**A longitudinal study of weight, energy intake, and physical activity change across two decades in older Scottish women**

**Authors:** Yang Tiffany C1, Gryka Anna A2, Aucott Lorna S3, Duthie Garry G4, Macdonald Helen M5

**Author affiliations and positions:** 1 Department of Health Sciences, University of York, York YO10 5DD, United Kingdom, 2Obesity Action Scotland, Royal College of Physicians and Surgeons of Glasgow, Glasgow G2 5RJ, United Kingdom, 4Natural Products Group, Rowett Institute of Nutrition and Health, University of Aberdeen, Aberdeen AB21 9SB, United Kingdom, 5University of Aberdeen, Health Sciences Building, Foresterhill, Aberdeen AB25 2ZD, United Kingdom.

Tiffany C Yang, research fellow

Anna A Gryka, policy officer

Lorna S Aucott, senior lecturer in Medical Statistics

Garry G Duthie, professor

Helen M Macdonald, professor

**Corresponding author:**

Tiffany Yang

Department of Health Sciences

Seebohm Rowntree Building

University of York

Heslington, York YO10 5DD

UK

+44 (0)1904 321612

tiffany.yang@york.ac.uk

**Keywords:** physical activity, obesity, middle age, epidemiology, longitudinal studies

**Word count**: 2811

**ABSTRACT**

**Background:** The peri- and post-menopausal periods are times of pronounced physiological change in body mass index (BMI), physical activity, and energy intake. Understanding these changes in middle-age could contribute to formation of potential public health targets.

**Method:** A longitudinal cohort of 5,119 peri-menopausal women from the Aberdeen Prospective Osteoporosis Screening Study (APOSS) recruited between 1990-1994, with follow-up visits at 1997-1999 and 2009-2011. At each visit, subjects were weighed, measured, and completed socio-economic and demographic questionnaires. Participants at the first visit were asked to recall body weights at 20, 30, and 40 years of age. We assessed trends in BMI, physical activity, and energy intake across and within visits.

**Results:** Over two decades, obesity prevalence doubled from 14% to 28% of the participants, with 69% of participants being categorized as overweight or obese. Greater than 70% of participants gained >5% of their baseline BMI with weight gain occurring across all weight categories. Energy intake and physical activity levels did not change during the two decades after menopause (*P-*trend=0.06 and 0.11, respectively) but, within the second visit, energy intake increased concomitantly with a decrease in physical activity across increasing quartiles of BMI (*P-*trend <0.001 for all).

**Conclusions:**  Overweight and obesity increased by over 50% over the course of 20 years. Weight gain occurred across the adult life course regardless of starting weight. The marked increase in dietary intake and decrease in physical activity levels in middle age suggest a potential critical period for intervention to curb excess weight gain.

**INTRODUCTION**

The current prevalence of overweight and obesity in Scotland is 65%, with men more likely to be overweight and obese than women (67% compared to 62%)[1]. Similarly, in England, 65% of men and 58% of women are categorized as overweight or obese[2]. Carrying excess body weight and a lack of physical activity can affect the quality of life in older adults[3,4]. Additionally, many co-morbidities are related to excess or insufficient body weight, and mobility and physical activity are linked[3,5]. The United Kingdom (UK) Chief Medical Officers recommend at least 150 minutes of moderate or 75 minutes of vigorous activity per week[6]. Yet, fewer than 40% of Scottish women between the ages of 55 and 74 years meet those guidelines, with declining adherence with increasing age[1].

The current obesity condition is a result of multiple etiologies and primary focus remains on energy intake and energy expenditure[7,8]. In the past few decades, overall energy intakes, based on food and drink purchases, in the British population have decreased while physical activity levels have increased even as prevalence of overweight and obesity increased, though variations are observed in different age and sex groups[9,10]. National data is composed of a series of cross-sectional collections and lack the ability to trace a subset of individuals through time; national health survey data are not able to determine the effects of aging. As adults age, a change towards a healthier pattern of eating may result in a decrease in energy intake while increasing an adherence to a healthier dietary pattern[11]. However, inactivity is more common in women than men and tends to rise with age[12,13]. Furthermore, the peri-menopausal period and middle-age are suggested to be a sensitive periods for obesity development, as the decrease in estrogen levels following menopause is related to a parallel increase in body fat mass, and middle age may be a key period that influences aging and longevity[14–17].

Our primary aim was to characterize the longitudinal patterns and relationships between body weight, physical activity levels, and energy intake over two decades in a population of peri-menopausal women. We explored trends in physical activity and energy intake within levels of BMI at each study visit and, within a subset of women with recalled history of body weight at ages 20, 30, and 40, we examined weight change over six decades.

**METHODS**

**Subjects and settings**

Subjects were women from the Aberdeen Prospective Osteoporosis Screening Study (APOSS) cohort, which initially recruited 5119 women aged 45-54 years between 1990-1994 using random selection from Community Health Index records[18]. Baseline participants were recruited for a population-based screening programme for osteoporosis fracture risk. At this visit, a subset of participants (n=1941) were asked to complete a questionnaire asking them to recall their body weights at ages 20, 30, and 40 years old. Participants were followed-up with second (1997-1999; n=3883) and third (2007-2011; n=2130) visits. All procedures involving human participants were approved by the East of Scotland Research Ethics Service. Written informed consent was obtained from all participants.

**Measurements**

Participants at all visits were weighed while wearing light clothing and no shoes on balance scales (Seca, Hamburg, Germany), calibrated to 0.05 kg. Heights (cm) were measured using a stadiometer (Holtain Ltd., Crymych, UK). Body weights at ages 20, 30, and 40 years old were self-reported at the first study visit. BMI was calculated as weight in kilograms divided by height in metres squared. Underweight was defined as BMI<18.5 kg/m2, normal weight as 18.5 kg/m2≤BMI<25kg/m2, overweight was defined as 25 kg/m2≤BMI<30kg/m2, and obesity as BMI>30 kg/m2.

National deprivation category is used as a measure for socioeconomic status and was assigned from postal codes in 1997-2000 for visits 2 and 3; the lowest number denotes the most affluent/least deprived [19]. Questionnaires and interviews at study visits were used to assess age, menopause status (pre-, peri-, post-menopausal), hormone-replacement therapy (HRT; past user, present user) use, and smoking status (yes/no).

**Energy intake and expenditure measurements**

 Energy intake was assessed via a semi-quantitative food frequency questionnaires (FFQ) that evaluated usual dietary intake over the previous 12 months and was based on the Caerphilly FFQ used for the Scottish Heart Health Study, but modified to include more detail on foods commonly eaten in northeast Scotland[20,21]. It had been validated using 7-day weighed food records[22,23]. Baseline FFQs were assessed shortly after the baseline, first, visit in 1993, and at each follow-up visit.

Physical activity level (PAL) was obtained using the same questionnaire as in the Scottish Heart Healthy Study[24]. PAL is calculated from the duration and intensity of activity performed in a 24-hour period divided by basal metabolic rate (BMR); these were assessed for working and non-working days[25]. PAL ranges in a general population between 1.4 and 2.5 with categories for those with sedentary or light activity lifestyles (1.4≤ PAL<1.7), active to moderately active lifestyles (1.7≤PAL<2), and those with the vigorous activity lifestyles (PAL ≥2.0), with values ≥1.75 as desirable for positive health outcomes[26]. BMR was calculated using the Schofield equations, which computes BMR using the age, sex, and weight of an individual[25]. These predictive equations were calculated from an analysis of anthropometric data and calorimetric measures of BMR compiled from mostly North American and Western European subjects and have been previously used to determine the UK Estimated Average Requirement (EAR) for energy in children and adults.

**Statistical analyses**

All analyses were conducted using SAS ver. 9.3 (SAS Institute, Inc.; Cary, NC, United States). Characteristics are presented as median (interquartile range). BMI loss was calculated as >5% loss in baseline BMI; gain was calculated >5% of baseline BMI; individuals who stayed within 5% of their initial body weight were categorized as having stable BMI. A change of 5% body weight was defined due to the clinical relevance of that amount of weight change[27]. Five individuals with retrospective weight recall reported abnormally low values for body weights at 40 years old and were removed from analysis. Linear trends were evaluated using ln-transformed variables and *contrast* statements inPROC GLM for participants who attended all visits and separately for each visit to observe potential dissimilarities between groups. Differences between continuous variables were calculated using the Kruskal-Wallis test for non-parametric variables; Chi-square tests were used for categorical variables.

**RESULTS**

**Participant characteristics**

At the first visit, participants had a median (IQR) age of 48 (46, 49) years; 3235 (64%) returned to the second visit at 55 (53, 56) years; and 2135 (66%; 42% of baseline) returned to the third visit at 66 (64, 67) years old (Table 1).

Table 1. Participants characteristics at visit 1 (1990-1993), visit 2 (1997-2000) and visit 3 (2007-2011).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Visit 1 1990-1993 |  | Visit 2 1997-2000 |  | Visit 3  2007-2011 |
|  | N | Median(IQR)/% | N | Median(IQR)/% | N | Median(IQR)/% |
| Age (yrs) | 5119 |  48.1 (46.7, 49.5) | 3235 | 54.5 (53.1, 56.1) | 2135 | 65.8 (64.5, 67.5) |
| PAL | 1049 | 1.7 (1.6, 1.9) | 3233 | 1.8 (1.6, 2.0) | 1682 | 1.7 (1.6, 1.8) |
| Total energy intake (kcal/day) | 1049 | 2447 (2241, 2724) | 3239 | 1837 (1534, 2231) | 1682 | 2404 (2265, 2612) |
| Weight (kg) | 5113 | 64 (58, 72) | 3232 | 67 (60, 75) | 2123 | 69.3 (62.2, 78.2) |
| Height (cm) | 5113 | 161 (157, 165) | 3233 | 160 (156, 164) | 2123 | 159 (156, 164) |
| BMI (kg/m2) | 5113 | 24.6 (22.4, 27.6) | 3233 | 25.7 (23.4, 29.0) | 2123 | 27.2 (24.4, 30.6) |
| Weight category |  |  |  |  |  |  |
| Underweight (BMI<18.5) | 76 | 1.49 | 29 | 0.9 | 13 | 0.61 |
| Normal weight (18.5≤BMI≤25) | 2712 | 53.04 | 1324 | 40.97 | 643 | 30.29 |
| Overweight (25<BMI≤30) | 1594 | 31.18 | 1229 | 38.03 | 873 | 41.12 |
| Obese (BMI>30) | 731 | 14.3 | 650 | 20.11 | 594 | 27.98 |
| Menopausal status and HRT use  |  |  |  |  |  |  |
| Pre-menopausal | 2085 | 41 | 124 | 3.2 | - | - |
| Peri-menopausal | 653 | 12.8 | 251 | 6.5 | - | - |
| Post-menopausal | 1192 | 23.4 | 1226 | 31.7 | 871 | 41 |
| Past HRT use | 317 | 6.2 | 848 | 21.9 | 1259 | 59 |
| Present HRT use | 841 | 16.5 | 1418 | 36.7 | - | - |
| Smoking status  |  |  |  |  |  |  |
| Current smokers | 767 | 19.84 | 576 | 17.88 | 188 | 8.83 |
| Non-smokers | 3099 | 80.16 | 2646 | 82.12 | 1940 | 91.17 |
| National Deprivation Category  |  |  |  |  |  |  |
| 1 | 216 | 8.05 | 960 | 24.9 | 578 | 27.26 |
| 2 | 893 | 33.3 | 1617 | 41.95 | 895 | 42.22 |
| 3 | 627 | 23.38 | 326 | 8.46 | 170 | 8.02 |
| 4 | 612 | 22.82 | 576 | 14.94 | 289 | 13.63 |
| 5 | 204 | 7.61 | 277 | 7.19 | 143 | 6.75 |
| 6 | 130 | 4.85 | 99 | 2.57 | 45 | 2.12 |

National Deprivation Category 1=least deprived/most affluent

 At the first visit, 31% and 14% of the participants were overweight and obese, respectively (Figure 1), increasing to 38% and 41% overweight and 20% to 28% obese, at the second and third visits. BMI increased, while heights decreased, across increasing levels of deprivation (results not shown). There were no differences in BMI between participants who had previously taken HRT or not, except at visit 2 (median BMI[IQR] for HRT use: 25.7[23.3, 28.7]; no HRT use: 25.9[23.6, 29.4]; p=0.008). Numbers of smoking decreased between each visit and, excepting the first visit, smokers had lower BMI than non-smokers (results not shown).

**Changes in body mass, physical activity level, and energy intake**

All three visits were attended by 1875 participants. Body weight increased an average of 5.4 kg over the visits, while height decreased by an average of 1.8 cm (Table 2).

Table 2. Changes in weight, height, BMI, PAL, and energy intake between visits 1 (1990-1993) – visit 3 (2007-2011) for participants attending all three visits.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | Difference |  |
|  | Visit 1 | Visit 2 | Visit 3 |  | V1-V2 | V2-V3 | V1-V3 |  |
|  | Median(IQR) | Median(IQR) | Median(IQR) |  | Mean(SD) | Mean(SD) | Mean(SD) | *P-*trend *trend*value\* |
| Weight (kg) | 63.5 (58.0, 71.0) | 66.5 (60.0, 74.0) | 69.3 (62.3, 77.8) |  | 2.7 (4.9) | 2.7 (6.1) | 5.4 (7.3) | <0.0001 |
| Height (cm) | 161.5 (157.7, 165.5) | 160.6 (156.8, 164.6) | 159.6 (156.0, 163.7) |  | -0.9 (1.0) | -1.0 (1.5) | -1.8 (1.6) | <0.0001 |
| BMI (kg/m2) | 24.2 (22.3, 26.9) | 25.6 (23.4, 28.6) | 27.1 (24.3, 30.4) |  | 1.3 (1.9) | 1.4 (2.3) | 2.7 (2.8) | <0.0001 |
| PAL | 1.69 (1.55, 1.86) | 1.77 (1.61, 1.99) | 1.67 (1.57, 1.81) |  | 0.11 (0.35) | -0.11 (0.32) | -0.01 (0.31) | 0.06 |
| Total energy intake (kcal) | 2438 (2245, 2688) | 1829 (1544, 2204) | 2402 (2265, 2612) |  | -636 (626) | 555 (599) | -21 (460) | 0.11 |
| N=1875 for all three visits  |  |  |  |  |  |  |  |
|  |  |  |

This resulted in a mean gain of 2.7 units of BMI. PAL increased from visit 1 to visit 2, but declined by a similar amount between visits 2 and 3, resulting in only a slight decrease overall from visit 1 to visit 3. Conversely, reported energy intake decreased from visit 1 to 2, but increased from visit 2 to 3.

The majority (72%) of participants gained >5% of their baseline BMI, while 23% remained stable and 6% lost >5% of their initial weight. Those who gained >5% of their baseline bodyweight had the lowest BMI at baseline among the three groups and decreased their energy intake between visits 1 and 3 (Supplementary File 1). Heights of all participants decreased from the first to third visits but were not significantly different between those who lost, gained, or remained stable in their BMI.

Table 3 shows how participants maintained or moved weight categories between visits 1 and 3. Of those categorized as normal weight at the baseline visit, 45% and 6% were overweight or obese, respectively, by the third visit. Very few individuals who were initially categorized as overweight or obese lost weight and were re-classified as normal weight. The majority of obese individuals (91%) remained obese, while 46% of overweight individuals became obese between the visits.

|  |
| --- |
| Table 3. Number (%) of participants maintaining or moving between weight categorys from visit 1 (1990-1993) to visit 3 (2007-2011) |
|   |   | Visit 3 (2007-2011) |
|  |  | Underweight BMI<18.5 | Normal weight 18.5≤BMI<25 | Overweight 25≤BMI<30 | Obese BMI≥30 |
| Visit 1 (1990-1993) | Underweight BMI<18.5 | 2 (10) | 16 (80) | 2 (10) | 0 (0) |
| Normal weight 18.5≤BMI<25 | 11 (1) | 589 (48) | 543 (45) | 70 (6) |
| Overweight 25≤BMI<30 | 0 (0) | 35 (6) | 307 (48) | 293 (46) |
| Obese BMI≥30 | 0 (0) | 3 (1) | 21 (8) | 231 (91) |

 Trends in BMI, PAL, and energy intake across quartiles of BMI at each study visit, are shown for participants who attended all three study visits (solid black line), or cross-sectionally at each visit (dashed line) (Figure 2). At visit 1, there was no trend of increasing PAL and total energy intake across quartiles of BMI (*P-*trend = 0.39, *P-*trend = 0.39, respectively). Visit 2 saw the greatest downward change in PAL and upward increase in energy intake across BMI quartiles. In contrast, while PAL at visit 3 decreased across quartiles of BMI, energy intake also decreased. Individuals who attended all study visits had similar BMI distributions compared to serial cross-sectional measurements.

Data from the subset of individuals who answered a retrospective questionnaire on weight for ages 20, 30, and 40 years show that individuals increased in weight steadily from their 20s onwards (Supplementary File 2). Greater spread in weight was observed at younger ages, with body weight ranging from 48 kg (quartile 1) to 66 kg (quartile 4), narrowing by the third study visit to 65 kg and 75 kg over 4 decades later.

**DISCUSSION**

In this study, we assessed changes in BMI, physical activity, and energy intake over two decades in a population of women who were peri-menopausal at the start of the study period. Over two decades, overweight and obesity increased by over 50%, from 45% to 69%. This increase is greater when considering only the individuals followed-up across all three studies: 40% to 69% were categorized as overweight or obese between the first and third visits, an increase of over 70% (results not shown). Much of the shift was observed with individuals who were categorized as having normal weight; over half shifted into overweight and obese categories over the study period. Similarly, almost half of those who were categorized as overweight shifted into the obese category, while those who were obese tended to stay obese.

Over 70% of women gained >5% of their starting BMI, but some of the increase in BMI was a result of both body weight gain as well as height loss. While we noted that those who gained >5% of their initial BMI had the lowest BMI at baseline, their baseline BMI was similar to those who maintained their BMI across study visits (BMI 24.1 vs 24.5). Regardless of starting BMI, most individuals gained weight; 75%, 71%, and 61% of those who were initially categorized as normal weight, overweight, and obese gained >5% of their starting BMI (results not shown). This weight gain was not only confined to the study period, when the women were beginning middle-age. We observed steadily increasing weight gain from when the women were young adults; this trend in weight gain shown as quartiles of recalled body weight when the women were 20 years old through to the third study visit mirrored what trends would be observed with quartiles of BMI at visit 1 through visit 3. Our results show that there is a constant gain in weight across the adult life course regardless of how much the women weighed as young adults. A wider distribution of weight at age 20 narrowed as the women aged, and this narrowing was mostly due to the movement of participants into higher weight categories, while those who were obese gained weight but at a slower pace.

These linear increases in body weight have been observed in other longitudinal cohorts[28–30]. In a racially-diverse cohort of men and women followed over a 25-year period from the ages of 18-30 years as well as using data from the National Health and Nutrition Examination Survey (NHANES), authors report that all groups reported steadily increasing BMI[28,30]. Similar to our findings, the authors noted that the greatest change in weight for women occurred when participants were young adults and levelling at later follow-up visits.

While the etiology of obesity is extremely complex, a balance between energy intake and expenditure is important in maintaining body weight[31]. An increase in energy intake and a decrease in PAL would have been expected, given the increases in levels of overweight and obesity. Levels of PAL at these visits were characterized as being sedentary or lightly active, which would not meet the UK physical activity recommendations and we did not observe significant changes in intake and expenditure between the first and third study visits. This discrepancy is attributed to underestimation of true caloric intake, which is more common among those who are overweight or obese[32,33]. A recent report suggests that under-reporting of energy intake has increased over time and may explain the reported declines in energy intake[9,33]. We found the greatest change in energy expenditure and intake at the second study visit when participants were in their mid-50s, where a decrease in PAL occurred concomitantly with an increase in energy intake. In this period of middle-age, individuals who were in the highest weight category not only had lower levels of physical activity, but also higher energy intakes. The time between the first and second visits also reflected the greatest increase in overweight and obesity in those followed across all three study visits, from 40% to 57%. Middle-age could therefore be an appropriate target of health interventions to stem the increase in weight gain, such as through slowly building up to 10-minute bouts of physical activity in older adults with low fitness levels[6]; the UK government has acknowledged the importance of this period by launching the One You campaign (<https://www.nhs.uk/oneyou>) to encourage health behavior change. Assessing the timing of greatest weight gain and decline in physical activity would be beneficial in advising interventions and policies pointed at adult weight gain.

Strengths of this study include a large sample size of women with multiple study visits over the course of twenty years, allowing for longitudinal analysis on a subset of participants. Weight trajectories over six decades of life were possible through questionnaires recalling body weights. Recall bias of past body weight necessitates caution when interpreting results as women tend to underestimate past body size, but provides insight into how individuals at lower or higher body weights in young adulthood track, and allowing us to observe weight cycling among many women [34,35]. The recalled weights would likely have been lower than actual body weights, so our observed weight trajectories are expected to be more pronounced than expected. However, a trend in weight increase throughout adult life would still have been observed.

Other limitations of our study include the inability to determine the source of body weight gain, as BMI is a surrogate measure of body fatness. However, aging parallels changes in anthropometry: decreasing muscle and increasing body fat gain[36]. We did not have measurements of fat- and lean-body mass and thus were unable to determine whether changes in body weight over time were due to increases in fat mass, decreases in lean muscle mass, or a combination of the two. We observed lower BMI among individuals in the lowest deprivation category (least deprived/most affluent), rising linearly with increasing levels of deprivation at each study visit, but did not observe similar trends for energy intake; this is in agreement with the 2014 Scottish Health Survey[10]. We are therefore unable to ascertain whether socioeconomic status differences in energy intake explain these trends. Participants were selected randomly using the Community Health Index, so that participants are more representative of the general population in northeast Scotland, but limits comparison with other populations. Results may also be biased because participants lost to follow-up tended to be shorter, heavier, and more likely to be smokers and come from a less affluent socioeconomic category.

**CONCLUSION**

 We observed considerable increases in the prevalence of overweight and obesity in a population of women in northeast Scotland over the course of two decades of follow-up. Over time, women lost height and gained body weight and, regardless of body weight as a young adult, a definite trend in increasing body weight was observed. The greatest change in physical activity and energy intake occurred when the women were in middle-age following the largest increase in prevalence of overweight and obesity; it may be beneficial to target obesity interventions in this sensitive period. Many women also exhibited weight cycling from their twenties onwards; future work could consider how these women differ from those who gain weight linearly.

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**Competing Interest**: None declared.

**Contributors:** HMM was involved in study design and as the principal investigator; HMM and GGD obtained funding; AAG and TCY drafted the plan for the data analyses, AAG and TCY contributed to, and TCY conducted, analyses; LSA provided statistical support; TCY drafted the manuscript; TCY and HMM had primary responsibility for content; all authors were involved in interpretation and revision of the manuscript and approved the final version. TCY and HMM are guarantors.

**Funding:** This work was supported by the Foods Standards Agency and the UK Department of Health (grant number N05086) and the Scottish Funding Council. We are grateful for funding from the Scottish Government's Rural and Environmental Science and Analytical Services (RESAS) Food, Land and People Programme. Any views expressed are the authors’ own; none of the funders had a role in design, analysis, or writing of the present study.

**Ethics:** All procedures involving human participants were approved by the East of Scotland Research Ethics Service. Written informed consent was obtained from all participants prior to any data collection.

**Transparency:** TCY and HMM affirm that the manuscript is a transparent, accurate, and honest account of the study being reported. No important aspects of the study have been omitted and any discrepancies resulting from the study as planned have been explained.

**Data sharing:** No additional data available.

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**FIGURE LEGENDS**

Figure 1. Changes in weight category from visit 1 (1990-1993) to visit 3 (2007-2011).

Figure 2. Median (IQR) BMI, PAL, and energy intake by quartiles of BMI at visit 1 (1990-1993), visit 2 (1997-2000), and visit 3 (2007-2011). Black lines denote participants who had data at all three study visits (n=1875); dotted line denotes cross-sectional data from each visit (Visit 1: n=5113; Visit 2: n=3232; Visit 3: n=2123).

**SUMMARY BOX**

**What is already known on this subject?**

As people age, they tend to put on body weight. In women, this is compounded in middle age by physiological changes that occur due to the menopausal transition. Many people fail to reach the recommended amount of moderate physical activity and most individuals are now overweight or obese. Whether weight gain in middle age is due to decreases in physical activity or increases in energy intake has not been studied in a longitudinal cohort of women.

**What does this study add?**

This study looks at trends in weight gain and obesity status over a twenty year period in the same group of women, assessed between 1990 and 2011. Recalled body weights showed that there was a larger spread of weight at age 20 which narrowed by the end of the study, when the women were in their mid-60s, by which time obesity had more than doubled. The largest discrepancy between increases in energy intake and decreases in physical activity occurred when women were middle-aged, and may be an important period to intervene to prevent excess body weight gain.