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Patterns of weight change and progression to overweight and obesity differ in men and women: implications for research and interventions

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Abstract

Objective: To evaluate long-term patterns of weight change and progression to overweight and obesity during adulthood.

Design: Prospective study. Changes in mean BMI, waist circumference (WC) and weight were assessed over a mean 26-year follow-up (1971–1975 to 1998–2001). Mean BMI (95 % CI) and mean WC (95 % CI) of men and women in BMI and age groups were computed. Mean weight change in BMI and age categories was compared using analysis of covariance.

Setting: Framingham Heart Study Offspring/Spouse Nutrition Study.

Subjects: Men and women (*n* 2394) aged 20–63 years.

Results: During follow-up, increases in BMI (men: 2·2 kg/m^2; women: 3·7 kg/m^2) and WC (men: 5·7 cm; women: 15·1 cm) were larger in women than men. BMI gains were greatest in younger adults (20–39 years) and smallest in obese older adults (50–69 years). The prevalence of obesity doubled in men (to 33·2 %) and tripled in women (to 26·6 %). Among normal-weight individuals, abdominal obesity developed in women only. The prevalence of abdominal obesity increased 1·8-fold in men (to 53·0 %) and 2·4-fold in women (to 71·2 %). Weight gain was greatest in the youngest adults (20–29 years), particularly women. Gains continued into the fifth decade among men and then declined in the sixth decade; in women gains continued into the sixth decade.

Conclusions: Patterns of weight change and progression to obesity during adulthood differ in men and women. Preventive intervention strategies for overweight and obesity need to consider age- and sex-specific patterns of changes in anthropometric measures.

Keywords
Long-term
Weight
Abdominal obesity
Sex

Overweight (BMI = 25·0–<30·0 kg/m^2) and obesity (BMI ≥ 30·0 kg/m^2) are major clinical and public health concerns accounting for approximately 3 % of direct medical costs of countries globally. One-third of adults worldwide and two-thirds of men and women in the USA are overweight or obese (BMI ≥ 25·0 kg/m^2)[1–3]. The prevalence of obesity is estimated to have doubled globally over the past three decades and is projected to further double globally and increase 1·5-fold in the USA by 2030[2,4,5]. The prevalence of overweight in the USA, which was relatively stable over the same period, is expected to increase minimally (1 %)[3,5]. Overweight and obesity contribute significantly to the development

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of CVD, type 2 diabetes mellitus and certain forms of cancer[6,7], as well as to cause-specific mortality and all-cause mortality[8].

Evidence mainly from Caucasian populations and cross-sectional studies indicates that abdominal obesity (waist circumference (WC): men ≥102 cm; women ≥88 cm), which affects approximately two-fifths (men: 29 %; women: 48 %) of adults worldwide[9] and 53 % of US adults[10], may be of greater importance in increasing morbidity and mortality risk than total obesity[11–13]. Additionally, abdominal obesity is a key component of the metabolic syndrome, a clustering of cardiometabolic risk factors which includes abdominal obesity, hypertension, low HDL-cholesterol, hypertriacylglycerolaemia and hyperglycaemia[14]. The metabolic syndrome is a major risk factor for CVD and type 2 diabetes mellitus[14,15]. About 20–30 % of the global adult population[16] and a third of US men and women[17] have the metabolic syndrome.

In the USA, obesity is the leading cause of morbidity after smoking and accounts for nearly 10 % of all deaths[18]. Obesity is projected to pass smoking as the leading cause of death if current trends continue[19]. The proportion of medical costs attributable to overweight and obesity, currently 10 %, is expected to rise to approximately 16–18 % ($US 861–957 billion) of total US medical costs by 2030[5].

Due to health-related consequences and associated medical costs, timely prevention of overweight and obesity, and in particular abdominal obesity, is critical[20]. However, information to aid in preventive interventions is limited since prospective research on longitudinal patterns of weight change and especially progression to obesity in adult populations is complex, costly and limited. Furthermore, sex differences in body composition, fat distribution and energy metabolism are evident[21,22] and experts are increasingly calling for sex-specific research in order to facilitate study of targeted management of men and women in relation to obesity-related and other health outcomes[21–23].

The association of obesity-related outcomes and diet quality in the Framingham Heart Study (FHS) Offspring/Spouse Nutrition Study (FNS) cohort has previously been reported[24–29]. The FNS cohort is a subset of the FHS Offspring/Spouse cohort comprising participants with comprehensive assessment of dietary data.

The primary objective of the present study was threefold: to evaluate changes in (i) BMI and (ii) weight over a mean follow-up of 26 years and (iii) changes in WC over an 11-year mean follow-up among FNS men and women. Mean BMI and WC were examined since the relationship with most health outcomes is continuous[12,13]. A secondary objective was to evaluate changes in the prevalence of normal weight, overweight and obesity during the 26-year mean follow-up and change in the prevalence of abdominal obesity over the 11-year mean follow-up. It was hypothesized that among men and women, patterns of BMI, WC and weight change differ by baseline BMI status and age.

Methods

Study population and sample

For over 50 years, the FHS, which is a mostly Caucasian, middle-class cohort, has investigated risk factors for, and the natural progression of, CVD among residents of Framingham, Massachusetts[30]. In 1971, a second-generation cohort of 5124 Framingham Study offspring and their spouses (men: 2483; women: 2641) were recruited, composing the Framingham Offspring/Spouse Study (FOS)[31].

Members of the FOS cohort participate in standardized clinical assessments about every 4 years including: a physical examination (exam), laboratory tests, non-invasive tests and updating of medical information[31]. A subgroup of this cohort who had dietary data was fully characterized as the Framingham Nutrition Studies at exam 3 (1984–1987)[32,33]. A total of 3544 men and women (69 % of the original offspring cohort; men: 1716; women: 1828) aged 20–63 years with BMI ≥ 18·5 kg/m^2 had data on alcohol intake and other covariates at exam 1 (1971–1975) as well as dietary data at exam 3. Of these participants, 2394 (68 %; 1126 men and 1268 women) participated in exam 1 through exam 7 (1998–2001); this is the sample used in the current prospective study with a 26-year mean follow-up (range: 23–30 years). A sub-sample of these participants (95 %, 1084 men and 1202 women) who had measurements on WC from exam 4 (1987–1990) was evaluated for WC change. WC measures were not available from exams 1–3 (Appendix).

Compared with FOS participants without dietary data (620 men and 615 women), FNS men (*n* 1716) were somewhat younger and had lower weight whereas FNS women (*n* 1828) were less likely to be on lipid-lowering medication. Both FNS men and women were less likely to smoke cigarettes, drink alcohol and to have CVD, diabetes mellitus or cancer than FOS participants without dietary data (all $P < 0·05$; data not shown).

The Boston University Medical Center's Human Subjects Institutional Review Board approved the study protocol and all participants provided written informed consent.

Anthropometric measures

BMI (weight (kg)/height (m^2)) was calculated using height and weight at exams 1–7. FHS clinic staff weighed participants (to the nearest 0·1 kg), who were dressed in hospital gowns and without shoes, using a calibrated scale (Physician Detecto Scale #439, Webb City, MO, USA) and height was measured (to the nearest 0·6 cm) using a stadiometer (Seca #216, Hanover, MD, USA) with participants standing[34]. BMI categories (normal weight: BMI = 18·5–<25·0 kg/m; overweight: BMI = 25·0–<30·0 kg/m^2; obese: BMI ≥ 30·0 kg/m^2) were based on the National Institutes of Health and WHO criteria[35].

WC was measured (to the nearest 0·6 cm) at the level of the umbilicus on standing participants with an anthropometric tape at exams 4–7[36]. Abdominal obesity (WC: men ≥102 cm; women ≥88 cm) was defined according to National Institutes of Health/American Heart Association criteria[15,35].

Covariates

Sociodemographic, behavioural, anthropometric and metabolic factors are routinely measured at Framingham exams[37] using validated published methods. Age, educational level, menopausal status, smoking status, physical activity, alcohol intake, hypertension and lipid-lowering medications and use of hormone replacement therapy were self-reported[37]. Current smokers were defined as participants who reported smoking ≥1 cigarette(s)/d prior to exam 1, former smokers as adults who stopped smoking between exams 1 and 7, and non-smokers as participants who had not smoked before exam 1. Physical activity was assessed using a standardized questionnaire[38]. CVD was defined as coronary artery disease, cerebrovascular disease, peripheral artery disease and heart failure; diabetes mellitus was defined as either fasting blood glucose level ≥126 mg/dl or treatment with insulin or an oral hypoglycaemic agent[37]; cancer classification was based on the 1976 WHO *International Classification of Disease for Oncology* code 185 and includes all cancers except melanoma[39]. Diagnoses of CVD and cancer were confirmed with medical records[37]. All covariates were measured at exam 1 (baseline) except for educational level and physical activity, which were evaluated at exam 2 (1979–1982; Appendix).

Statistical analysis

Given the gender differences in weight experiences, sex-specific analyses were conducted *a priori*[21,29]. Participant characteristics analysed at baseline include age, weight, BMI, education level, physical activity index, alcohol intake, smoking status, hypertension medication (yes/no), lipid-lowering medication (yes/no), disease presence (yes/no), as well as postmenopausal status (yes/no) and hormone replacement therapy (yes/no) in women. Marital status and parity (women) were not evaluated since data were not collected at baseline. Characteristics were summarized using means and their standard errors for continuous measures and percentages for categorical variables.

The study cohort was classified into three BMI categories (normal weight, overweight and obese) at exams 1 (baseline) and exam 7; the cohort was also classed into four baseline age groups (20–29, 30–39, 40–49 and 50–69 years). The 50–59 years and 60–69 years age groups were combined owing to the small number of participants aged 60–69 years (four men and one woman).

Change in mean BMI and waist circumference

Mean BMI and corresponding 95 % confidence intervals for men and women in each BMI category were computed overall and by age group at each exam. Mean WC and 95 % confidence intervals were similarly calculated at exams 4–7. PROC GLIMMIX was used to compute pair-wise mean differences between the exam cycles.

In secondary analyses, absolute change in prevalence (%) of normal weight, overweight and obesity between exams 1 and 7, as well as absolute change in prevalence (%) of abdominal obesity between exams 4 and exam 7, were computed.

Mean weight change

Weight change was defined as weight at exam 7 minus weight at exam 1. Change in mean weight and its standard error were calculated. Age-adjusted and multivariable-adjusted analysis of covariance models, that were fitted using the SAS PROC GLM procedure[40], were used to assess whether weight change varied according to BMI category and age group. Least-squares means and their standard errors of weight change were calculated for each BMI category and age group. Multivariable linear regression models were adjusted for baseline age, physical activity index, alcohol intake and smoking status. These factors have been shown to be associated with weight change in this cohort[29]. *Post hoc* pair-wise comparisons were assessed using Tukey's Honestly Significant Difference test where indicated. In secondary analyses, models were additionally adjusted for baseline weight, which was forced in the model since weight change can depend on initial weight status[41]. We also conducted regression analyses using stepwise selection with $P < 0·05$ for retention in the model to select the final set of covariates to include in the model. The final model included baseline age, smoking category and alcohol intake in men, and baseline age, physical activity index and alcohol intake in women.

All analyses were performed using the statistical software package SAS version 9·2 (2008). $P < 0·05$ was considered statistically significant. All statistical tests were two-sided.

Results

At baseline (1971–1975), mean weight, BMI, WC and alcohol intake, as well as prevalence of former smokers, current smokers, overweight and obesity, were higher in men than in women. Sociodemographic characteristics, physical activity index, as well as prevalence of hypertension and lipid-lowering medication use and disease were comparable in men and women (Table 1).

Table 1 Characteristics of Framingham Offspring/Spouse Nutrition Study men and women (*n* 2394)*

Characteristic	Men (*n* 1126)		Women (*n* 1268)	
	Mean	SE	Mean	SE
Age (years)	36·5	0·3	36·7	0·3
Weight (kg)	82·3	0·3	62·5	0·3
BMI (kg/m^2)	26·6	0·1	23·9	0·1
WC (cm)†	98·0	0·3	82·0	0·4
Physical activity index‡	35·7	0·2	33·7	0·1
Alcohol (g/week)	142·0	5·7	62·5	2·8
	%		%	
Education level, ≥12 years (%)‡	93·4		94·5	
Non-smokers	34·3		43·6	
Former smokers (exam 1–exam 7)	25·3		18·5	
Smokers (%)	40·4		37·9	
Postmenopausal (%)	N/A		17·2	
Hormone replacement therapy (%)	N/A		3·0	
Hypertension medication (%)	2·7		2·6	
Lipid-lowering medication (%)	0·7		0·2	
Diseases (%)§	2·6		1·2	
Normal weight (BMI = 18·5–<25·0 kg/m^2) (%)	33·2		72·7	
Overweight (BMI = 25·0–<30·0 kg/m^2) (%)	52·0		19·4	
Obese (BMI ≥ 30·0 kg/m^2) (%)	14·7		7·9	
Abdominal obesity (WC ≥102 cm in men and ≥88 cm in women) at exam 4 (%)†	29·2		29·1	

WC, waist circumference; N/A, not applicable.
*Values are from baseline (1971–1975) unless otherwise noted. Variables are unadjusted.
†WC was assessed at exam 4 (1987–1990).
‡Physical activity index and education level were assessed at exam 2 (1979–1982).
§Diseases include CVD, type 2 diabetes mellitus and cancer.

Change in BMI, by baseline BMI status and age group, from 1971–1975 to 1998–2001

During the 26-year mean follow-up to exam 7, BMI increased by 2·2 kg/m^2 in men and by 3·7 kg/m^2 in women. Overall, BMI increased throughout follow-up in men and women aged 20–49 years at baseline and decreased in older adults (baseline 50–69 years) in the eighth decade (all *P*-trend <0·0001; data not shown).

In all BMI categories, among both sexes, BMI gains were larger in younger men and women (baseline 20–39 years); conversely, BMI decreased in adults aged 50–69 years at baseline, particularly in the obese. BMI increase was more pronounced in women than in men (Figs 1 and 2).

Baseline normal-weight men aged 20–39 years experienced BMI increases throughout follow-up (both *P*-trend <0·0001). Normal weight progressed to overweight in men aged 20–29 years (fifth decade), 30–39 years (sixth decade) and 40–49 years (seventh decade). BMI increased all through follow-up among baseline overweight men aged 20–49 years (all *P*-trend <0·0001). Obesity emerged only in the youngest overweight men (20–29 years) in the fifth decade. Among obese men, BMI increased throughout follow-up in those aged 20–49 years subsequent to stable BMI (age 20–29 years) and a decrease in BMI (age 30–49 years; *P*-trend <0·01; Fig. 1 and Supplementary Materials, Table 1). In absolute terms, the prevalence of normal weight decreased by 15·0 % (from 33·25 % to 18·2 %) and that of overweight by 3·4 % (from 52·0 % to 48·6 %). The prevalence of obesity increased by 18·5 % (from 14·7 % to 33·2 %), with the largest increase occurring in men aged 20–29 years (6·6 %) and the least increase in men aged 50–69 years (–1·5 %).

Normal-weight women aged 20–49 years at baseline had BMI gains throughout follow-up (all *P*-trend <0·0001). Overweight developed in women aged 20–29 years (fifth decade), 30–39 years (sixth decade), and 40–49 years (seventh decade). Among overweight women, BMI increased all through follow-up only in those aged 30–39 years (*P*-trend <0·0001). Obesity emerged in the youngest overweight women a decade earlier than in overweight men (fourth decade); it also developed in overweight women aged 30–39 years (fifth decade). Among obese women, BMI increased most of the time in the younger groups (20–39 years) except for a slight decrease in mid follow-up (both *P*-trend <0·0001; Fig. 2 and Supplementary Materials, Table 2). The prevalence of normal weight, in absolute terms, decreased by 36·3 % (from 72·7 % to 36·4 %) whereas that of overweight and obesity increased by 17·7 % (from 19·4 % to 37·1 %) and 18·7 % (from 7·9 % to 26·6 %), respectively. Women aged 20–29 years had the largest increase (12·5 %) in obesity prevalence and those aged 40–49 years the least increase (–14·7 %).

Change in waist circumference, by baseline BMI status and age group, from 1987–1990 to 1998–2001

Over the 11-year mean follow-up, between exams 4 and 7, WC increased by 5·7 cm in men and 15·1 cm in women. Overall, WC increased throughout follow-up in all age groups (all *P*-trend <0·0001; data not shown).

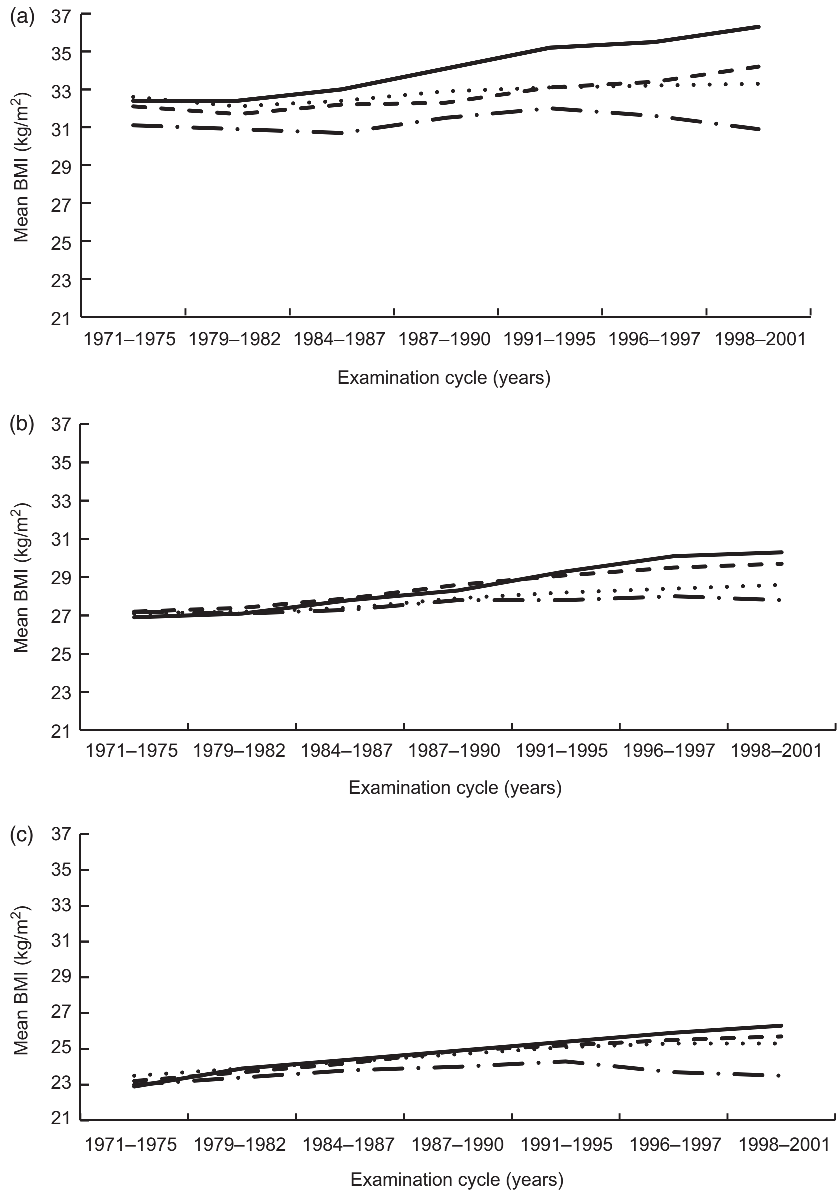

Fig. 1 Mean BMI, 1971–1975 to 1998–2001, by baseline BMI category (a, obese; b, overweight; c, normal weight) and age group (———, 20–29 years; – – – –, 30–39 years; · · · · ·, 40–49 years; — · — · —, 50–69 years) among Framingham Offspring/Spouse Nutrition Study men (n 1126; normal weight: n 374; overweight: n 586; obese: n 166). All values are mean (95 % confidence interval). PROC GLIMMIX was used to compute pair-wise mean differences between the examination cycles

Among men, WC increased in all BMI categories except for an initial decline among obese men aged 40–49 years (P-trend $<0·05$). The youngest men (20–29 years) and obese men aged 30–39 years had larger WC gains. In normal-weight men, the rate increased all through follow-up among those aged 40–69 years. Among overweight men the rate increased throughout follow-up in those aged 40–49 years. Abdominal obesity emerged in all overweight men (20–29 years: fifth decade; 30–39 years: sixth decade; 40–49 years: seventh decade; and 50–69 years: eighth decade). In obese men, the rate increased throughout follow-up in those aged 30–49 years (Fig. 3 and Supplementary Materials, Table 3). Overall absolute increase in prevalence of abdominal obesity was 23·8 % (from 29·2 % to 53·0 %). Among normal-weight, overweight and obese men at exam 4, prevalence increased by 1·6 % (from 2·0 % to 3·6 %), 26·3 % (from 15·9 % to 42·2 %) and 10·7 % (from 84·6 % to 95·3 %), respectively.

Among baseline normal-weight women, WC increased in all age groups particularly women aged 40–49 years (all P-trend $<0·0001$). Abdominal obesity developed in all normal-weight women (20–29 years: fifth decade; 30–39 years: sixth decade; 40–49 years: seventh decade; 50–69 years: eighth decade). WC similarly increased among all overweight women especially younger women (20–39 years; all P-trend $<0·0001$). Abdominal obesity

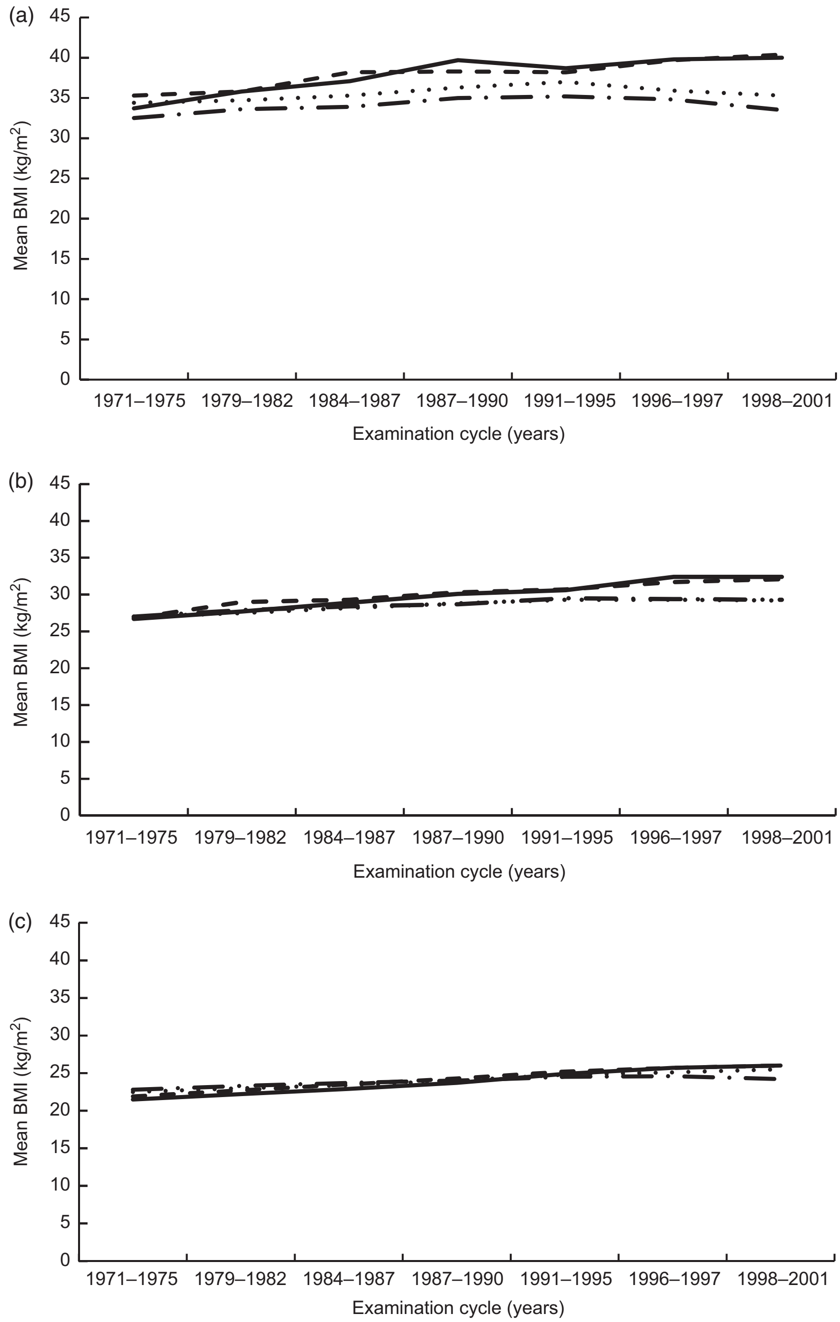

Fig. 2 Mean BMI, 1971–1975 to 1998–2001, by baseline BMI category (a, obese; b, overweight; c, normal weight) and age group (———, 20–29 years; – – – –, 30–39 years; · · · · ·, 40–49 years; — · — · —, 50–69 years) among Framingham Offspring/Spouse Nutrition Study women (*n* 1268; normal weight: *n* 922; overweight: *n* 246; obese: *n* 100). All values are mean (95 % confidence interval). PROC GLIMMIX was used to compute pair-wise mean differences between the examination cycles

was already present in all age groups by exam 4. Among obese women WC increased all through follow-up only in those aged 30–49 years (both *P*-trend $<0\cdot0001$). Increase was larger in women aged 30–39 years. Generally, WC increase was more pronounced in women than in men (Fig. 4 and Supplementary Materials, Table 4). The prevalence (absolute) of abdominal obesity increased by 42·1 % (from 29·1 % to 71·2 %) overall. The prevalence increased by 31·6 % (from 2·0 % to 33·6 %), 52·6 % (from 35·5 % to 88·1 %) and 4·4 % (from 94·7 % to 99·1 %) in normal-weight, overweight and obese women at exam 4, respectively.

Weight change

Mean weight change was 5·7 (SD 0·3) kg (range: –48·2 to 52·7 kg) among men and 8·6 (SD 0·3) kg (range: –67·7 to 54·1 kg) among women. In multivariable-adjusted analyses, baseline normal-weight women gained 2·4 kg

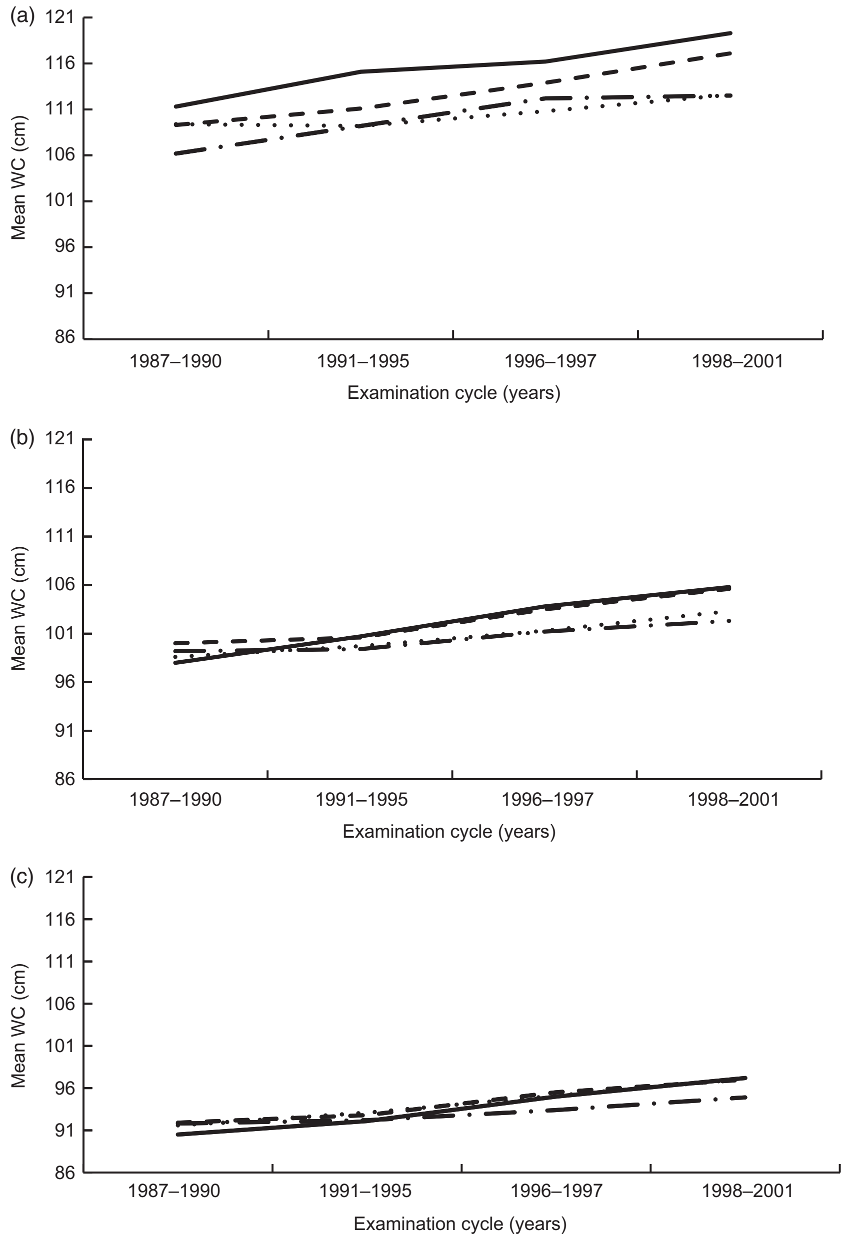

Fig. 3 Mean waist circumference (WC), 1987–1990 to 1998–2001, by baseline BMI category (a, obese; b, overweight; c, normal weight) and age group (———, 20–29 years; – – – –, 30–39 years; · · · · ·, 40–49 years; — · — · —, 50–69 years) among Framingham Offspring/Spouse Nutrition Study men (*n* 1084; normal weight: *n* 359; overweight: *n* 567; obese: *n* 158). All values are mean (95 % confidence interval). PROC GLIMMIX was used to compute pair-wise mean differences between the examination cycles

more than obese women and overweight women gained 3·3 kg more than obese women ($P<0·05$). In age-adjusted analyses, baseline normal-weight men gained more weight than obese men (6·3 (SD 0·5) kg *v.* 4·2 (SD 0·7) kg, respectively; df = 2; $P<0·0001$). The statistical significance of the association between weight gain and baseline BMI category was, however, attenuated in multivariable-adjusted models ($P=0·07$; Fig. 5a).

In secondary analysis, the statistical significance of weight change in relation to baseline BMI status became non-significant ($P=0·82$) after additional adjustment for baseline weight). However, adjusting for variables selected in backward elimination did not qualitatively alter the results (data not shown).

In multivariable-adjusted regression models, the youngest men (20–29 years) gained 11·4 kg more than older men (50–69 years); the equivalent weight gain for women was 11·0 kg (both sexes *P*-trend <0·0001). Weight gain continued into the fifth decade and then began to decline in the sixth decade among men. By contrast, women continued to gain weight into the sixth decade (Fig. 5b). Further adjustment for baseline

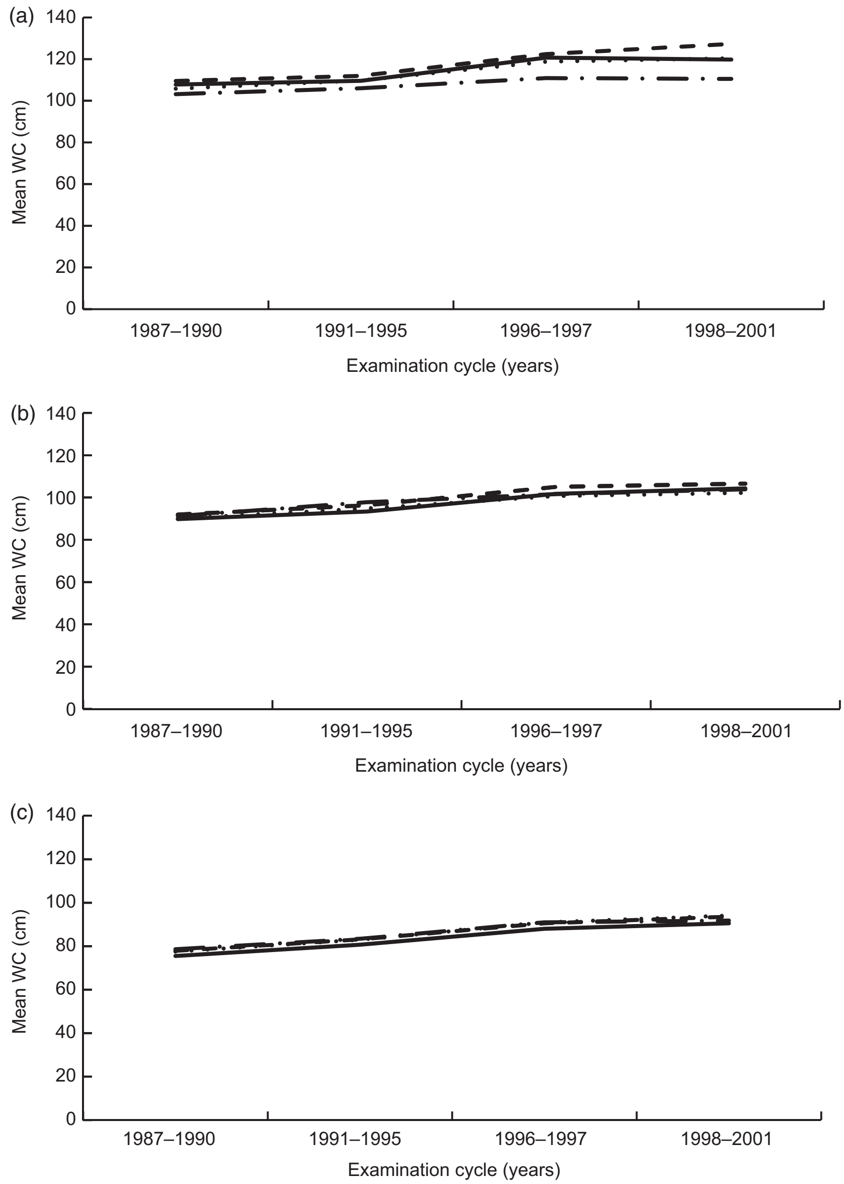

Fig. 4 Mean waist circumference (WC), 1987–1990 to 1998–2001, by baseline BMI category (a, obese; b, overweight; c, normal weight) and age group (———, 20–29 years; – – – –, 30–39 years; · · · · ·, 40–49 years; — · — · —, 50–69 years) among Framingham Offspring/Spouse Nutrition Study women (*n* 1202; normal weight: *n* 886; overweight: *n* 226; obese: *n* 90). All values mean (95 % confidence interval). PROC GLIMMIX was used to compute pair-wise mean differences between the examination cycles

weight and for variables selected in backward elimination did not materially alter the findings (data not shown).

Discussion

Important sex and age differences were observed in patterns of BMI and weight change over the 26-year mean follow-up as well as in patterns of WC change during the 11-year mean follow-up. On average, increases in BMI (men: 2·2 kg/m^2; women: 3·7 kg/m^2), WC (men: 5·7 cm; women: 15·1 cm) and weight (men: 5·7 kg; women: 8·6 kg) were larger in women than in men. BMI increase was generally more pronounced in younger adults (20–39 years); conversely, the largest BMI decrease occurred in obese older adults (50–69 years). Although more overweight women than men progressed to obesity and at an earlier age, the prevalence of overweight and obesity was higher in men than in women. The prevalence of obesity doubled in men and tripled in women. WC and/or the rate of WC increase decreased over time in all women; conversely, the rate increased throughout follow-up among normal-weight men aged 40–69 years, overweight men aged 40–49 years, as well as in obese men aged 30–49 years. Among normal-weight individuals, abdominal obesity developed in women only;

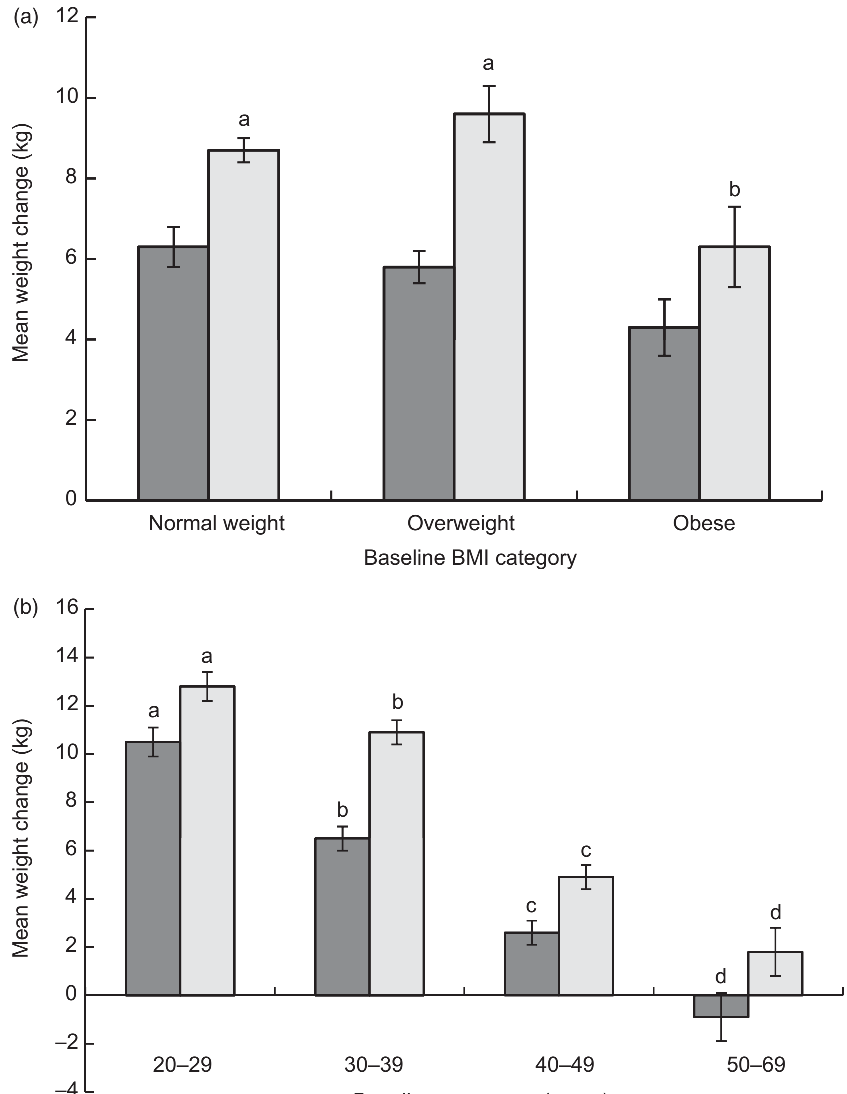

Fig. 5 Multivariable-adjusted mean weight change (kg)*, from 1971–1975 to 1998–2001, in Framingham Offspring/Spouse Nutrition Study men (■) and women (□). (a) Mean weight change by baseline BMI category (men: *n* 1116; normal weight: *n* 369; overweight: *n* 582; obese: *n* 165; and women: *n* 1250; normal weight: *n* 909; overweight: *n* 242; obese: *n* 99); analyses were adjusted for baseline age, BMI category, physical activity index, smoking status (non-smoker, former smoker, current smoker) and alcohol intake. (b) Mean weight change by baseline age group (men: *n* 1116; 20–29 years: *n* 287; 30–39 years: *n* 409; 40–49 years: *n* 324; 50–69 years: *n* 96; and women: *n* 1250; 20–29 years: *n* 318; 30–39 years: *n* 425; 40–49 years: *n* 398; 50–69 years: *n* 109); analyses were adjusted for baseline age group, physical activity index, smoking status (non-smoker, former smoker, current smoker) and alcohol intake. Men: P-trend $<0{\cdot}0001$; women: P-trend $<0{\cdot}0001$. *All values are least-squares means with their standard errors represented by vertical bars. Analysis of covariance was used to obtain multivariable-adjusted means and to identify significant differences in the BMI categories and age groups. [a,b,c,d]For each sex, mean values with unlike superscript letters were significantly different ($P<0{\cdot}05$; Tukey's Honestly Significant Difference test)

abdominal obesity also emerged earlier in overweight women than in their male counterparts. The prevalence of abdominal obesity increased 1·8-fold in men and 2·4-fold in women. Younger adults, in particular young women, gained weight more rapidly and exhibited only a trend of decreasing weight gain with more advanced age (sixth decade of life and beyond).

Our results are largely consistent with those of the Tehran Lipid and Glucose Study (TLGS)[42] and the West of Scotland Twenty-07 Study[43] that demonstrate greater WC gains in women and older men. Younger adults and women likewise had larger BMI gains in the Tromsø Study (15–20 years of follow-up)[44], as did younger adults in the TLGS[42], the West of Scotland Twenty-07 Study[43], the OsLof Study[45] and the First National Health and Nutrition Survey (NHANES I) Epidemiologic Follow-up Study[46] (follow-up: 7–11 years). In the US Coronary Artery Risk Development in Young Adults (CARDIA)

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study, BMI and WC increases were more pronounced in African Americans, particularly women, than in Caucasians during a 10-year follow-up[47]. However, our study is the first to show the association between WC change and BMI status in prospective analysis. It is also unique in demonstrating BMI change in BMI categories in a wide range of age groups in long-term longitudinal analysis.

In NHANES I[48], weight gain was greatest in the youngest age group and decreased with advancing age, with loss occurring in older adults, over 20 years of follow-up, similar to FNS participants. In a recent FNS study (16 years of follow-up)[29] as well as in the CARDIA study[47], San Antonio Heart Study[49], rural Wisconsin[50], the Canadian Multicentre Osteoporosis Study[51], the West of Scotland Twenty-07 Study[43], the Melbourne Collaborative Cohort Study[52], the HUNT Study[53] and the OsLof study[45] (follow-up: 5–11 years), younger adults likewise gained more weight. Similar to the present study, larger weight gains also occurred in normal-weight and overweight women in the previous FNS study[29], NHANES I[48], HUNT[53] and OsLof [45] studies as well as in overweight Australian women[52]. In the USA, younger, normal-weight and overweight African Americans generally gained more weight than their Caucasian counterparts; older African-American women, however, started losing weight earlier (fifth and sixth decades) and faster than Caucasian women[47,48]. There were no differences in weight gain between Mexican Americans and Caucasians over an 8-year period[49]. The present FNS prospective study provides information on weight change in relation to BMI status for the longest follow-up period in adults of diverse age range.

A striking result from the study was the emergence of abdominal obesity, which increases risk of many chronic diseases independently of total adiposity[11–13], particularly among women during follow-up. While weight gain might be expected, presence of abdominal obesity is among the first indications of detrimental metabolic changes. Women with abdominal obesity and the metabolic syndrome are at higher risk for CVD and diabetes mellitus than men[15,21]. Additionally, the rates of WC gain increased in middle-aged and older men all through follow-up. Moreover, obesity developed much earlier in overweight women than in overweight men and weight gain in women continued 10 years beyond that in men, through to the sixth age decade. FNS findings thus indicate that studies of obesity-related outcomes need to consider both abdominal and total obesity. Findings further advocate for sex- and age-specific preventive interventions with consideration of both abdominal and total adiposity. Particularly in women as well as middle-aged and older men, focus needs to be on prevention of abdominal obesity. Conversely, total obesity appears to be a larger problem in younger adults.

Nutrition professionals and health promotion specialists are well positioned to continue advocating for and providing lifestyle preventive intervention expertise for weight gain and obesity risk in adults[54,55]. Abdominal obesity is shown to be responsive to physical activity independent of weight loss[56,57]; as such, exercise may be especially beneficial for women and older adults. Data on dietary interventions for abdominal obesity are not yet established. Public health nutrition professionals are further in an ideal position to tailor nutrition intervention strategies to the specific needs of men and women and to target the unique aspects of their habitual eating practices and dietary patterns, which differ markedly[24–29].

The strengths of our study include a well-characterized population, the long follow-up of men and women with a broad age range and incorporation of data on WC. Although FNS participants exhibited somewhat healthier profiles than FOS participants without dietary data, the differences were small and our findings are consistent with other FHS studies suggesting the representativeness of the FNS sample. Also, possible survival and response bias might somewhat limit the generalizability of our findings. The age distribution of the FNS sample did not enable the evaluation of older adults (≥60 years at baseline). Similarly, we could not assess change in WC over the entire study period since WC measures were not available until exam 4. Other dietary and non-dietary factors including energy intake, carbohydrates, fats, marital status, parity and weight fluctuation were not available at baseline; as such their effect on weight change could not be determined but this has been done so in this cohort with shorter follow-up[29]. The FNS cohort is exclusively white and of homogeneous socio-economic status but study findings may be generalizable to adults of other racial/ethnic populations as biological mechanisms of weight change are expected to be similar in human populations, with genetics possibly accounting for any within- and between-population differences.

Conclusions

Distinct patterns of BMI, WC and weight change and progression to overweight, obesity and abdominal obesity were observed in Framingham Study men and women. Younger women experienced the greatest weight gain and more women developed obesity and abdominal obesity, while many men, more overweight and obese at baseline, continued to gain WC throughout follow-up. Weight gain continued throughout the sixth decade among women but declined in the sixth decade among men. Obesity-related health outcomes need to be related to both total and abdominal obesity in studies. Furthermore, strategies for preventive interventions need to consider age- and sex-specific patterns of BMI, WC and weight change, with a particular focus on abdominal obesity in women as well as middle-aged and older men, early onset in men compared with women and sex-specific patterns of weight gain in young adults. Further studies are needed on long-term patterns of weight change and progression to overweight, obesity and abdominal obesity during adulthood in populations of diverse race and ethnicity.

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Supplementary Materials

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Appendix

Variables assessed at clinic examination cycles of the Framingham Offspring/Spouse Nutrition Study

	Exam 1 (1971–1975)	Exam 2 (1979–1982)	Exam 3 (1984–1987)	Exam 4 (1987–1990)	Exam 5 (1991–1995)	Exam 6 (1996–1997)	Exam 7 (1998–2001)
Age	X	X	X	X	X	X	X
Marital status	–	–	X	–	–	–	–
Education	–	X	–	–	–	–	–
Weight	X	X	X	X	X	X	X
Height	X	X	X	X	X	X	X
Waist circumference	–	–	–	X	X	X	X
Parity	–	–	X	–	–	–	–
Menopausal status	X	X	X	X	X	X	X
Physical activity index	–	X	–	X	X	X	X
Smoking	X	X	X	X	X	X	X
Weight fluctuation	–	–	X	–	X	–	–
Hormone replacement therapy	X	X	X	X	X	X	X
Hypertension medication	X	X	X	X	X	X	X
Lipid-lowering medication	X	X	X	X	X	X	X
Alcohol*	X	X	X	X	X	X	X
Comprehensive dietary measures using 24 h recall, 3 d records, FFQ and food habit questionnaire	–	–	X	–	X	–	–
Dietary measures using FFQ	–	–	–	–	–	X	X
CVD	X	X	X	X	X	X	X
Glucose	X	X	X	X	X	X	X
Treatment with insulin or an oral hypoglycaemic agent	X	X	X	X	X	X	X
Cancer	X	X	X	X	X	X	X

'X' denotes that the variable was assessed; '–' denotes that the variable was not assessed.
*Qualitative self-assessment of alcohol intake.

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