



PAPER

Family lifestyle and parental body mass index as predictors of body mass index in Australian children: a longitudinal study

V Burke^{1*}, LJ Beilin¹ and D Dunbar¹

¹Department of Medicine, Royal Perth Hospital, University of Western Australia, and the Western Australian Heart Research Institute, Perth, Australia

OBJECTIVE: To investigate associations between body mass index (BMI) and family characteristics, including lifestyle, in parents and offspring from Australian families.

DESIGN AND SUBJECTS: Longitudinal survey of 219 families of Australian children who had been surveyed 3-yearly between the ages of 9 and 18 y.

MEASUREMENTS: Socio-economic status, weight and height, diet from 3 day records or food frequency questionnaires, alcohol consumption, smoking habits and physical fitness in offspring (bicycle ergometry in 18-y-olds).

RESULTS: In 18-y-olds, in models examining offspring's lifestyle variables, BMI was predicted negatively by physical fitness ($P=0.012$), and positively by alcohol intake ($P=0.046$) in sons while, in daughters, only a negative association with physical fitness was significant. In models including parental characteristics, BMI in 18-y-old sons and daughters was significantly predicted by mothers' and fathers' BMI, independently of offsprings' alcohol intake, smoking, physical fitness and parents' education, and, in daughters, by fathers' alcohol intake. These models explained 48% of variance in daughters and 33% in sons. In both sons and daughters, BMI over the 9 y of the survey was consistently higher in offspring with overweight or obese fathers ($P=0.033$ for sons, $P=0.024$ for daughters) or mothers ($P=0.031$ for sons, $P=0.037$ for daughters). Physical fitness at the ages of 12, 15 and 18 y was negatively related to fathers' obesity in daughters and mothers' obesity in sons. Obesity in fathers was associated with a four-fold increase in risk of obesity at the age of 18 y in both sons and daughters with an independent eight-fold increase in risk for daughters if mothers were obese. Birthweight was unrelated to overweight or obesity in the 18-y-olds. Alcohol intake in sons related significantly to alcohol intake in either parent while, for daughters, there was a significant association only with fathers' alcohol consumption. In daughters, fat intake was positively associated with fat intake score in both fathers and mothers.

CONCLUSION: Parental overweight or obesity may identify children at risk for a range of unhealthy behaviours. Promotion of a healthy lifestyle targeting overweight families, particularly in lower socio-economic groups, should be a priority.

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Introduction

Obesity tends to aggregate within families¹ as a result of interaction between genetic and environmental factors.^{2–4} Parental obesity is associated with increased prevalence of obesity in children⁵ and increases the risk that a child will

become an obese adult,⁶ independent of obesity status in childhood.⁷

Tracking of cardiovascular risk factors, including obesity, through childhood to adult life⁸ suggests that early recognition of individuals at risk, along with programs to encourage improved health behaviours, may have long-term benefits for lifestyle diseases. The importance of optimizing health-related behaviours in childhood is also suggested by reports of tracking through childhood of behaviours including physical activity, food choice⁹ and intake of nutrients and energy.¹⁰ Markers for risk and identification of risk behaviours, both in individuals and within a shared family

*Correspondence: V Burke, University Department of Medicine, Royal Perth Hospital, Box X2213 GPO, Perth 6847, Australia.
E-mail: vburke@cyllene.uwa.edu.au
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environment,¹¹ are needed to recognize vulnerable groups in whom improvements in health behaviours should be a priority.

In the present study we examined longitudinal data from a cohort of Western Australian children, surveyed 3-yearly between the ages of 9 and 18 y, in relation to body mass index (BMI) of mothers and fathers when the offspring were 18 y old, as well as to measures of lifestyle in offspring and parents. As gender-specific associations between parents and offspring have been documented for blood pressure¹² and for risk behaviours,¹¹ we carried out analyses separately for sons and daughters in relation to BMI and measures of health behaviours in fathers and mothers.

Subjects and methods

The study design has been described in detail elsewhere¹³ and was based on repeated surveys of a cohort of Perth children, 1565 in total, at the ages of 9, 12, 15 and 18 y. Of the 1119 individuals who could be traced at the age of 18 y, 798 (71%) participated in the resurvey. Socio-economic status (SES) was classified in three groups based on tertiles of the relative urban advantage of the current address as described by the Australian Bureau of Statistics.¹⁴ Participants gave written permission and the study was approved by the University of Western Australia Committee for Human Rights.

Dietary intakes, including alcohol consumption, were assessed using a previously validated method based on two consecutive weekday 24 h diet records.¹³ Information about 'safe' drinking of alcohol intake was obtained by a questionnaire which defined 'safe' drinking as not more than 2 drinks/day for females and not more than 4 drinks/day for males.¹⁷ Whether subjects had ever smoked, whether they were currently smokers and the interval since giving up smoking for those who had quit was also elicited by questionnaire. Physical activity, including duration and type, was recorded using questionnaires. The amount of activity for each day of the week was recorded on a five-point scale ranging from none to over 2 h and scores were summed over the week giving a possible maximum of 35. Questionnaires completed by the subjects at home in consultation with their parents included information about parents' educational level and history of hypertension.

Physical fitness in 18-y-olds was measured as the physical work capacity at a heart rate of 170 beats/min (PWC_{170}) using sub-maximal testing on bicycle ergometers.¹⁵ Physical fitness was not measured at the age of 9 y. The time taken to complete a 1.6 km run was used in 12-y-olds, and the Leger shuttle run in 15-y-olds.¹⁶ Weight was measured in lightly clad subjects using a beam balance and height using a stadiometer.

All parents with a history of hypertension and parents from a similar number of randomly selected families without reported paternal or maternal hypertension were invited to attend our department for measurement of height, weight

and blood pressure using the same methods as for the offspring.¹⁸ Parents who attended also completed a simple food frequency questionnaire, allowing assessment of usual fat intake by a fat-score¹⁹ as well as a retrospective 7-day alcohol diary. The fat-score addressed frequency of consumption of fried foods, gravies and sauces, use of fat in cooking or serving foods, processed meats, pastries, fat-containing snack foods, ice-cream, low-fat and high-fat dairy products and use of spreads as well as cooking methods. Responses were scored on a scale of 1 (infrequent) to 5 (frequent) and summed to provide a total fat score. Information about parents' smoking habits allowed classification as non-smokers, current smokers and ex-smokers (for at least 5 y), as well as recording the amount smoked currently. No information about physical activity in parents was available. The study included 174 fathers and 214 mothers and 104 sons and 115 daughters from separate families. Both mother and father attended from 169 families, mother only from 45 families and father only from five families.

Statistical methods

In surveys before the age of 18 y, obesity was defined as BMI greater than the 95th age- and sex-specific centile and overweight as BMI between the 85th and 95th centiles using Australian data.²⁰ In 18-y-olds and in parents cut-off points were defined according to the National Heart Lung and Blood Institute²¹ with overweight being $BMI > 25 < 30 \text{ kg m}^{-2}$ and obesity $BMI > 30 \text{ kg m}^{-2}$. One-way analysis of variance was used to compare continuous variables in cross-sectional analysis; general linear models (GLM) were used to adjust for covariates. Data are presented from the survey at the age of 18 y to allow consideration of lifestyle variables, such as smoking habits and alcohol consumption, which were not collected in previous surveys. Univariate and multivariate regression models were used to examine associations between data from parents and offspring with logistic regression used for binary outcome variables. Repeated measures analysis of variance was used to examine longitudinal relationships. For data that were not normally distributed groups were compared using Mann–Whitney tests. Results were considered significant at a level of $P < 0.05$. All results for offspring refer only to individuals who had at least one parent participating in the family study. Data from the entire cohort surveyed at the age of 18 y has been reported elsewhere.^{13,18}

Results

Characteristics of sons and daughters

Table 1 summarizes the characteristics of the sons and daughters included in the sample. Ten percent of sons and 11% of daughters were overweight and 6% of sons and 4% of daughters were obese.

Table 1 Characteristics of parents and offspring

Variable	Fathers	Mothers	Sons	Daughters
Age (y)	52.1 (0.4)	49.1 (0.3)	18.1 (0.01)	18.1 (0.01)
BMI (kg m ⁻²)	27.8 (0.3)	26.7 (0.2)	22.7 (0.3)	21.8 (0.3)
BMI group				
< 25 kg m ⁻²	41 (24%)	98 (46%)	87 (84%)	95 (85%)
25–30 kg m ⁻²	85 (49%)	69 (32%)	10 (10%)	12 (11%)
> 30 kg m ⁻²	48 (28%)	47 (22%)	6 (6%)	5 (4%)
Fat intake ^a	24.1 (0.6)	20.7 (0.4)	36.0 (0.7)	34.9 (0.8)
Alcohol intake (ml/week)	143.8 (11.4)	54.0 (5.1)	25.9 (1.5)	2.4 (0.7)
'Unsafe' drinking ^b	27 (16%)	23 (11%)	41 (47%)	45 (46%)
Current smokers	24 (14%)	20 (9.3%)	22 (27%)	27 (29%)
Ex-smokers	75 (44%)	61 (29%)	21 (26%)	25 (27%)

^aFat intake measured by fat intake score in parents and by percentage energy from diet records in offspring.

^bDrinking in excess of four standard drinks per day for males, two standard drinks per day for females.

Birthweight and subsequent fatness.

Birthweight correlated positively with BMI at the age of 9 y in daughters ($r=0.227$, $P=0.033$), but there were no other significant relationships between BMI and birthweight in sons or daughters. Correlation coefficients ranged from -0.002 to 0.174 in sons and from 0.113 to 0.132 in daughters. Birthweight was not related to overweight or obesity in sons or daughters. Because of the report of greater central obesity associated with lower birthweight in adolescent girls, particularly those who were overweight,²² the associations between birthweight and waist-to-hip ratio and the ratio of subscapular to triceps skinfolds were examined at the ages of 15 and 18 y. In univariate regression, birthweight (g) showed a significant positive association with waist-to-hip ratio in daughters ($b=2.63 \times 10^{-5}$, $P=0.037$), but not in sons ($b=1.16 \times 10^{-5}$, $P=0.247$) at the age of 15 y with similar results at the age of 18 y with respective coefficients of 1.61×10^{-5} ($P=0.037$) and 5.82×10^{-6} ($P=0.410$). Associations with the log-transformed subscapular to triceps ratio were opposite in sign but were not significant in sons or daughters at 15 or 18 y of age. Coefficients for 18-y-olds were -5.85×10^{-5} in daughters ($P=0.217$) and -6.35×10^{-5} in sons ($P=0.251$). After subdividing the group using a BMI of 25 kg m^{-2} as a cut-off point, a significant negative association between birthweight and subscapular to triceps ratio emerged in daughters with $\text{BMI} < 25 \text{ kg m}^{-2}$ ($b=-1.10 \times 10^{-4}$, $P=0.009$). No other relationships were significant and, in particular, there were no significant associations with birthweight in overweight sons or daughters. Relationships were similar after adjustment for parental education.

Socio-economic status

When classified into three SES groups based on tertiles of relative urban advantage,¹⁴ 18.6% of families were in the lowest (manual) SES group, 35.2% in the middle SES group and 46.2% in the highest (professional) group. BMI in sons was not significantly related to SES. In daughters, however,

BMI was lower ($P=0.019$) in the highest SES group at the age of 12 y (mean 19.4 kg m^{-2} , s.e.m. 0.6 in the lowest SES group; 17.9 kg m^{-2} , s.e.m. 0.3 in the highest). At the age of 15 y respective means were 21.2 kg m^{-2} (s.e.m. 1.0) and 20.7 kg m^{-2} (s.e.m. 0.5) and at 18 y were 22.6 kg m^{-2} (s.e.m. 0.9) and 21.3 kg m^{-2} (s.e.m. 0.5), but these differences were not significant.

Lifestyle variables and BMI

In 18-y-olds, alcohol intake was significantly greater ($P=0.012$) in sons with $\text{BMI} > 25 \text{ kg m}^{-2}$ (mean 9.0 g day^{-1} , s.e.m. 2.8) than in those with $\text{BMI} < 25 \text{ kg m}^{-2}$ (mean 1.4 g day^{-1} , s.e.m. 1.2). There were no such differences in daughters (mean 0.31 g day^{-1} , s.e.m. 0.41 vs 0.32 g day^{-1} , s.e.m. 0.20, $P=0.970$). However, intake of alcohol was calculated from 2 day mid-week diet records which showed very low alcohol consumption for daughters who, according to questionnaire responses, consumed most of their alcohol at weekends. BMI was not significantly related to smoking habits in sons or daughters (22.2 kg m^{-2} , s.e.m. 0.3, vs 22.4 kg m^{-2} , s.e.m. 1.0, in male smokers and non-smokers; 21.6 kg m^{-2} , s.e.m. 0.4, and 22.5 kg m^{-2} , s.e.m. 0.7, in female smokers vs non-smokers).

At the age of 18 y physical fitness, as measured by the PWC_{170} , was significantly lower ($P=0.002$) in obese or overweight sons (mean $12.6 \text{ kg kg}^{-1} \text{ min}^{-1}$, s.e.m. 0.7) than in those with $\text{BMI} < 25 \text{ kg m}^{-2}$ (mean $15.4 \text{ kg kg}^{-1} \text{ min}^{-1}$, s.e.m. 0.4). For daughters the respective means were $9.0 \text{ kg kg}^{-1} \text{ min}^{-1}$ (s.e.m. 0.5) and $11.9 \text{ kg kg}^{-1} \text{ min}^{-1}$ (s.e.m. 0.2) ($P < 0.001$).

In sons, BMI was significantly related negatively to physical fitness (PWC_{170}) and positively to alcohol intake in regression models adjusted for parental education (Table 2). In daughters there were significant negative associations between BMI and physical fitness and with energy intake, the latter finding being consistent with dieting or under-reporting of intake. In multivariate models there were independent associations with physical fitness ($b=-0.253$, s.e.=0.098, $P=0.012$) and alcohol intake ($b=0.886$, s.e.=0.438, $P=0.046$) in sons, explaining 11% of variance but, for daughters, only physical fitness was significant in the model (Table 2). Because the PWC_{170} is usually expressed in relation to body weight, the unstandardized PWC_{170} was also examined but, as the relationships were essentially unchanged, the variable standardized for body weight was used in all analyses. As increased BMI results from both increased non-fat mass and fat mass, we examined triceps and subscapular skinfolds in relation to measures of fitness. Among sons; there were significant correlations between fitness and subscapular skinfold thickness at the age of 12 y ($r=-0.390$, $P < 0.001$), 15 y ($r=-0.516$, $P < 0.001$) and 18 y ($r=-0.402$, $P < 0.001$). Correlation coefficients were similar for triceps skinfolds with values of -0.455 ($P < 0.001$) at the age of 12 y, -0.625 ($P < 0.001$) at the age of 15 ($P < 0.001$) and -0.397 ($P < 0.001$) at the age of 18 y. Among daughters

Table 2 Regression models with BMI as the dependent variable, adjusted for mothers' education, and relating physical fitness, dietary variables and alcohol intake to BMI at the age of 18 y. Separate models were used for sons and daughters

Independent variable	Group	Regression coefficient (s.e.)	Adjusted r^2	P-value
PWC ₁₇₀ (kg kg ⁻¹ min ⁻¹)	Sons	- 0.28 (0.10)	0.083	0.007
	Daughters	- 0.73 (0.14)	0.220	< 0.001
Alcohol (g day ⁻¹)	Sons	0.85 (0.40)	0.032	0.047
	Daughters	2.2 (1.7)	0	0.206
Total fat (percentage energy)	Sons	- 0.04 (0.06)	0	0.473
	Daughters	- 0.03 (0.05)	0	0.596
Saturated fat (percentage energy)	Sons	- 0.03 (0.02)	0	0.130
	Daughters	0.05 (0.09)	0	0.593
Protein (percentage energy)	Sons	0.03 (0.10)	0	0.748
	Daughters	0.18 (0.11)	0.010	0.094
Carbohydrate (percentage energy)	Sons	- 0.01 (0.004)	0.018	0.077
	Daughters	- 0.01 (0.005)	0.014	0.057
Energy (MJ)	Sons	- 0.1 (0.1)	0	0.398
	Daughters	- 5.0 (0.1)	0.078	0.003

the correlation coefficients for subscapular skinfolds were -0.470 ($P=0.022$) in 12-y-olds, -0.498 ($P=0.002$) at 15 and -0.483 ($P<0.001$) at 18 y; for triceps skinfolds, respective correlation coefficients were -0.413 ($P<0.001$), -0.385 ($P=0.003$) and -0.553 ($P<0.001$).

Longitudinal data

Obesity in 18-y-olds was examined in relation to obesity in previous surveys, combining data from sons ($n=145$) and daughters ($n=126$) because of the smaller number of subjects who attended all surveys. All subjects who were obese at

the age of 18 were overweight or obese at the age of 15 y ($P<0.001$); 91% were obese or overweight at the age of 12 y ($P<0.001$) and 90% were obese or overweight at the age of 9 y ($P<0.001$).

Correlation coefficients showed significant tracking over the 9 y of the survey for BMI in both sons and daughters (Table 3). Total fat intake (percentage energy) correlated significantly between the ages of 12 and 18, and 15 and 18 in sons and between 9 and 18, 12 and 18 and 15 and 18 in daughters. Intake of saturated fat (percentage energy) correlated significantly between the ages of 9 and 18, 12 and 18, and 15 and 18 y in both sons and daughters (Table 3). Energy

Table 3 Tracking between surveys of BMI and variables relating to diet and physical activity according to correlation coefficients, shown separately for sons and daughters. Correlations are shown between values at the age of 9, 12, 15 and 18 y; 12, 15 and 18 y and 15 and 18 y. Statistically significant coefficients ($P<0.05$) are shown in bold

Variable	Age (y)	Sons Age (y)			Age (y)	Daughters Age (y)		
		12	15	18		12	15	18
BMI	9	0.849	0.797	0.641	9	0.801	0.617	0.660
	12		0.916	0.754	12		0.795	0.745
	15			0.855	15			0.878
Total fat (percentage energy)	9	0.098	0.030	0.178	9	0.155	- 0.114	0.221
	12		0.009	0.202	12		0.142	0.209
	15			0.221	15			0.314
Saturated fat (percentage energy)	9	- 0.001	- 0.010	0.247	9	0.177	- 0.252	0.299
	12		- 0.024	0.209	12		0.059	0.281
	15			0.207	15			0.217
Energy (kJ)	9	0.135	0.025	0.177	9	0.051	- 0.015	0.210
	12		0.261	0.159	12		0.119	0.182
	15			0.289	15			0.273
Physical fitness (rank)	9	NA			9	NA		
	12		0.596	0.244	12		0.596	0.496
	15			0.288	15			0.385
Physical activity (weekly score)	9	NA			9	NA		
	12		0.295	0.227	12		0.272	0.296
	15			0.352	15			0.318

intake correlated significantly between 12 and 15, and 15 and 18 in sons, and 9 and 18, and 15 and 18 in daughters. There were no significant correlations between intake of carbohydrate or protein in different surveys (data not shown).

In daughters, reported fat intake decreased in overweight or obese daughters during adolescence. At the age of 18 y, reported total daily fat intake increased by a mean of 2.7 g day⁻¹ (s.e.m. 4.6) in daughters with BMI < 25 kg m⁻² and decreased by 23.5 g day⁻¹ (s.e.m. 11.0) in those with BMI > 25 kg m⁻² ($P=0.038$). This pattern of change in reported fat intake was not seen in sons who showed a mean increase in fat consumption of 3.8 g day⁻¹ (s.e.m. 5.9) in those with BMI < 25 kg m⁻² and a decrease of 3.9 g day⁻¹ (s.e.m. 12.9) in those with BMI > 25 kg m⁻² ($P=0.589$). These data are consistent with under-reporting or dieting in daughters.

At the age of 15 y, fat intake (percentage energy) was significantly greater (38.1%, s.e.m. 1.5 vs 34.1%, s.e.m. 0.6; $P=0.018$) in sons who were overweight or obese when they were 18 y old, while carbohydrate intake (percentage energy) was significantly lower (43%, s.e.m. 1.4 in overweight or obese vs 48%, s.e.m. 0.6, $P=0.001$). In 18-y-olds, protein consumption (percentage energy) was greater in obese or overweight daughters (18%, s.e.m. 1.0 vs 16%, s.e.m. 0.4, $P=0.049$) who also showed a trend to greater consumption of total fat (38.4%, s.e.m. 1.7 vs 35.5%, s.e.m. 0.7, $P=0.093$) and lower intake of carbohydrate (48%, s.e.m. 1.7 vs 51%, s.e.m. 0.7, $P=0.076$) at the age of 12 y. There were no significant differences in intake of saturated, monounsaturated or polyunsaturated fat or in fibre consumption in any survey in relation to BMI status at the age of 18 y and no significant associations between nutrient intake and overweight or obesity in cross-sectional analyses at each survey.

Physical activity and physical fitness both showed significant tracking for sons and daughters (Table 3) at the ages of 12, 15 and 18 y. At the age of 12 y, obese or overweight sons ran a distance of 1.6 km in 7.7 min (s.e.m. 0.5) compared with 6.2 min (s.e.m. 0.2, $P=0.022$). Respective means in daughters were 6.6 min (s.e.m. 0.5) and 4.9 min (s.e.m. 0.2, $P=0.001$). At the age of 15 y, obese or overweight sons completed 60 laps (s.e.m. 6.8) in the Leger shuttle run compared with 79.5 laps (s.e.m. 2.4) in the remainder ($P=0.001$) with respective means for daughters of 36.5 laps (s.e.m. 3.4) and 53.1 laps (s.e.m. 1.8, $P=0.002$).

Parental characteristics

Table 1 shows the characteristics of the parents. Both parents were obese in 16 families (9.5%), both were overweight in 30 families (17.8%) and one parent obese and one overweight in 58 families (34.3%). BMI correlated significantly between mothers and fathers ($r=0.180$, $P=0.019$). Among fathers 38% had completed tertiary or technical education, 38% had completed secondary schooling and in 24% education

was below this level. Respective proportions for mothers were 25%, 46% and 29%.

Lifestyle variables and BMI

Fat intake as measured by the fat-score,¹⁹ adjusted for fathers' education, was significantly higher in overweight and obese fathers with means of 25.5 (s.e.m. 1.2) in obese fathers, 23.8 (s.e.m. 0.90) in overweight fathers and 21.7 (s.e.m. 1.4) in the remainder. Fat-score did not differ significantly in mothers in relation to BMI grouping with respective means of 19.6 (s.e.m. 1.0), 20.1 (s.e.m. 0.8) and 21.2 (s.e.m. 0.8). Fat-score correlated significantly ($r=0.229$, $P=0.003$) between mothers and fathers and was significantly lower in mothers than in fathers ($P<0.001$). Alcohol intake, adjusted for fathers' education, was significantly greater ($P=0.044$) among obese fathers with a mean of 176.2 ml week⁻¹ (s.e.m. 19.1) compared with 118.9 ml week⁻¹ (s.e.m. 15.2) in overweight fathers and 123.9 (s.e.m. 20.8) in fathers with BMI < 25 kg m⁻². There was a trend ($P=0.108$) to lower alcohol intake among obese mothers with a mean intake of 37.8 ml week⁻¹ (s.e.m. 12.6) compared with 69.6 ml week⁻¹ (s.e.m. 9.2) in overweight mothers and 52.0 (s.e.m. 8.1) in the remainder. Alcohol consumption correlated significantly between mothers and fathers ($r=0.526$, $P<0.001$). BMI was not significantly related to smoking in either parent.

In regression models, adjusted for fathers' education, fathers' BMI was significantly related to fat-score (regression coefficient (b)=0.09, s.e.=0.04, $P=0.020$) and independently to alcohol intake ($b=0.005$, s.e.=0.002, $P=0.028$) with 6% of variance explained. There were no significant associations between BMI and fat-score or alcohol intake in mothers with or without adjustment for educational level. Smoking status was not significant in the models.

In logistic regression, obesity in fathers was significantly related independently to socio-economic status with an odds ratio relative to the highest SES group of 2.86 (95% CI 1.06, 7.68) for the lowest SES group and 2.84 (95% CI 1.16, 6.97) for the middle SES group, as well as to alcohol intake (OR 1.003, 95% CI 1.001, 1.006). For mothers the odds ratio was 2.48 (95% CI 1.09, 5.58) for the lowest SES group and 2.59 (95% CI 1.15, 5.82) for the middle SES group with no significant association with alcohol intake or fat-score. In fathers, alcohol intake was lowest in the middle SES group with a mean of 103.6 ml week⁻¹ (s.e.m. 16.5), compared with 166.9 ml week⁻¹ (s.e.m. 25.5) in the lowest and 165.1 (s.e.m. 19.5) in the highest SES group. These differences were significant ($P=0.044$). There were no significant differences in alcohol intake in mothers in relation to SES group with means of 51.5 ml week⁻¹ (s.e.m. 11.6), 49.3 ml week⁻¹ (s.e.m. 9.1) and 59.4 ml week⁻¹ (s.e.m. 8.1) in lowest to highest SES groups. Fat-score differed significantly in fathers in relation to SES with a mean of 45.0 (s.e.m. 1.0) in the lowest, 26.1 (s.e.m. 1.3) in the middle and 22.2 (s.e.m. 0.9) in the highest SES group. There were no significant differences in mothers' fat-score with respective means of 20.0 (s.e.m.

0.7), 20.0 (s.e.m. 0.8) and 21.8 (s.e.m. 1.1). The proportion of fathers who smoked also differed significantly in relation to SES with 30% of smokers in the lowest SES group, 13% in the middle and 11% in the highest SES group ($P=0.039$). Respective proportions for mothers were 11%, 12% and 7% and these differences were not significant.

Associations between characteristics of parents and 18-y-olds

Lifestyle variables. Associations between measures of lifestyle in parents and children differed according to the sex of parent and child (Table 3). Alcohol intake in sons correlated significantly with alcohol intake in fathers ($r=0.290$, $P=0.020$) and mothers ($r=0.333$, $P=0.003$), while in daughters there was a significant association with fathers' alcohol intake ($r=0.253$, $P=0.021$) but not with mothers'. As mid-week alcohol intake did not reflect weekend drinking in daughters, parental alcohol intake was examined in relation to 'safe' and 'unsafe' drinking in offspring. 'Unsafe' drinking in sons related significantly to higher alcohol consumption in fathers (mean 199.3 ml week⁻¹ (s.e.m. 34.3) in fathers of 'unsafe' drinkers vs 124.9 ml week⁻¹ (s.e.m. 24.4) in fathers of 'safe' drinkers; $P=0.049$) and in mothers (mean 76.4 ml week⁻¹, s.e.m. 14.2 vs 36.1 ml week⁻¹ s.e.m. 9.9 for mothers of 'unsafe' and 'safe' drinkers respectively; $P=0.022$). Similar trends associated with 'unsafe' drinking in daughters were not significant, with respective means in fathers of 160.4 ml week⁻¹ (s.e.m. 29.0) vs 118.4 ml week⁻¹ (s.e.m. 16.2; $P=0.175$), and in mothers 54.7 ml week⁻¹ (s.e.m. 10.5) and 43.9 ml week⁻¹ (s.e.m. 8.1; $P=0.411$).

There were significant positive relationships between fathers' fat-score and daughters' intake of total fat, saturated fat and monounsaturated fat as well as a significant negative association between fathers' fat-score and daughters' carbo-

hydrate intake (Table 4), independent of parental education. Mothers' fat-score related positively to daughters' intake of total fat, monounsaturated fat and energy, and negatively with daughters' carbohydrate consumption. In sons, protein intake was predicted significantly by fathers' fat-score.

Associations between parental BMI, lifestyle and BMI in offspring

Among 18-y-olds, BMI was significantly related to fathers' BMI in sons (regression coefficient (b)=0.231, s.e.=0.112, $r^2=0.040$, $P=0.042$), and daughters ($b=0.441$, s.e.=0.102, $r^2=0.164$, $P<0.001$) and with mothers' BMI in sons ($b=0.167$, s.e.=0.063, $r^2=0.058$, $P=0.009$) and daughters ($b=0.239$, s.e.=0.066, $r^2=0.099$, $P<0.001$). These associations were additive. In sons, the additive model explained 21% of the variance with coefficients of 0.272 (s.e.=0.097, $P=0.001$) for mothers' BMI and 0.271 (s.e.=0.104, $P=0.011$) for fathers'. In daughters the model accounted for 20% of the variance with coefficients of 0.194 (s.e.=0.081, $P=0.018$) for mothers' BMI and 0.365 (s.e.=0.104, $P=0.001$) for fathers'. In daughters, there was an additional independent relationship with fathers' alcohol consumption ($b=0.006$, s.e.=0.003, $P=0.048$). These associations were independent of 'unsafe' drinking, physical fitness, fat consumption, smoking in offspring, and parental education. Multivariate models accounted for 48.3% of variance in BMI for daughters and 32.6% in sons.

In logistic regression adjusted for parental education, BMI > 25 kg m⁻² in 18 y-old offspring was coded as 1 and BMI < 25 kg m⁻² coded as zero. Obesity in fathers predicted BMI > 25 kg m⁻² in sons (OR 4.38, 95% CI 1.16, 16.48) but the association was not significant for mothers' BMI (OR 2.49, 95% CI 0.69, 8.89). In daughters there were significant independent associations with obesity in both fathers (OR

Table 4 Regression models, adjusted for socioeconomic status, relating fat-score in father and mother to nutrient intake in 18-y-old sons and daughters. Fat score was determined by summing the responses to a food frequency questionnaire that focused on items affecting fat intake. Figures in bold indicate $P<0.05$

Dependent variable	Fathers' fat score				Mothers' fat score			
	Group	Coefficient (s.e.)	Adjusted r ²	P-value	Group	Coefficient (s.e.)	Adjusted r ²	P-value
Total fat (percentage energy)	Sons	0.06 (0.12)	0.011	0.635	Sons	0.12 (0.12)	0	0.299
	Daughters	0.29 (0.12)	0.098	0.020	Daughters	0.31 (0.12)	0.111	0.010
Saturated fat (percentage energy)	Sons	0.05 (0.07)	0	0.418	Sons	0.05 (0.06)	0	0.393
	Daughters	0.13 (0.07)	0.088	0.046	Daughters	0.13 (0.07)	0.066	0.048
Monosaturated fat (percentage energy)	Sons	0.06 (0.05)	0.014	0.158	Sons	0.06 (0.05)	0.006	0.233
	Daughters	0.11 (0.05)	0.093	0.028	Daughters	0.11 (0.05)	0.085	0.035
Polyunsaturated fat (percentage energy)	Sons	-0.01 (0.04)	0	0.700	Sons	0.02 (0.04)	0	0.513
	Daughters	0.01 (0.04)	0.001	0.820	Daughters	-0.02 (0.04)	0	0.720
Energy (kJ day)	Sons	-15.7 (56.0)	0	0.956	Sons	18.5 (55.5)	0	0.740
	Daughters	41.9 (31.5)	0.069	0.188	Daughters	74.4 (37.2)	0.025	0.049
Protein (percentage energy)	Sons	0.12 (0.05)	0.048	0.029	Sons	-0.07 (0.06)	0	0.199
	Daughters	-0.04 (0.05)	0	0.473	Daughters	0.03 (0.06)	0	0.642
Carbohydrate (percentage energy)	Sons	-0.11 (0.14)	0.001	0.427	Sons	-0.01 (0.13)	0	0.926
	Daughters	-0.28 (0.13)	0.089	0.033	Daughters	-0.32 (0.12)	0.118	0.011
Fibre (g day ⁻¹)	Sons	0.13 (0.20)	0	0.506	Sons	0.07 (0.19)	0	0.712
	Daughters	-0.17 (0.15)	0.033	0.260	Daughters	-0.15 (0.14)	0.056	0.274

3.83, 95% CI 1.01, 14.54) and mothers (OR 7.88, 95% CI 1.97, 31.43). Associations with obesity in mothers were independent of offspring's fitness, smoking and alcohol intake in daughters but not in sons.

Figure 1 shows the time course of BMI in sons and daughters in relation to BMI less than 25 kg m^{-2} , overweight or obesity in fathers and mothers of 18-y-olds. Using repeated measures GLM, BMI over the 9 y of follow-up was significantly associated with fathers' BMI group in sons ($P=0.033$) and in daughters ($P=0.024$). Repeated measures analysis also showed a significant relationship between mothers' BMI and BMI in sons ($P=0.031$) and daughters ($P=0.037$) over the 9 y of the study.

Physical fitness in offspring was also significantly related to obesity in parents. Because different methods were used to assess physical fitness in different surveys, each variable was transformed to a rank to display results of each fitness test on the same scale (Figure 2). Mann-Whitney tests were used to compare groups in relation to obesity ($\text{BMI} > 30 \text{ kg m}^{-2}$) or $\text{BMI} < 25 \text{ kg m}^{-2}$ in parents. Note that in the 1.6 km run a lower value, with the run completed in a quicker time, indicates greater fitness and for the other two tests a higher score means greater fitness. Sons of non-obese mothers had

significantly lower ranks for the 1.6 km run test at the age of 12 y (Mann-Whitney test, $P=0.005$) and greater ranks for the shuttle run at the age of 15 y (Mann-Whitney test, $P < 0.001$) and for the PWC_{170} test in 18-y-olds (Mann-Whitney test, $P=0.048$) There were no significant differences in these tests in relation to obesity in fathers ($P=0.256, 0.154$ and 0.175 , respectively). In contrast, physical fitness in daughters related significantly to obesity in fathers. In 12 y-olds the rank for the 1.6 km run was significantly lower in daughters with non-obese fathers (Mann-Whitney test, $P=0.011$) while both the rank of the Leger test at 15 y (Mann-Whitney test, $P=0.007$) and the PWC_{170} in 18-y-olds were significantly greater (Mann-Whitney test, $P=0.025$). Fitness in daughters was not significantly associated with maternal obesity ($P=0.259, 0.354$ and 0.467 respectively).

Discussion

BMI in both sons and daughters is predicted additively by BMI in fathers and mothers, with independent contributions from variables reflecting health behaviours, particularly physical fitness and alcohol intake. This study has confirmed

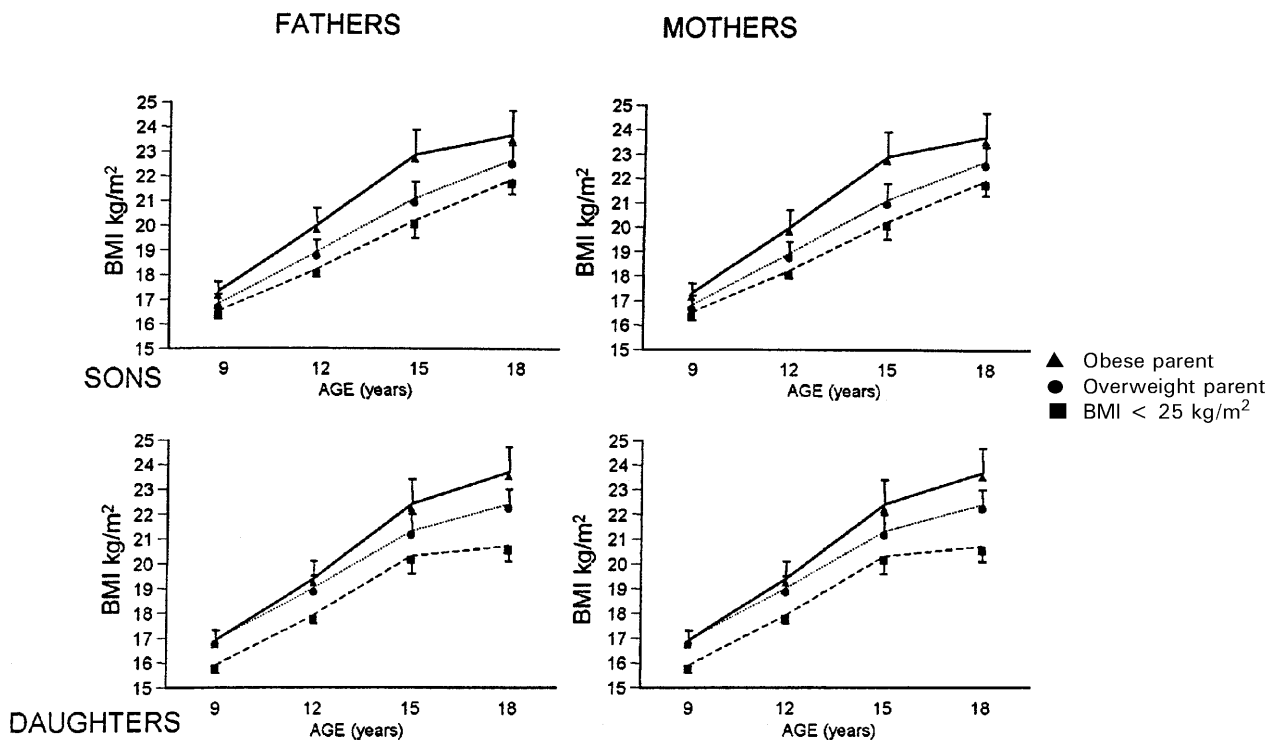


Figure 1 Body mass index in sons and daughters from the age of 9 to 18 y in relation to $\text{BMI} < 25 \text{ kg m}^{-2}$, $25-30 \text{ kg m}^{-2}$ and $> 30 \text{ kg m}^{-2}$ in fathers and mothers. Repeated measures analysis of variance showed significant associations between BMI in fathers and sons ($P=0.033$), fathers and daughters ($P=0.024$), mothers and sons ($P=0.031$) and mothers and daughters ($P=0.037$).

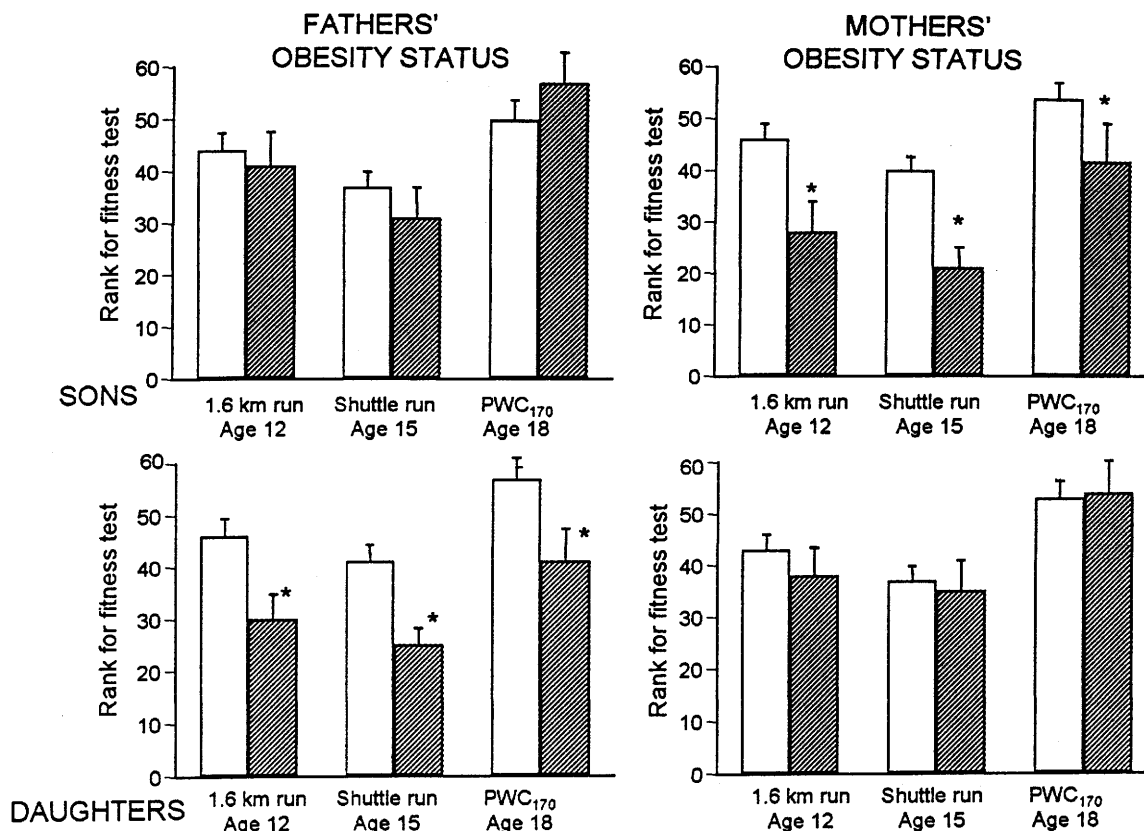


Figure 2 Rank in tests of physical fitness in sons and daughters in relation to obesity or BMI <math>< 30 \text{ kg m}^{-2}</math> in parents. The 1.6 km run was used at 12 y, the shuttle run at 15 y and the PWC₁₇₀ on bicycle ergometers at the age of 18 y. Results are presented as ranks to allow results of different tests to be displayed on the same scale. For PWC₁₇₀ and the shuttle run variables are ranked from highest to lowest as higher scores represent greater fitness; for the 1.6 km run the variable is ranked from lowest to highest as lower times represent greater fitness. * $P < 0.05$. Hatched box, obese parent; open box, non-obese parent.

that health behaviours and BMI aggregate within families and has shown associations between health behaviours in parents and BMI in offspring. Tracking of such associations over a 9 y period suggests that parental overweight or obesity may allow early identification of children at risk, for whom promotion of healthy behaviours targeting the family should be a priority. The finding that more than 70% of fathers and 50% of mothers were obese or overweight in middle-age augers badly for future risk of obesity, diabetes, cardiovascular disease and dyslipidaemia in their offspring, given the familial associations in BMI and health behaviours.

BMI is influenced by both non-fat and fat mass. However, relationships with variables predicting BMI were similar for both central and peripheral skinfolds, suggesting that, in this population, BMI was an appropriate measure of fitness. Reference values for BMI in childhood and adolescence for different populations^{22,23} have been published and are readily applied to assessment of adiposity.

In both sons and daughters, lower physical fitness, or physical inactivity, was the strongest predictor of increased BMI. Physical inactivity, as measured by TV-watching, lack of leisure-time physical activity^{24,25} or lower physical fitness²⁶

is associated with greater adiposity in children and adolescents. As well as substituting for active pursuits, TV-watching may contribute to obesity through consumption of snack foods while viewing.²⁷ Patterns of physical activity in children in the United States are already established in sixth-graders,⁹ suggesting the need for early intervention to encourage the habit of physical activity in younger children, before behaviours become resistant to change.

Parental modelling influences the adoption of physical activity by offspring in childhood and adolescence, continuing after offspring leave home,^{11,28} and, in adolescents, was predicted by paternal, but not maternal, exercise patterns.¹¹ In the present study, assessments of parental physical activity were not available but there were significant associations from the age of 12 to 18 y between mothers' BMI and physical fitness in sons and fathers' BMI and fitness in daughters, possibly reflecting less physical activity in obese parents. The persistence of physical activity patterns from childhood implies greater long-term risk for lifestyle diseases²⁹ in children with lower levels of fitness.

Tracking of energy and nutrient consumption¹⁰ and food preferences⁹ in childhood through adolescence suggests that

patterns of food choice are determined early in life. Our finding of tracking from the age of 9 y of total fat intake, saturated fat intake and energy consumption supports the view that health promotion to achieve healthy food choices should target primary school children and adolescents before health behaviours become established.

Children's preference for high-fat foods has also been related to parental overweight^{36,37} and associations between fat intake in mothers and fathers and adolescent offspring are recognized.⁹ We found that, in daughters, but not in sons, fat intake was positively and carbohydrate intake negatively related to fat-score in both parents, consistent with a shared family environment. Fewer associations between parental fat consumption and nutrient intake in sons may be explained, in part, by sons eating more foods outside the home. We found, using data from the larger cohort, that scores for a food factor¹³ including convenience foods (biscuits, cakes, sweet and savory pastries, snack foods, take-away foods), were significantly greater in 18-y-old sons than in daughters.

Obesity has been associated with consumption of a greater proportion of dietary fat,³⁰ but reported relationships between body fat and fat intake in childhood have been inconsistent, perhaps because of variations in the age groups studied.³¹⁻³³ We found that associations between the pattern of nutrient intake and overweight or obesity varied with age, possibly dependent on timing of pubertal growth and changing body proportions. Under-reporting of intake or dieting, particularly in overweight subjects, consistent with our findings in adolescent daughters, may distort relationships between nutrient intake and BMI.³⁴ In the present study, mean BMI was greater by 2.2 kg m⁻² in daughters and by 4.3 kg m⁻² in sons with low energy intake to basal metabolic rate ratio (EI/BMR; $P=0.001$). As we could not separate under-reporters from dieters and the EI/BMR ratio does not give a complete picture of energy balance,³⁵ we did not exclude data from participants with low EI/BMR.

Fat consumption in parents was measured by a simple food frequency questionnaire reported to be valid and reproducible in assessing fat intake.¹⁹ Higher BMI was associated with a higher score on the fat intake questionnaire in fathers but not in mothers, whose fat-score was significantly lower than for fathers, a difference consistent with other Australian studies showing lower consumption of fat in women.³⁸ This may be explained by the greater importance to women of body image³⁹ as well as their greater uptake of nutrition education.⁴⁰ The similarity in fat-score between obese and non-obese mothers, associated with a trend to lower alcohol intake in the more obese group, could be explained by dieting or under-reporting of fat consumption.

Alcohol intake was related to BMI in both sons and daughters. In sons, alcohol intake measured from mid-week diet records predicted BMI while in daughters, fathers' alcohol intake was the significant variable. Given the associations observed between alcohol intake in offspring and parents in the present study, similar to previous reports,⁹ it is

likely that fathers' alcohol intake was a surrogate for alcohol intake in daughters. The use of mid-week records in the present study led to under-recording of alcohol consumption in daughters in whom the predominant pattern was of weekend drinking. While sons showed a similar preference for weekend drinking, they consumed a greater proportion of alcohol on weekdays than did the daughters. Associations between alcohol consumption and higher BMI in fathers and in both sons and daughters suggest a lack of awareness of the contribution of alcohol to total energy intake. This is so even for overweight offspring in whom there may have been under-reporting of dietary energy consumption or dieting. Programs targeting weight control must emphasize the importance of alcohol as a source of energy.

In the present study, cross-sectional data showed significant additive associations between BMI in offspring and BMI in both parents, while longitudinal analyses showed clear differences from the age of 9 y in BMI of sons and daughters in relation to parental BMI 9 y later. Lake *et al*,⁶ using self-reported measures of height and weight in parents of 11-y-olds, found that children of overweight or obese parents had a consistently greater risk of obesity between the ages of 7 and 33 y. In a retrospective analysis of height and weight in parents and over 800 children in the USA,⁷ parental obesity was associated with an increased risk of obesity in adult life for both obese and non-obese offspring, particularly in children less than 10 y old.⁷ These longitudinal studies, as well as extrapolation from our own study, suggest that overweight or obesity in one or both parents indicates offspring at risk of obesity. Modification of health behaviours within these families is likely to improve outcomes for both parents and offspring.

Data from parents in the present study confirmed the reported association between lower SES and overweight or obesity.⁴¹ Greater consumption of fat and a higher rate of smoking were seen in fathers in the lowest SES group, and greater alcohol intake in both the highest and lowest SES groups, consistent with earlier reports.⁴²⁻⁴⁴ Among offspring, the only significant association between BMI and SES was seen at the age of 12 y in daughters. We have previously shown that adverse dietary choices in both 15-y-old and 18-y-old daughters in the larger cohort were significantly related to lower SES.¹³

Lower birthweight may be associated with a central distribution of body fat,²² particularly in overweight adolescent girls. However, we found that birthweight correlated positively with waist-to-hip ratio in 15- and 18-y-old daughters. There were no significant associations between birthweight and subscapular-to-triceps ratio, the measure of central obesity used by Barker *et al*.²² Our findings do not suggest that lower birthweight is linked with central adiposity in adolescence and are more consistent with reports associating overweight and higher birthweight.⁴⁵

Genetic factors are important determinants of body fat.^{46,47} However, a genetic predisposition does not inevitably lead to obesity,²⁷ and early recognition of individuals at

risk of obesity, allowing appropriate health promotion, is likely to have long-term benefits. A family-based approach focusing on diet and physical activity has been more successful than conventional programs in achieving weight loss and compliance in obese children and their fathers.⁴⁸ In our experience, involvement of the family led to greater improvement in health behaviours in nutrition and physical activity programs for school children.⁴⁹

BMI and health behaviours are associated within families. Parental overweight or obesity indicates a greater risk of obesity in offspring and should be recognized as a marker of families at risk. Our findings suggest that alcohol intake, physical activity and eating patterns within families should be targeted to control obesity. Early intervention to improve health behaviours, particularly before children's habits have become established, has the potential for long-term benefits in reducing the prevalence of lifestyle diseases.

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