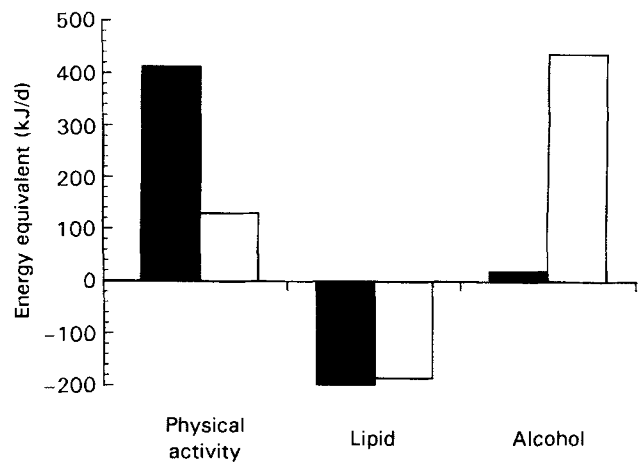

Fig. 1. Estimated mean energy equivalent of changes over time in vigorous physical activity as well as lipid and alcohol intake in parents (■) and children (□) of both sexes in the Québec Family Study.

Discussion

Recent research in human subjects has allowed better characterization of some of the lifestyle factors that may account for deviations in body energy and fat balance. According to a recent study performed in our laboratory (Tremblay *et al.* 1995*a*) and other observations (Dreon *et al.* 1988; Romieu *et al.* 1988; Tremblay *et al.* 1989, 1990); Ballor & Keesey, 1991), high fat and alcohol intakes and reduced participation in vigorous physical activities represent factors promoting body-fat gain. From a nutritional standpoint, this suggests that alcohol consumption should receive as much attention as dietary fat in interventions aimed at preventing obesity. With respect to participation in physical activity, exercise intensity may influence post-exercise fat oxidation and energy expenditure and intake. QFS offers the opportunity to study changes in these factors over time. The present study was based on two generations of subjects before and after a 12-year follow-up period. At the second examination, parents were, on average, in their mid-fifties, whereas their offspring had become young adults.

Dietary energy as fat and alcohol, i.e. from substrates exerting a weak suppressing effect on energy intake (Blundell *et al.* 1993; Lawton *et al.* 1993; Rolls *et al.* 1994; Tremblay & St-Pierre, 1996), was about 40 % in parents at baseline and it decreased to 38 % after 12 years of follow-up. This relative decrease was mainly explained by a reduction in relative fat intake, which is concordant with current nutritional recommendations. This phenomenon may result from the efforts to advocate a decrease in fat intake in a variety of health promotion campaigns. In offspring, the transition between prepuberty and adulthood was also accompanied by a decrease in relative fat intake which was, however, compensated by an increase in alcohol intake. Thus, total dietary energy as fat and alcohol increased from about 35 to 38 % over the 12-year follow-up period.

Another subject of interest is the stability over time in fat and alcohol intake, as assessed by correlation studies. Correlations between values obtained at baseline and 12 years later were significant in parents. In addition, the correlations were equivalent in male and female adults. On the other hand, results showed that fat and alcohol intake values were essentially uncorrelated over the 12-year follow-up period in offspring. This observation reflects the fact that fat and alcohol intake behaviours evolve during growth. It suggests that growth may be a critical period in which to educate children about healthy food habits in order to reduce the risk of excessive body fat accumulation.

Participation in vigorous physical activities significantly increased over time in both adults and offspring. In the parents, the mean number of 15-min periods during which they engaged in vigorous activities increased by 2·5 in 3 d, which corresponded to an increase of about 12 min/d. Results obtained in offspring revealed a similar trend. In this case, it was equivalent to an increase of 5 min/d in the time allocated to vigorous physical activities. Thus, changes in physical activity were small but nevertheless represented a step towards the adherence to a more active lifestyle.

The correlations between physical activity at baseline and 12 years later were significant in the overall group of adults, although the correlations were lower than for fat and alcohol intake. Correlations of the same order were found in offspring for participation in vigorous physical activities, an indication that it was more predictable over time than fat and alcohol intake. However, the correlation was not significant in male offspring.

As expected, parents gained a significant amount of body fat over the 12-year period. The fact that this change occurred concomitantly with a decrease in relative fat intake and an increase in participation in physical activity suggests that the age-related effects on other determinants of energy balance are particularly important. The same trend was observed in offspring but a substantial part of their morphological changes was attributable to growth.

Although the reliability of the two diaries used in this study was found to be moderate to high (Bouchard *et al.* 1983; Tremblay *et al.* 1983), it should be noted that changes over the 12-year follow-up were based on two 3 d observation periods, which might be too short to provide a complete description of food and activity habits. The use of methods allowing more detailed and precise measurements of these variables will be useful in further investigations of this issue. Another limitation of this study pertains to the small energy equivalents of changes in physical activity as well as in fat and alcohol intake revealed by the diaries. The main consequence is that our data do not permit us to quantify the impact of ageing on fat and energy balance. Ideally, we would test some individuals whose lifestyle changes would be sufficient to prevent body weight and fat gain. The assessment of energy equivalents of these changes would then provide an indirect measure of the effect of ageing on energy balance. Finally, it is also relevant to consider that the perception of exercise duration and/or intensity might change over time. In practical terms, this means that even if the number of entries coded 8 and 9 in the physical activity diary increased over time, the change in energy expenditure might not be as high as that derived from the activity record.

In summary, the present study shows that in adult subjects over a 12-year period there was improvement in behaviours thought to affect fat balance. With the exception of alcohol consumption, this was also observed in offspring who experienced the transition from growth to adulthood. These changes were predictable in adults but the tracking of these variables was poor in children who reached adulthood over the study period. Indeed, there was essentially no association between fat and alcohol intake measured before and after the 12-year follow-up in children, which is considered as evidence that lifestyle habits could be substantially changed in children during the transition from prepuberty to adulthood. In adults, lifestyle changes observed during the follow-up would have been expected to favour body-weight maintenance, but in fact, adiposity significantly increased with ageing. These results suggest that age-related effects on fat balance are strong since they largely dominated over the estimated lifestyle changes that should have promoted fat loss.

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