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# Do the associations of body mass index and waist circumference with back pain change as people age? 32 years of follow-up in a British birth cohort

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## Contributors

SGM and RH had full access to all the data in the study and take full responsibility for the integrity and the accuracy of data analysis. SGM, DK, and RC conceived the idea for this study; SGM, DK, RH and RC contributed to the development of the study objectives; DK, RH and RC acquired the data; SGM and RH analysed the data; SGM and RH drafted the manuscript; all authors contributed to the manuscript's critical revision and provided final approval of the version to be published.

**Abstract**

**Objectives:** To investigate whether associations of body mass index (BMI) and waist circumference (WC) with back pain change with age and extend into later life.

**Design:** British birth cohort study

**Setting:** England, Scotland and Wales

**Participants:** Up to 3426 men and women from the MRC National Survey of Health and Development

**Primary outcome measures:** Back pain was self-reported at ages 36, 43, 53, 60-64 and 68 years. Mixed-effects logistic regression models were fitted to test the repeated cross-sectional and longitudinal associations of nurse-assessed BMI and WC with back pain and whether these associations varied by age.

**Results:** Higher BMI was consistently associated with increased odds of back pain at all ages, except at age 68, but was stronger at age 60-64 than at any other age. Sex-adjusted odds ratios of back pain per 1 standard deviation increase in BMI were: 1.13 (95% CI 1.01, 1.26), 1.11 (95% CI 1.00, 1.23), 1.17 (95% CI 1.05, 1.30), 1.31 (95% CI 1.15, 1.48) and 1.08 (95% CI 0.95, 1.24) at ages 36, 43, 53, 60-64 and 68-69, respectively. Similar patterns of associations were observed for WC. These associations were maintained when potential confounders, including education, occupational class, height, cigarette smoking status, physical activity and symptoms of anxiety and depression were accounted for. BMI showed stronger associations than WC in models including both measures.

**Conclusions:** These findings demonstrate that higher BMI is a persistent risk factor for back pain across adulthood. This highlights the potential lifelong consequences of the rising levels of obesity on back pain and outcomes these precipitate including disability and functional limitations in later life.

## Article summary

### Strengths and limitations of this study

- The availability of data on back pain, body mass index (BMI) and waist circumference (WC) prospectively ascertained over 32 years of follow-up in a large representative population-based sample is a key and unique strength of this study.
- This allowed us to formally test whether the cross-sectional and prospective relationships of BMI and WC with back pain change with age, extend into later life and are independent of each other so addressing important gaps in our current understanding.
- Back pain was not assessed in exactly the same way at different time points across adulthood, timing of onset of pain was not recorded and severity and chronicity were not distinguished but despite this we were able to show that associations were largely consistent across adulthood.
- Residual confounding cannot be fully ruled out as a potential explanation of our findings however, the risk of this has been minimised by taking account of a wide range of potential confounders measured prospectively across adulthood.
- Cross-sectional associations between body size and back pain may be explained by reverse causality, but we also investigated longitudinal associations between BMI and back pain and our conclusions remained unchanged.

**Introduction**

Back pain is one of the most commonly reported musculoskeletal disorders and was recently ranked as the number one cause of disability in most countries worldwide.[1] As it is a major cause of activity limitation and functional decline in later life[2-8] the fact that its prevalence is projected to increase as population ageing continues is a considerable cause for concern. As a result, there have been calls to intensify research efforts to address the public health challenge of the burden of low back pain.[9]

Obesity, usually indicated by high body mass index (BMI), has been identified as an important risk factor for back pain in systematic reviews.[10-12] However, the majority of existing studies have examined cross-sectional associations at a single time-point, often in early or mid-adulthood[10, 13-17] and/or are in occupational-based cohorts.[10] There are few studies on obesity and back pain in older populations. This is despite evidence to suggest that the aetiology of back pain may change with age as degenerative back disorders become increasingly common; these disorders may have different risk factors to conditions that precipitate back pain earlier in life. This is coupled with reduced pain-modulatory capacity occurring with advancing age partly explaining increases in persistent and disabling pain conditions among older adults.[18] In one study of older populations (age >50 years) from nine countries, high BMI was associated with increased odds of back pain in European countries (Poland, Russia, Finland, Spain) and South Africa.[19] However, whether or not the associations found among these older adults were weaker, due to potential changes in the underlying aetiology of back pain, or of similar strength to those that would have been observed in these populations if they had been assessed at younger ages could not be established. To our knowledge, no study has formally investigated whether the association between BMI and back pain changes with age; thus whether or not obesity remains a suitable target for intervention for the prevention of back pain into later life remains to be established.

Higher central adiposity, as well as higher BMI, has been related to increased risk of back pain[12-17, 20] and may be more indicative of inflammatory processes due to increases in fat mass. Despite this, few studies[20] have compared the strength of associations between BMI and abdominal adiposity or tested whether there is any additional effect of abdominal adiposity over and above BMI as a general marker of total adiposity.  This could provide new aetiological insights to help inform the development of interventions to prevent or alleviate back pain.

The MRC National Survey of Health and Development (NSHD), the oldest of the British birth cohort studies, has assessed BMI, waist circumference (WC) and back pain at multiple time points across adulthood from midlife up to age 69. It therefore provides a unique opportunity to address important research gaps by examining whether the cross-sectional and prospective relationships of BMI and WC with back pain change with age, extend into later life and are independent of each other.

**Subjects and Methods**

The NSHD is a socially stratified sample of 5362 single, legitimate births that occurred in England, Wales and Scotland in one week of March 1946.  To date participants have been assessed on 24 occasions up to age 69.[21-23]  All waves of data collection have complied with ethical standards. Ethical approval for the most recent data collection at age 68-69 was obtained from the Queen Square Research Ethics Committee (14/LO/1073) and the Scotland

A Research Ethics Committee (14/SS/1009). All methods were carried out in accordance with the relevant guidelines and regulations and written informed consent was obtained.

*Patient and public involvement*

Over the 73 years of this study, the research has increasingly involved participants, in line with changing norms about conducting cohort studies. Participant involvement includes receiving personal letters from the research team as required, and invitations to participate in birthday celebrations, public engagement activities and focus groups to discuss future data collections. When piloting new questionnaires and assessments, including those used in these analyses, patients from general practices and the University College London Hospitals Patient Public Involvement group were recruited and asked to provide feedback which was taken into account when designing the mainstage fieldwork.

*Back pain assessment*

Back pain was ascertained during nurse interviews at ages 36, 43, 53 and 60-64 and in a postal questionnaire at age 68. At all ages except age 68, participants were asked whether they had sciatica, lumbago, or recurring/severe backache all or most of the time (ever at ages 36 and 43 and in the previous 12 months at ages 53 and 60-64). At age 68, participants were asked whether they had experienced any ache or pain in the previous month which had lasted for one day or longer, not including pain occurring during the course of a feverish illness such as flu. Those who responded positively were asked to shade the location of their pain using a four-view body manikin. Those who shaded any back site were classified as having back pain for the purposes of these analyses.

*Anthropometric measurements*

Height, weight and waist circumference (taken at the midpoint between the costal margin and iliac crest) were measured by nurses using standardised protocols at ages 36, 43, 53, 60-64 and 69 years. BMI was calculated at each age as weight (kg)/height (m)$^2$. BMI and waist circumference at each age were sex-standardised (to a mean of 0 and standard deviation (SD) of 1); our units of analysis for BMI and waist circumference are both 1SD to facilitate comparisons of effect sizes across age and sex.

*Fat and lean mass at 60-64 years*

Measures of body composition were obtained in participants who attended one of six Clinical Research facilities when aged 60-64 years using a QDR 4500 Discovery DXA scanner (Hologic Inc, Bedford, MA, USA) whilst the individuals were in a supine position. Whole body fat mass was measured and whole body lean mass was calculated as total mass minus fat and bone mass. Mass from the head was excluded and measures were converted to kg. Full details are provided elsewhere.[24] Fat mass index (kg/m$^2$) and lean mass index (kg/m$^2$) were calculated by dividing the measures of mass by height-squared.

*Covariates*

Covariates representing different domains of the biopsychosocial model of pain were selected *a priori*.[25] This included variables that have previously been identified as key risk factors for back pain.[20, 26, 27] These were sex, educational attainment at age 26, occupational class at age 53, measures of height, smoking status, physical activity, and symptoms of anxiety and depression, which were available at ages 36, 43, 53, 60-64 and 68-69 and so included as time varying covariates.

The highest education level achieved by age 26 was grouped into no qualifications, up to O-level or equivalent, or A-level or equivalent and above. Own occupation at age 53 was categorised according to the Registrar General's social classification into three groups: high (I or II: professional, managerial or technical); middle (IIINM skilled non-manual or IIIM: skilled manual); low (IV or V: partly skilled or unskilled manual).

Smoking status was assessed by self-report at each wave and categorised as never-, ex and current smoker. Participation in sports, vigorous leisure activities or exercise was assessed at each wave and participants were grouped as inactive, moderately active (1-4 times/month) or regularly active (≥5 times/month).[28]

Symptoms of anxiety and depression were also assessed at all five waves. At age 36, a shortened version of the Present State Examination[29] was used at a nurse interview and the total score was recoded to a binary variable using the recommended threshold for caseness of 5 or more. At age 43, participants completed the 18-item Psychiatric Symptom Frequency (PSF) scale[30] and the total score was calculated and then dichotomised into absence of symptoms (PSF score <23) and presence of symptoms (PSF score ≥23). At ages 53, 60-64 and 68/69 the 28-item General Health Questionnaire (GHQ-28)[31] was self-administered and scores of all items were summed and further dichotomised using a recommended threshold for caseness of 5 or more.

*Statistical analysis*

Multilevel mixed-effects logistic regression models with a random intercept were used to test associations between BMI and back pain with measurement occasion nested within individuals. These models allow for the correlation between measurements on the same individual. We fitted measurement wave as a categorical variable with age 36 as the reference category and adjusted for sex. Interactions between wave and sex were tested in the model however, these were not statistically significant and so were removed in subsequent models. We then tested associations of BMI with back pain across adulthood by fitting body size measures as time varying covariates. Formal tests of sex interaction were performed by including sex by BMI interaction terms in models. Deviations from linearity were assessed by including quadratic terms for body size but no evidence of this was found. To assess whether the association of BMI with back pain changed with age, separate models were fitted that included interactions between wave and BMI. Models were then additionally adjusted for potential confounding variables. Analyses were repeated replacing BMI with WC and then a final confounder adjusted model was run in which BMI and WC were included together. All models included the maximum number of participants, which was those participants with a valid measure of back pain, BMI, WC and all covariates for at least one age (n=3426) (see table S1 for number of participants who contributed data at each wave).

We then repeated the same modelling approach to assess prospective associations between body size and back pain. To achieve this, we used back pain at 43, 53, 60-64 and 68 as outcomes and related them to body size at the prior age (i.e. at ages 36, 43, 53 and 60-64). These models included a sample size of 3044.

Finally, in the sub-sample with body composition measures at age 60-64 (n=1186) supplementary analyses using multiple regression models, assessed the associations between fat mass index and lean mass index at 60-64 years and back pain at 68 years. Model 1 included sex and both body composition measures and model 2 added the same covariates used in previous models.

All analyses were performed using STATA version 14.1.

**Results**

The characteristics of the study sample are shown in Table 1 (and Table S2). Overall, the percentage reporting back pain varied from 17.9% and 32.3% and was higher in women than men at every age (Table 1).

In sex-adjusted models, higher BMI was associated with increased odds of back pain at every age (Table 2). Sex-adjusted odds ratios (ORs) of back pain per 1SD increase in BMI were 1.13 (95% CI 1.01, 1.26), 1.11 (95% CI 1.00, 1.23), 1.17 (95% CI 1.05, 1.30), 1.31 (95% CI 1.15, 1.48) and 1.08 (95% CI 0.95, 1.24) at ages 36, 43, 53, 60-64 and 68-69, respectively. Adjustment for potential confounders had minimal impact on these ORs (Table 2). There was some evidence to suggest that the association was strongest at age 60-64 (age 60-64 wave by BMI interaction: p=0.07) but there was no evidence of a difference in association between age 36 and any other age (wave by BMI interactions p>0.5) (Supplementary Table S3). There was also evidence to suggest that the association at age 60-64 was stronger than the associations at 53 (p=0.03) and 68-69 (p=0.03).

A similar, albeit less variable, pattern of association was observed for WC, with no evidence that the association at age 60-64 was stronger than at other ages (wave by BMI interaction: p=0.2) (Table 2, Supplementary Table S3). Adjustment for potential confounders attenuated all ORs somewhat, and to a greater extent than the ORs for BMI (Table 2).

Including both BMI and WC in the same fully adjusted model with all interaction terms led to inflated standard errors. We therefore included only the age 60-64 wave by BMI and the age 60-64 wave by WC interaction, finding only evidence of the interaction with BMI. Our final fully adjusted model thus included only the interaction with BMI; the association of BMI with back pain (OR per SD (95% CI): 1.11 (0.99, 1.24) at 36, 43, 53 and 68-69y and 1.28 (1.09,1.50) at 60-64y) was stronger than that for WC (OR per SD (95% CI): 1.02 (0.91,1.13)) at all ages.

Findings for both BMI and WC were very similar when relating the body size measure at the prior age to subsequent back pain (Table 3). In supplementary analyses (n=1186), higher fat mass index was associated with higher odds of back pain at age 68 (OR per SD (95% CI): 1.23 (1.04, 1.45)) in a model adjusting for sex and lean mass index, but no association was observed for lean mass index (Supplementary Table S4). The association with fat mass index was maintained after adjustment for other potential confounders.

## Discussion

In a large nationally representative British birth cohort higher BMI and WC were consistently associated with increased odds of back pain between ages 36 and 68. These associations were maintained after adjustment for confounders and, BMI remained more strongly related to back pain, particularly at age 60-64 years, than WC in a model including both variables. Findings were similar when prospective associations were investigated for back pain between 43 and 68.

Our findings are consistent with previous studies which have reported associations between overweight and obesity, indicated by high BMI, and increased odds of back pain.[10]

Findings from cross-sectional studies also suggest positive associations between higher WC and low back pain in women, but not in men.[12-17] These previous studies have sampled participants across a range of different ages (15 years and older) and although they have adjusted for age, none has examined whether associations of BMI and WC with back pain vary with age or whether associations remain into older age. Our study shows persisting associations of BMI and WC with back pain until age 68 years with little evidence of variation with age. The slightly stronger association at age 60-64 needs to be interpreted with caution as this may be due to the differences in how the outcome was assessed at different ages. However, the question used at 60-64 was also used at age 53 and this shows an association consistent with other ages. In addition, we are confident that the association does persist into older age because associations at each age were fairly constant despite the differences in method of outcome ascertainment.

Another key finding is that BMI exhibited a stronger association than WC in a model including both measures. This suggests that mechanisms specifically related to central adiposity do not fully underlie the associations observed. This contrasts with a previous study in young adults (age 24-39 years) which found that WC but not BMI remained associated with back pain in mutually adjusted models in women only.[13] Our findings in relation to fat and lean mass suggest that associations with BMI may be driven by whole body fat mass, rather than abdominal fat mass specifically. In testing these associations we are addressing the call made in a recent systematic review for further high-quality studies on the relationships of body composition with pain.[32] Our findings are consistent with a prospective study[12] included in this review that found evidence that fat mass was associated with low back pain intensity and disability in both sexes. Likewise, a cross-sectional study found that higher fat mass (independent of lean mass) was associated with higher levels of low back pain intensity and disability but found no relationship with lean mass after adjusting for fat mass.[11] The stronger associations with BMI than WC may point to the importance of mechanical effects, with increased BMI resulting in higher compressive force on the spine during activity.[10] However, we cannot rule out the fact that chronic inflammatory or metabolic pathways may also be relevant. For example, atherosclerosis and chronic inflammation, which are linked to obesity, have also been associated with disc degeneration and low back pain.[33, 34]

A key strength of our study is the large representative population-based sample of adults with assessments of back pain and measured height, weight and waist circumference at five time points over 32 years of follow-up. Although back pain was not assessed in exactly the same way at different time points across adulthood and, severity and chronicity were not distinguished we were able to show that associations are consistent across adulthood and persist into old age. Another strength is the availability of data on a wide range of potential confounders measured prospectively across adulthood that allowed us to adjust for a range of time-varying covariates. While residual confounding cannot be fully ruled out, the risk of this has been minimised. It is acknowledged that any cross-sectional associations between body size and back pain may be explained by reverse causality, but we also investigated associations between back pain and BMI measured at a prior age and findings remained unchanged. Finally, our study population comprised Caucasian men and women born in Britain in 1946. While this allows us to rule out confounding by age or ethnicity as potential explanations of our findings, it may limit their generalisability. Further research is thus necessary to consider the implications of these findings for more ethnically diverse cohorts and also more recently born cohorts, the latter who are likely to have spent more of their lives overweight or obese.[35]

In summary, our findings suggest that there is a consistent relationship between higher adiposity and back pain across adulthood. Our results also show that WC does not add further information once BMI has been accounted for in this relationship. This underscores the importance of primary and secondary interventions to prevent excessive weight gain and reduce overweight and obesity across the whole of adulthood in order to help prevent back pain and its disabling consequences as individuals age.

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**Competing interests**

The authors declare no financial or non-financial competing interests

**Data sharing statement**

Data used in this publication are available to bona fide researchers upon request to the NSHD Data Sharing Committee via a standard application procedure. Further details can be found at http://www.nshd.mrc.ac.uk/data. doi: 10.5522/NSHD/Q101; doi: 10.5522/NSHD/Q102; 10.5522/NSHD/Q103

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**Table 1: Characteristics of the MRC National Survey of Health and Development sample included in analysis [a]**

| | | Male | Female | p-value[b] |
|---|---|---|---|---|
| **Back pain, N (%), at age:** | | | | |
| 36y | | | | .08 |
| | No | 1283 (83.3) | 1256 (80.9) | |
| | Yes | 257 (16.7) | 297 (19.1) | |
| 43y | | | | .06 |
| | No | 1106 (74.6) | 1042 (71.5) | |
| | Yes | 377 (25.4) | 415 (28.6) | |
| 53y | | | | .06 |
| | No | 925 (69.4) | 903 (66.0) | |
| | Yes | 407 (30.6) | 465 (34.0) | |
| 60-64y | | | | .06 |
| | No | 629 (72.1) | 643 (68.1) | |
| | Yes | 243 (27.9) | 301 (31.9) | |
| 68y | | | | .02 |
| | No | 637 (74.1) | 635 (69.2) | |
| | Yes | 223 (25.9) | 282 (30.8) | |
| **BMI (kg/m$^2$), mean (SD), at age:** | | | | |
| 36y | | 24.8 (3.3) | 23.5 (4.1) | <.001 |
| 43y | | 25.7 (3.5) | 25.1 (4.7) | <.001 |
| 53y | | 27.4 (4.1) | 27.4 (5.4) | .85 |
| 60-64y | | 27.9 (4.1) | 27.9 (5.5) | .99 |
| 69y | | 28.1 (4.5) | 28.0 (5.6) | .93 |
| **Waist circumference (cm), mean (SD), at age:** | | | | |
| 36y | | 89.5 (9.3) | 76.9 (11.5) | <.001 |
| 43y | | 91.8 (9.9) | 77.7 (11.2) | <.001 |
| 53y | | 97.7 (10.9) | 85.8 (12.8) | <.001 |
| 60-64y | | 100.8 (11.1) | 92.2 (13.0) | <.001 |
| 69y | | 100.9 (12.3) | 92.1 (14.0) | <.001 |

*Note.* BMI: body mass index; WC: waist circumference; SD: Standard Deviation; y: years

[a] Maximum N=3426 (1723 males and 1703 females) (this includes participants with a valid measure of back pain, BMI, waist circumference and each covariate for at least one age). Number of participants contributing data at each age: 36y, N=3093; 43y, N=2940; 53y, N=2700; 60-64y, N=1816; 68-69y, N=1777 (see Supplementary table S1 for more details)

[b] p-values from formal tests of sex differences using chi-squared and t-tests as appropriate

**Table 2: Odds Ratios (OR) of back pain at each age per 1 standard deviation increases in BMI and waist circumference at the same age estimated from multilevel logistic models (12 326 observations nested within 3426 individuals)**

| | BMI | | | |
|---|---|---|---|---|
| | Model 1[a] | | Model 2[b] | |
| Per SD BMI at: | OR (95% CI) | P value | OR (95% CI) | P value |
| 36y | 1.13 (1.01 , 1.26) | 0.03 | 1.12 (1.00,1.25) | 0.05 |
| 43y | 1.11 (1.00 , 1.23) | 0.06 | 1.11 (1.00,1.23) | 0.05 |
| 53y | 1.17 (1.05 , 1.30) | 0.003 | 1.17 (1.05,1.30) | 0.003 |
| 63y | 1.31 (1.15 , 1.48) | <0.001 | 1.30 (1.14,1.47) | <0.001 |
| 68y | 1.08 (0.95 , 1.24) | 0.2 | 1.07 (0.94,1.22) | 0.3 |
| | Waist circumference | | | |
| | Model 1[a] | | Model 2[b] | |
| Per SD WC at: | OR (95% CI) | P value | OR (95% CI) | P value |
| 36y | 1.17 (1.05 , 1.31) | 0.005 | 1.14 (1.02,1.27) | 0.02 |
| 43y | 1.12 (1.01 , 1.24) | 0.03 | 1.08 (0.98,1.20) | 0.1 |
| 53y | 1.16 (1.05 , 1.29) | 0.005 | 1.13 (1.02,1.25) | 0.03 |
| 63y | 1.27 (1.12 , 1.44) | <0.001 | 1.21 (1.07,1.38) | 0.003 |
| 68y | 1.12 (0.98 , 1.27) | 0.1 | 1.07 (0.94,1.22) | 0.3 |

*Note.* BMI: body mass index; SD: Standard Deviation; OR: Odds Ratio; y: years

[a] Model 1: adjusted for sex

[b] Model 2: adjusted for sex, education, occupational class and time-varying covariates (height, cigarette smoking status, physical activity and symptoms of anxiety and depression)

**Table 3: Odds Ratios (OR) of back pain at each age per 1 standard deviation increase in BMI and waist circumference at the previous age estimated from multilevel logistic models (8 595 observations nested within 3044 individuals)**

| | | BMI | | | |
|---|---|---|---|---|---|
| | | Model 1[a] | | Model 2[b] | |
| Per SD BMI/WC at age: | Back pain at age: | OR (95% CI) | P value | OR (95% CI) | P value |
| 36y | 43y | 1.08 (0.97 , 1.20) | 0.2 | 1.06 (0.96,1.18) | 0.3 |
| 43y | 53y | 1.17 (1.05 , 1.31) | 0.004 | 1.16 (1.04,1.29) | 0.009 |
| 53y | 63y | 1.32 (1.15 , 1.51) | <0.001 | 1.29 (1.13,1.48) | <0.001 |
| 63y | 68y | 1.11 (0.96 , 1.28) | 0.2 | 1.08 (0.94,1.25) | 0.3 |
| | | Waist circumference | | | |
| | | Model 1[a] | | Model 2[b] | |
| | | OR (95% CI) | P value | OR (95% CI) | P value |
| 36y | 43y | 1.12 (1.01 , 1.24) | 0.04 | 1.08 (0.97,1.21) | 0.1 |
| 43y | 53y | 1.17 (1.05 , 1.30) | 0.004 | 1.14 (1.02,1.26) | 0.02 |
| 53y | 63y | 1.28 (1.12 , 1.47) | <0.001 | 1.23 (1.07,1.40) | 0.003 |
| 63y | 68y | 1.10 (0.96 , 1.26) | 0.2 | 1.06 (0.92,1.21) | 0.4 |

*Note.* BMI: body mass index; SD: Standard Deviation; OR: Odds Ratio; y: years

[a] Model 1: adjusted for sex

[b] Model 2: adjusted for sex, education, occupational class and time-varying covariates (height, cigarette smoking status, physical activity and symptoms of anxiety and depression)

**Supplementary information: Do the associations of body mass index and waist circumference with back pain change as people age? 32 years of follow-up in a British birth cohort**

Stella G Muthuri, Rachel Cooper, Diana Kuh & Rebecca Hardy

**Table S1: Number of MRC National Survey of Health and Development participants contributing data at each age and number with missing data[a]**

| Age | Total N contributing data at specified age (no. of males; no. of females) | N with data on back pain but missing data on BMI/WC at specified age | N with data on back pain and BMI/WC at specified age but missing data on covariates |
|---|---|---|---|
| 36y | 3093 (1540; 1553) | 48 | 175 |
| 43y | 2940 (1483; 1457) | 52 | 259 |
| 53y | 2700 (1332; 1368) | 44 | 243 |
| 60-64y | 1816 (872; 944) | 29 | 390 |
| 68-69y | 1777 (860; 917) | 485 | 158 |

[a] A total of 3426 MRC NSHD participants were included in the main analyses. Participant's data could be included at a specified age if there was complete information on back pain, BMI, waist circumference and all covariates at that age
BMI: Body mass index; WC: waist circumference

**Table S2: Characteristics of the MRC National Survey of Health and Development sample included in analysis [a]**

| | Male | Female |
|---|---|---|
| **Highest education level achieved by age 26y, N (%)** | | |
| A-level/equivalent or above | 706 (41.0) | 463 (27.2) |
| O-level/equivalent or below | 357 (20.7) | 587 (34.5) |
| None | 660 (38.3) | 653 (38.3) |
| **Own occupational class at age 53y, N (%)** | | |
| High (I/II) | 853 (49.5) | 593 (34.8) |
| Middle (IIINM/IIIM) | 662 (38.4) | 740 (43.5) |
| Low (IV/V) | 208 (12.1) | 370 (21.7) |
| **Time varying covariates[b]** | | |
| **Height (cm), mean (SD), at age:** | | |
| 36y | 175.4 (6.5) | 162.4 (6.0) |
| 43y | 175.2 (6.6) | 162.4 (6.2) |
| 53y | 174.7 (6.5) | 161.6 (5.9) |
| 60-64y | 174.8 (6.5) | 161.9 (5.9) |
| 69y | 174.0 (6.4) | 160.7 (5.9) |
| **Smoking status, N (%), at age:** | | |
| 36y | | |
| Current | 530 (34.4) | 524 (33.7) |
| Ex | 617 (40.1) | 518 (33.4) |
| Never | 393 (25.5) | 511 (32.9) |
| 43y | | |
| Current | 460 (31.0) | 417 (28.6) |
| Ex | 522 (35.2) | 373 (25.6) |
| Never | 501 (33.8) | 667 (45.8) |
| 53y | | |
| Current | 323 (24.3) | 315 (23.0) |
| Ex | 544 (40.8) | 391 (28.6) |
| Never | 465 (34.9) | 662 (48.4) |
| 60-64y | | |
| Current | 97 (11.1) | 105 (11.1) |
| Ex | 410 (47.0) | 322 (34.1) |
| Never | 365 (41.9) | 517 (54.8) |
| 68-69y | | |
| Current | 76 (8.8) | 65 (7.1) |
| Ex | 411 (47.8) | 314 (34.2) |
| Never | 373 (43.4) | 538 (58.7) |
| **Leisure time physical activity, N (%), at age:** | | |
| 36y | | |
| Inactive | 475 (30.8) | 651 (41.9) |
| Less active | 407 (26.4) | 376 (24.2) |

| | | | |
|---|---|---|---|
| | Most active | 658 (42.7) | 526 (33.9) |
| 43y | | | |
| | Inactive | 714 (48.2) | 805 (55.3) |
| | Less active | 354 (23.9) | 338 (23.2) |
| | Most active | 415 (28.0) | 314 (21.6) |
| 53y | | | |
| | Inactive | 627 (47.1) | 689 (50.4) |
| | Less active | 252 (18.9) | 227 (16.6) |
| | Most active | 453 (34.0) | 452 (33.0) |
| 60-64y | | | |
| | Inactive | 557 (63.9) | 585 (62.0) |
| | Less active | 118 (13.5) | 142 (15.0) |
| | Most active | 197 (22.6) | 217 (23.0) |
| 68-69y | | | |
| | Inactive | 491 (57.1) | 520 (56.7) |
| | Less active | 101 (11.7) | 141 (15.4) |
| | Most active | 268 (31.2) | 256 (27.9) |
| **Symptoms of anxiety and depression, N(%), at age:** | | | |
| 36y | | | |
| | No | 1482 (96.2) | 1420 (91.4) |
| | Yes | 58 (3.8) | 133 (8.6) |
| 43y | | | |
| | No | 1350 (91.0) | 1233 (84.6) |
| | Yes | 133 (9.0) | 224 (15.4) |
| 53y | | | |
| | No | 1147 (86.1) | 1035 (75.7) |
| | Yes | 185 (13.9) | 333 (24.3) |
| 60-64y | | | |
| | No | 765 (87.7) | 739 (78.3) |
| | Yes | 107 (12.3) | 205 (21.7) |
| 69y | | | |
| | No | 781 (90.8) | 764 (83.3) |
| | Yes | 79 (9.2) | 153 (16.7) |

SD: Standard Deviation; y: years

[a] Maximum N=3426 (this includes participants with a valid measure of back pain, BMI, waist circumference and each covariate for at least one age)

[b] See number of participants with valid data at specified age in Supplementary Table S1

**Table S3: Coefficients from the multilevel models for BMI and waist circumference with back pain across adulthood (N=3426)**

| | BMI | | | |
|---|---|---|---|---|
| | Model 1 | | Model 2[a] | |
| | Log-odds (SE) | P value | Log-odds (SE) | P value |
| BMI (per SD) | 0.119 (0.071) | 0.03 | 0.112 (0.056) | 0.05 |
| Sex (female) | 0.221 (0.072) | 0.002 | 0.500 (0.102) | <0.001 |
| Age 43 | 0.683 (0.073) | <0.001 | 0.674 (0.074) | <0.001 |
| Age 53 | 1.008 (0.074) | <0.001 | 0.993 (0.076) | <0.001 |
| Age 60-64 | 0.869 (0.083) | <0.001 | 0.895 (0.087) | <0.001 |
| Age 68 | 0.786 (0.084) | <0.001 | 0.876 (0.088) | <0.001 |
| Age 43*BMI | -0.019 (0.071) | 0.8 | -0.009 (0.071) | 0.9 |
| Age 53*BMI | 0.037 (0.072) | 0.5 | 0.045 (0.072) | 0.5 |
| Age 60-64*BMI | 0.148 (0.082) | 0.07 | 0.148 (0.081) | 0.07 |
| Age 68*BMI | -0.040 (0.084) | 0.6 | -0.046 (0.084) | 0.6 |

| | Waist circumference | | | |
|---|---|---|---|---|
| | Model 1 | | Model 2[a] | |
| | Log-odds (SE) | P value | Log-odds (SE) | P value |
| WC (per SD) | 0.160 (0.057) | 0.005 | 0.129 (0.057) | 0.02 |
| Sex (female) | 0.221 (0.071) | 0.002 | 0.442 (0.102) | <0.001 |
| Age 43 | 0.684 (0.073) | <0.001 | 0.674 (0.074) | <0.001 |
| Age 53 | 1.010 (0.074) | <0.001 | 0.990 (0.076) | <0.001 |
| Age 60-64 | 0.875 (0.083) | <0.001 | 0.896 (0.087) | <0.001 |
| Age 68 | 0.787 (0.084) | <0.001 | 0.867 (0.088) | <0.001 |
| Age 43*WC | -0.048 (0.072) | 0.5 | -0.049 (0.072) | 0.5 |
| Age 53*WC | -0.011 (0.073) | 0.9 | -0.009 (0.073) | 0.9 |
| Age 60-64*WC | 0.076 (0.083) | 0.4 | 0.063 (0.083) | 0.5 |
| Age 68*WC | -0.050 (0.084) | 0.6 | -0.058 (0.084) | 0.5 |

*Note.* BMI: body mass index; WC: waist circumference; SE: standard error; SD: Standard Deviation;

[a] Model 2: model 1 + education, occupational class and time-varying covariates (height, cigarette smoking status, physical activity and symptoms of anxiety and depression)

**Table S4: Associations between body composition measures[a] at age 60-64 and back pain at age 68 (n=1186)**

| Sex-standardised body composition measures | Model 1[b] Odds ratio (95%CI) | Model 1[b] P value | Model 2[c] Odds ratio (95%CI) | Model 2[c] P value |
|---|---|---|---|---|
| Lean mass index | 0.93 (0.79, 1.10) | 0.4 | 0.91 (0.77, 1.08) | 0.3 |
| Fat mass index | 1.23 (1.04, 1.45) | 0.01 | 1.24 (1.04, 1.47) | 0.02 |

[a]Assessment of body composition measures has been described in detail by Bann et al[1]

[b] Model 1: includes sex, lean mass index and fat mass index

[c] Model 2: model 1 + education at age 26, occupational class at age 53 and the following covariates (assessed at age 60-64): height, cigarette smoking status, physical activity and symptoms of anxiety and depression

## References

1. Bann D, Kuh D, Wills AK, et al. Physical activity across adulthood in relation to fat and lean body mass in early old age: Findings from the Medical Research Council National Survey of Health and Development, 1946–2010. *Am J Epidemiol.* 2014;179:1197-207.

**STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cohort studies***
**Checklist completed for: Do the associations of body mass index and waist circumference with back pain change as people age? 32 years of follow-up in a British birth cohort**

| Section/Topic | Item # | Recommendation | Reported on page # |
|---|---|---|---|
| **Title and abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract | 1; 2 |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | 2 |
| **Introduction** | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | 4-5 |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | 5 |
| **Methods** | | | |
| Study design | 4 | Present key elements of study design early in the paper | 5-9 |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 5-6 |
| Participants | 6 | (*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up | 5-9 |
| | | (*b*) For matched studies, give matching criteria and number of exposed and unexposed | n/a |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 6-8 |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 6-8 |
| Bias | 9 | Describe any efforts to address potential sources of bias | 8-9 |
| Study size | 10 | Explain how the study size was arrived at | 9, Table S1 |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 6-8, Table 1, Table S2 |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | 8-9 |
| | | (*b*) Describe any methods used to examine subgroups and interactions | 8-9 |
| | | (*c*) Explain how missing data were addressed | 8-9, table S1 |
| | | (*d*) If applicable, explain how loss to follow-up was addressed | n/a |

| | | | |
|---|---|---|---|
| | | (*e*) Describe any sensitivity analyses | 9 |
| **Results** | | | |
| Participants | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed | 5, 9 |
| | | (b) Give reasons for non-participation at each stage | 5 |
| | | (c) Consider use of a flow diagram | See Stafford et al 2013 |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | Table 1 and Table S2 |
| | | (b) Indicate number of participants with missing data for each variable of interest | Table S1 and Table S2 |
| | | (c) Summarise follow-up time (eg, average and total amount) | n/a |
| Outcome data | 15* | Report numbers of outcome events or summary measures over time | Tables |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | 9-11, Tables 2-3 |
| | | (*b*) Report category boundaries when continuous variables were categorized | Tables 1-3 |
| | | (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | - |
| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses | 9 |
| **Discussion** | | | |
| Key results | 18 | Summarise key results with reference to study objectives | 11 |
| **Limitations** | | | |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 11-13 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | 13 |
| **Other information** | | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based | 18 |

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

# Do the associations of body mass index and waist circumference with back pain change as people age? 32 years of follow-up in a British birth cohort

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| Keywords: | Back pain < ORTHOPAEDIC & TRAUMA SURGERY, EPIDEMIOLOGY, PUBLIC HEALTH |
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# Do the associations of body mass index and waist circumference with back pain change as people age? 32 years of follow-up in a British birth cohort

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**Word count (main text):** 3282

**Key words:** back pain; obesity; adiposity; birth cohort; ageing

## Contributors

SGM and RH had full access to all the data in the study and take full responsibility for the integrity and the accuracy of data analysis. SGM, DK, and RC conceived the idea for this study; SGM, DK, RH and RC contributed to the development of the study objectives; DK, RH and RC acquired the data; SGM and RH analysed the data; SGM and RH drafted the manuscript; all authors contributed to the manuscript's critical revision and provided final approval of the version to be published.

**Abstract**

**Objectives:** To investigate whether cross-sectional and longitudinal associations of body mass index (BMI) and waist circumference (WC) with back pain change with age and extend into later life.

**Design:** British birth cohort study

**Setting:** England, Scotland and Wales

**Participants:** Up to 3426 men and women from the MRC National Survey of Health and Development

**Primary outcome measures:** Back pain (sciatica, lumbago, or recurring/severe backache all or most of the time) was self-reported during nurse interviews at ages 36, 43, 53 and 60-64 years and in a postal questionnaire using a body manikin at age 68.

**Results:** Findings from mixed-effects logistic regression models indicated that higher BMI was consistently associated with increased odds of back pain across adulthood. Sex-adjusted odds ratios of back pain per 1 standard deviation increase in BMI were: 1.13 (95% CI 1.01, 1.26), 1.11 (95% CI 1.00, 1.23), 1.17 (95% CI 1.05, 1.30), 1.31 (95% CI 1.15, 1.48) and 1.08 (95% CI 0.95, 1.24) at ages 36, 43, 53, 60-64 and 68-69, respectively. Similar patterns of associations were observed for WC. These associations were maintained when potential confounders, including education, occupational class, height, cigarette smoking status, physical activity and symptoms of anxiety and depression were accounted for. BMI showed stronger associations than WC in models including both measures.

**Conclusions:** These findings demonstrate that higher BMI is a persistent risk factor for back pain across adulthood. This highlights the potential lifelong consequences on back pain of the rising prevalence of obesity within the population.

## Article summary

### Strengths and limitations of this study

- The availability of data on back pain, body mass index (BMI) and waist circumference (WC) prospectively ascertained over 32 years of follow-up in a large representative population-based sample is a key and unique strength of this study.
- This allowed us to formally test whether the cross-sectional and longitudinal relationships of BMI and WC with back pain change with age, extend into later life and are independent of each other so addressing important gaps in our current understanding.
- As back pain was not assessed in exactly the same way at different time points across adulthood, timing of onset of pain was not recorded and severity and chronicity were not distinguished results need to be interpreted with some caution.
- Residual confounding cannot be fully ruled out as a potential explanation of our findings however, the risk of this has been minimised by taking account of a wide range of potential confounders measured prospectively across adulthood.
- Cross-sectional associations between body size and back pain may be explained by reverse causality, but we also investigated longitudinal associations between BMI and back pain and our conclusions remained unchanged.

## Introduction

Back pain is one of the most commonly reported musculoskeletal disorders and was recently ranked as the number one cause of disability in most countries worldwide.[1] As it is a major cause of activity limitation and functional decline in later life[2-8] the fact that its prevalence is projected to increase as population ageing continues is a considerable cause for concern. As a result, there have been calls to intensify research efforts to address the public health challenge of the burden of low back pain.[9]

Obesity, usually indicated by high body mass index (BMI), has been identified as an important risk factor for back pain (typically self-reported during a structured interview or self-completion questionnaire).[10-14] However, the majority of existing studies have examined cross-sectional associations at a single time-point, often in early or mid-adulthood[10, 13-19] and/or are in occupational-based cohorts.[10] There are few studies on obesity and back pain in older populations. This is despite evidence to suggest that the aetiology of back pain may change with age as degenerative back disorders become increasingly common; these disorders may have different risk factors to conditions that precipitate back pain earlier in life. This is coupled with reduced pain-modulatory capacity occurring with advancing age partly explaining increases in persistent and disabling pain conditions among older adults.[20] In one study of older populations (age >50 years) from nine countries, high BMI was associated with increased odds of back pain, assessed during an interview using a simple question on experience of back pain in the last 30 days, in European countries (Poland, Russia, Finland, Spain) and South Africa.[21] However, whether or not the associations found among these older adults were weaker, due to potential changes in the underlying aetiology of back pain, or of similar strength to those that would have been observed in these populations if they had been assessed at younger ages could not be established. To our knowledge, no study has formally investigated whether the association between BMI and back pain changes with age; thus whether or not obesity remains a suitable target for intervention for the prevention of back pain into later life, alongside the important role of interventions targeting obesity to prevent many other chronic conditions, remains to be established.

Higher central adiposity, as well as higher BMI, has been related to increased risk of back pain[12, 15-19, 22] and may be more indicative of inflammatory processes due to increases in fat mass. Despite this, few studies[22] have compared the strength of associations between BMI and abdominal adiposity or tested whether there is any additional effect of abdominal adiposity over and above BMI. This could provide new aetiological insights to help inform the development of interventions to prevent or alleviate back pain.

The MRC National Survey of Health and Development (NSHD), the oldest of the British birth cohort studies, has assessed BMI, waist circumference (WC) and back pain at multiple time points across adulthood from midlife up to age 69. We therefore address important research gaps by first examining whether the cross-sectional relationships of BMI and WC with back pain change with age, extend into later life and are independent of each other. We then assess the prospective associations of BMI and WC with back pain at the subsequent age to assess the extent to which patterns of association with age may be affected by reverse causality.

**Subjects and Methods**

The NSHD is a socially stratified sample of 5362 single, legitimate births that occurred in England, Wales and Scotland in one week of March 1946. To date the same participants have been assessed on up to 24 occasions between birth and age 69, with participation rates remaining relatively high (i.e. >80% of eligible sample responding) across life.[23-25] All waves of data collection have complied with ethical standards. Ethical approval for the most recent data collection at age 68-69 was obtained from the Queen Square Research Ethics Committee (14/LO/1073) and the Scotland A Research Ethics Committee (14/SS/1009). All methods were carried out in accordance with the relevant guidelines and regulations and written informed consent was obtained.

*Patient and public involvement*

Over the 74 years of this study, the research has increasingly involved participants, in line with changing norms about conducting cohort studies. Participant involvement includes receiving personal letters from the research team as required, and invitations to participate in birthday celebrations, public engagement activities and focus groups to discuss future data collections. When piloting new questionnaires and assessments, including the most recent of those used in these analyses, patients from general practices and the University College London Hospitals Patient Public Involvement group were recruited and asked to provide feedback which was taken into account when designing the mainstage fieldwork.

*Back pain assessment*

Back pain was ascertained during five of the main assessments of NSHD participants via structured nurse interviews at ages 36, 43, 53 and 60-64 and in a postal questionnaire at age 68 (see Supplementary Methods for questions used). At all ages except age 68, participants were asked whether they had sciatica, lumbago, or recurring/severe backache all or most of the time (ever at ages 36 and 43 and in the previous 12 months at ages 53 and 60-64). At age 68, participants were asked whether they had experienced any ache or pain in the previous month which had lasted for one day or longer, not including pain occurring during the course of a feverish illness such as flu. Those who responded positively were asked to shade the location of their pain using a four-view body manikin. Those who shaded any back site were classified as having back pain for the purposes of these analyses.

*Anthropometric measurements*

Height, weight and waist circumference (taken at the midpoint between the costal margin and iliac crest) were measured by nurses using standardised protocols at ages 36, 43, 53, 60-64 and 69 years. BMI was calculated at each age as weight (kg)/height (m)$^2$. BMI and waist circumference at each age were sex-standardised (to a mean of 0 and standard deviation (SD) of 1 (calculated as ($x$-mean$_i$)/SD$_j$ where $x$ is the raw measure and mean$j$ and SD$j$ are the sample mean and SD for sex $j$); our units of analysis for BMI and waist circumference are both 1SD to facilitate comparisons of effect sizes across age and sex.

*Fat and lean mass at 60-64 years*

Measures of body composition were obtained in participants who attended one of six Clinical Research facilities when aged 60-64 years using a QDR 4500 Discovery DXA scanner (Hologic Inc, Bedford, MA, USA) whilst the individuals were in a supine position. Whole body fat mass was measured and whole body lean mass was calculated as total mass minus fat and bone mass. Mass from the head was excluded and measures were converted to kg. Full details are provided elsewhere.[26] Fat mass index (kg/m$^2$) and lean mass index (kg/m$^2$) were calculated by dividing the measures of mass by height-squared.

*Covariates*

Covariates representing different domains of the biopsychosocial model of pain were selected *a priori*.[27] This included variables that have previously been identified as key risk factors for back pain and could potentially confound the main associations.[28-30] These were sex, educational attainment at age 26, occupational class at age 53 and measures of height, smoking status, physical activity, and symptoms of anxiety and depression, which were available at ages 36, 43, 53, 60-64 and 68-69 and so included as time varying covariates.

The highest education level achieved by age 26 was grouped into no qualifications, up to O-level or equivalent, or A-level or equivalent and above. Own occupation at age 53 was categorised according to the Registrar General's social classification into three groups: high (I or II: professional, managerial or technical); middle (IIINM skilled non-manual or IIIM: skilled manual); low (IV or V: partly skilled or unskilled manual).

Smoking status was assessed by self-report at each wave and categorised as never, ex and current smoker. Participation in sports, vigorous leisure activities or exercise was assessed at each wave and participants were grouped as inactive, moderately active (1-4 times/month) or regularly active (≥5 times/month).[31]

Symptoms of anxiety and depression were also assessed at all five waves. At age 36, a shortened version of the Present State Examination[32] was used at a nurse interview and the total score was recoded to a binary variable using the recommended threshold for caseness of 5 or more. At age 43, participants completed the 18-item Psychiatric Symptom Frequency (PSF) scale[33] and the total score was calculated and then dichotomised into absence of symptoms (PSF score <23) and presence of symptoms (PSF score ≥23). At ages 53, 60-64 and 68/69 the 28-item General Health Questionnaire (GHQ-28)[34] was self-administered and scores for all items were summed and further dichotomised using a recommended threshold for caseness of 5 or more.

*Statistical analysis*

We first examined descriptive statistics for each variable and formally tested sex differences in their distributions using chi-squared and t-tests as appropriate.

Multilevel mixed-effects logistic regression models with a random intercept were then used to test associations between BMI and back pain with measurement occasion nested within individuals. These models allow for the correlation between measurements on the same individual. We fitted measurement wave as a categorical variable with age 36 as the reference category and adjusted for sex. Interactions between wave and sex were tested in the model however, as there was no evidence of interactions these were removed in subsequent models. We then added BMI as a time varying covariate. Formal assessment of whether associations between BMI and back pain varied by sex were performed by including sex by BMI interaction terms in models and where no evidence of interaction was found models were sex-adjusted. Deviations from linearity were assessed by including quadratic terms for BMI but no evidence of this was found. To assess whether the association of BMI with back pain changed with age, interactions between wave and BMI were included (Model 1). The model was then adjusted for potential confounding variables (Model 2). Analyses were repeated replacing BMI with WC and then a final confounder adjusted model was run in which BMI and WC were included together. All models included the maximum number of participants, which was those participants with a valid measure of back pain, BMI, WC and all covariates for at least one age (n=3426) (see table S1 for number of participants who contributed data at each wave).

We then repeated the same modelling approach to assess prospective associations between BMI, WC and back pain. To achieve this, we used back pain at 43, 53, 60-64 and 68 as outcomes and related them to BMI and WC at the prior age (i.e. at ages 36, 43, 53 and 60-64). These models included a sample size of 3044.

Finally, in the sub-sample with body composition measures at age 60-64 (n=1186) supplementary analyses using multiple regression models, assessed the associations between fat mass index and lean mass index at 60-64 years and back pain at 68 years. Model 1 included sex and both body composition measures and model 2 added the same covariates used in previous models.

All analyses were performed using STATA version 14.1.

**Results**

The characteristics of the study sample are shown in Table 1 (and Table S2). Overall, the percentage reporting back pain varied from 17.9% and 32.3% and was higher in women than men at every age (Table 1).

There was no evidence of an interaction between sex and either BMI (p=0.2) or waist circumference (p=0.9) and so the main models were sex-adjusted. In sex-adjusted models, higher BMI was associated with increased odds of back pain at every age (Table 2). Sex-adjusted odds ratios (ORs) of back pain per 1SD increase in BMI estimated from this model were 1.13 (95% CI 1.01, 1.26), 1.11 (95% CI 1.00, 1.23), 1.17 (95% CI 1.05, 1.30), 1.31 (95% CI 1.15, 1.48) and 1.08 (95% CI 0.95, 1.24) at ages 36, 43, 53, 60-64 and 68-69, respectively. There was no evidence of a difference in association between age 36 and ages 43, 53, or 68 (wave by BMI interactions p>0.5) and only weak evidence that the association at age 60-64 was stronger than at age 36 (age 60-64 wave by BMI interaction: p=0.07) (Supplementary Table S3). Adjustment for potential confounders had minimal impact on these findings and estimated ORs for each age remained similar (Table 2).

A similar, and slightly less variable, pattern of association was observed for WC, with no evidence that the association at age 60-64 was stronger than at other ages (wave by BMI interaction: p=0.2) (Table 2, Supplementary Table S3). Adjustment for potential confounders attenuated all ORs somewhat, and to a greater extent than the ORs for BMI (Table 2).

Including both BMI and WC in the same fully adjusted model with all age interaction terms led to inflated standard errors. We therefore included only the age 60-64 wave by BMI and the age 60-64 wave by WC interaction, finding stronger evidence of the interaction with BMI. Our final fully adjusted model thus included only the interaction between BMI and age 60-64; the association of BMI with back pain (OR per SD (95% CI): 1.11 (0.99, 1.24) at 36, 43, 53 and 68-69y and 1.28 (1.09,1.50) at 60-64y) was stronger than that for WC (OR per SD (95% CI): 1.02 (0.91,1.13)) at all ages.

Findings for both BMI and WC were very similar in the longitudinal analysis, when relating the body size measure at the prior age to subsequent back pain (Table 3). In supplementary analyses (n=1186), higher fat mass index was associated with higher odds of back pain at age 68 (OR per SD (95% CI): 1.23 (1.04, 1.45)) in a model adjusting for sex and lean mass index, but no association was observed for lean mass index (Supplementary Table S4). The association with fat mass index was maintained after adjustment for other potential confounders.

**Discussion**

In a large nationally representative British birth cohort higher BMI and WC were consistently associated with increased odds of back pain between ages 36 and 68. These associations were maintained after adjustment for confounders and, BMI remained more strongly related to back pain than WC in a model including both variables. Findings were similar when prospective associations were investigated for back pain between 43 and 68.

Our findings are consistent with previous studies which have reported associations between overweight and obesity, indicated by high BMI, and increased odds of back pain.[10] Findings from cross-sectional studies also suggest positive associations between higher WC and low back pain in women, but not in men.[12, 15-19] These previous studies have sampled participants across a range of different ages (15 years and older) and although they have adjusted for age, none has examined whether associations of BMI and WC with back pain vary with age or whether associations remain into older age. Our study shows persisting associations of BMI and WC with back pain until age 68 years with little evidence of variation with age.

Another key finding is that BMI exhibited a stronger association than WC in a model including both measures. This suggests that mechanisms specifically related to central adiposity do not fully underlie the associations observed. This contrasts with a previous study in young adults (age 24-39 years) which found that WC but not BMI remained associated with back pain in mutually adjusted models in women only.[15] Our findings in relation to fat and lean mass suggest that associations with BMI may be driven by whole body fat mass, rather than abdominal fat mass specifically. In testing these associations we are addressing the call made in a recent systematic review for further high-quality studies on the relationships of body composition with pain.[35] Our findings are consistent with a prospective study[12] included in this review that found evidence that fat mass was associated with low back pain intensity and disability in both sexes. Likewise, a cross-sectional study found that higher fat mass (independent of lean mass) was associated with higher levels of low back pain intensity and disability but found no relationship with lean mass after adjusting for fat mass.[11] The stronger associations with BMI than WC may point to the importance of mechanical effects, with increased BMI resulting in higher compressive force on the spine during activity.[10] However, we cannot rule out the fact that chronic inflammatory or metabolic pathways may also be relevant. For example, atherosclerosis and chronic inflammation, which are linked to obesity, have also been associated with disc degeneration and low back pain.[36, 37]

A key strength of our study is the large representative population-based sample of adults with assessments of back pain and measured height, weight and waist circumference at five time points over 32 years of follow-up. We assessed back pain using simple questions asked during structured nurse interviews and in a self-completed questionnaire which are commonly used methods in population-based studies of back pain.[10-14, 21] The prevalence estimates of back pain in our study at different ages were comparable to those reported in other studies,[2] and we were able to show that associations with BMI are consistent across adulthood and persist into old age. Another strength is the availability of data on a wide range of potential confounders measured prospectively across adulthood that allowed us to adjust for a range of time-varying covariates and reduce the risk of residual confounding.

Alongside key strengths, our results need interpreting in the context of a number of potential limitations. Firstly, while our study population were selected to be nationally representative at birth and due to high participation rates across life have remained so in many respects,[23-25] bias may have been introduced due to the necessary exclusion of all those lost to follow-up before age 36 and/or with missing data on back pain, body size and covariates at all 5 waves. Secondly, cross-sectional associations observed between body size and back pain may be at least partly explained by reverse causality, especially at the latest wave when back pain was measured at age 68 years, a year prior to the assessment of body size due to the design of the data collection at age 68-69 years. However, we also investigated associations between back pain and BMI measured at a prior age and findings remained unchanged. A third potential limitation, relating to the fact that our analyses are post-hoc i.e. data are drawn from a large population-based study designed to capture information on a wide range of different measures of health and their risk factors across life rather than to address this specific research question, is that back pain was not assessed in exactly the same way at different time points across adulthood. In addition, it was not possible to establish the severity and chronicity of back pain, and the validity of the back pain assessments used has not been evaluated. Finally, our study population comprised Caucasian men and women born in Britain in 1946. While this allows us to rule out confounding by age or ethnicity as potential explanations of our findings, it may limit their generalisability. Further research is thus necessary to consider the implications of these findings for more ethnically diverse cohorts and also more recently born cohorts, the latter who are likely to have spent more of their lives overweight or obese.[38]

In summary, our findings suggest that there is a consistent relationship between higher adiposity and back pain across adulthood. Our results also show that WC does not add further information once BMI has been accounted for in this relationship. This underscores the importance of primary and secondary interventions to prevent excessive weight gain and reduce overweight and obesity across the whole of adulthood in order to help prevent back pain and its disabling consequences as individuals age.

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**Competing interests**

The authors declare no financial or non-financial competing interests

**Data sharing statement**

Data used in this publication are available to bona fide researchers upon request to the NSHD Data Sharing Committee via a standard application procedure. Further details can be found at http://www.nshd.mrc.ac.uk/data. doi: 10.5522/NSHD/Q101; doi: 10.5522/NSHD/Q102; 10.5522/NSHD/Q103

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**Table 1: Characteristics of the MRC National Survey of Health and Development sample included in analysis [a]**

| | | Male | Female | p-value[b] |
|---|---|---|---|---|
| **Back pain, N (%), at age:** | | | | |
| 36y | | | | .08 |
| | No | 1283 (83.3) | 1256 (80.9) | |
| | Yes | 257 (16.7) | 297 (19.1) | |
| 43y | | | | .06 |
| | No | 1106 (74.6) | 1042 (71.5) | |
| | Yes | 377 (25.4) | 415 (28.6) | |
| 53y | | | | .06 |
| | No | 925 (69.4) | 903 (66.0) | |
| | Yes | 407 (30.6) | 465 (34.0) | |
| 60-64y | | | | .06 |
| | No | 629 (72.1) | 643 (68.1) | |
| | Yes | 243 (27.9) | 301 (31.9) | |
| 68y | | | | .02 |
| | No | 637 (74.1) | 635 (69.2) | |
| | Yes | 223 (25.9) | 282 (30.8) | |
| **BMI (kg/m$^2$), mean (SD), at age:** | | | | |
| 36y | | 24.8 (3.3) | 23.5 (4.1) | <.001 |
| 43y | | 25.7 (3.5) | 25.1 (4.7) | <.001 |
| 53y | | 27.4 (4.1) | 27.4 (5.4) | .85 |
| 60-64y | | 27.9 (4.1) | 27.9 (5.5) | .99 |
| 69y | | 28.1 (4.5) | 28.0 (5.6) | .93 |
| **Waist circumference (cm), mean (SD), at age:** | | | | |
| 36y | | 89.5 (9.3) | 76.9 (11.5) | <.001 |
| 43y | | 91.8 (9.9) | 77.7 (11.2) | <.001 |
| 53y | | 97.7 (10.9) | 85.8 (12.8) | <.001 |
| 60-64y | | 100.8 (11.1) | 92.2 (13.0) | <.001 |
| 69y | | 100.9 (12.3) | 92.1 (14.0) | <.001 |

*Note.* BMI: body mass index; WC: waist circumference; SD: Standard Deviation; y: years

[a] Maximum N=3426 (1723 males and 1703 females) (this includes participants with a valid measure of back pain, BMI, waist circumference and each covariate for at least one age). Number of participants contributing data at each age: 36y, N=3093; 43y, N=2940; 53y, N=2700; 60-64y, N=1816; 68-69y, N=1777 (see Supplementary table S1 for more details)

[b] p-values from formal tests of sex differences using chi-squared and t-tests as appropriate

**Table 2: Odds Ratios (OR) of back pain at each age per 1 standard deviation increases in BMI and waist circumference at the same age estimated from multilevel logistic models (12 326 observations nested within 3426 individuals)**

| | BMI | | | |
|---|---|---|---|---|
| | Model 1[a] | | Model 2[b] | |
| Per SD BMI at: | OR (95% CI) | P value | OR (95% CI) | P value |
| 36y | 1.13 (1.01 , 1.26) | 0.03 | 1.12 (1.00,1.25) | 0.05 |
| 43y | 1.11 (1.00 , 1.23) | 0.06 | 1.11 (1.00,1.23) | 0.05 |
| 53y | 1.17 (1.05 , 1.30) | 0.003 | 1.17 (1.05,1.30) | 0.003 |
| 60-64y | 1.31 (1.15 , 1.48) | <0.001 | 1.30 (1.14,1.47) | <0.001 |
| 68y | 1.08 (0.95 , 1.24) | 0.2 | 1.07 (0.94,1.22) | 0.3 |
| | Waist circumference | | | |
| | Model 1[a] | | Model 2[b] | |
| Per SD WC at: | OR (95% CI) | P value | OR (95% CI) | P value |
| 36y | 1.17 (1.05 , 1.31) | 0.005 | 1.14 (1.02,1.27) | 0.02 |
| 43y | 1.12 (1.01 , 1.24) | 0.03 | 1.08 (0.98,1.20) | 0.1 |
| 53y | 1.16 (1.05 , 1.29) | 0.005 | 1.13 (1.02,1.25) | 0.03 |
| 60-64y | 1.27 (1.12 , 1.44) | <0.001 | 1.21 (1.07,1.38) | 0.003 |
| 68y | 1.12 (0.98 , 1.27) | 0.1 | 1.07 (0.94,1.22) | 0.3 |

*Note.* BMI: body mass index; SD: Standard Deviation; OR: Odds Ratio; y: years

Please see Table S5 for results from analyses rerun with BMI and WC modelled in raw units, i.e. $kg/m^2$ and cm, respectively

[a] Model 1: Includes age as a categorical variable, standardised BMI or WC (mean=0, SD=1) and an age by BMI or age by WC interaction (as appropriate), adjusted for sex (as there was no evidence of a sex by BMI (p=0.2) or a sex by WC (p=0.9) interaction)

[b] Model 2: Includes age as a categorical variable, standardised BMI or WC (mean=0, SD=1) and an age by BMI or age by WC interaction (as appropriate), adjusted for sex, education, occupational class and time-varying covariates (height, cigarette smoking status, physical activity and symptoms of anxiety and depression)

**Table 3: Odds Ratios (OR) of back pain at each age per 1 standard deviation increase in BMI and waist circumference at the previous age estimated from multilevel logistic models (8 595 observations nested within 3044 individuals)**

| | | BMI | | | |
|---|---|---|---|---|---|
| | | Model 1[a] | | Model 2[b] | |
| Per SD BMI/WC at age: | Back pain at age: | OR (95% CI) | P value | OR (95% CI) | P value |
| 36y | 43y | 1.08 (0.97 , 1.20) | 0.2 | 1.06 (0.96,1.18) | 0.3 |
| 43y | 53y | 1.17 (1.05 , 1.31) | 0.004 | 1.16 (1.04,1.29) | 0.009 |
| 53y | 60-64y | 1.32 (1.15 , 1.51) | <0.001 | 1.29 (1.13,1.48) | <0.001 |
| 60-64y | 68y | 1.11 (0.96 , 1.28) | 0.2 | 1.08 (0.94,1.25) | 0.3 |
| | | Waist circumference | | | |
| | | Model 1[a] | | Model 2[b] | |
| | | OR (95% CI) | P value | OR (95% CI) | P value |
| 36y | 43y | 1.12 (1.01 , 1.24) | 0.04 | 1.08 (0.97,1.21) | 0.1 |
| 43y | 53y | 1.17 (1.05 , 1.30) | 0.004 | 1.14 (1.02,1.26) | 0.02 |
| 53y | 60-64y | 1.28 (1.12 , 1.47) | <0.001 | 1.23 (1.07,1.40) | 0.003 |
| 60-64y | 68y | 1.10 (0.96 , 1.26) | 0.2 | 1.06 (0.92,1.21) | 0.4 |

*Note.* BMI: body mass index; SD: Standard Deviation; OR: Odds Ratio; y: years

Please see Table S6 for results from analyses rerun with BMI and WC modelled in raw units, i.e. kg/m$^2$ and cm, respectively

[a] Model 1: Includes age as a categorical variable, standardised BMI or WC (mean=0, SD=1) and an age by BMI or age by WC interaction (as appropriate), adjusted for sex (as there was no evidence of a sex by BMI (p=0.5) or a sex by WC (p=0.9) interaction)

[b] Model 2: Includes age as a categorical variable, standardised BMI or WC (mean=0, SD=1) and an age by BMI or age by WC interaction (as appropriate), adjusted for sex, education, occupational class and time-varying covariates (height, cigarette smoking status, physical activity and symptoms of anxiety and depression)

**Supplementary information: Do the associations of body mass index and waist circumference with back pain change as people age? 32 years of follow-up in a British birth cohort**

Stella G Muthuri, Rachel Cooper, Diana Kuh & Rebecca Hardy

**Supplementary methods:**

**Questions used to assess back pain in the MRC National Survey of Health and Development**

***Ages 36 and 43 years [nurse interviews]:***

Do you have any of the following (sciatica, lumbago or recurring backache) all or most of the time?

0 No

1 Yes

***Ages 53 and 60-64 years [nurse interviews]:***

In the last 12 months, have you had sciatica, lumbago or severe backache?

0 No

1 Yes

***Age 68 years [self-completion questionnaire]:***

In the *last month,* have you had any ache or pain which has lasted for *one day or longer*? (Please do not include pain occurring only during the course of a feverish illness such as flu)

0 No

1 Yes

Below you will find four diagrams of the body.

Please **shade** in all the places where you have felt or feel the aches and pains.

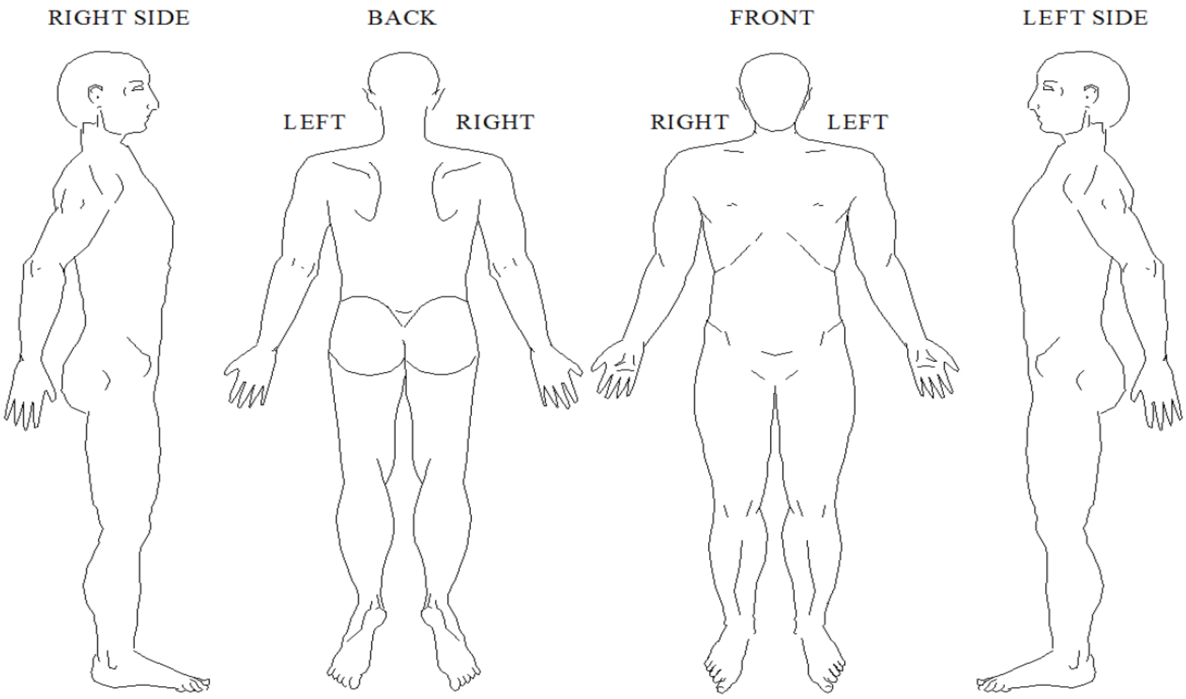

**Table S1: Number of MRC National Survey of Health and Development participants contributing data at each age and number with missing data[a]**

| Age | Total N contributing data at specified age (no. of males; no. of females) | N with data on back pain but missing data on BMI/WC at specified age | N with data on back pain and BMI/WC at specified age but missing data on covariates |
|---|---|---|---|
| 36y | 3093 (1540; 1553) | 48 | 175 |
| 43y | 2940 (1483; 1457) | 52 | 259 |
| 53y | 2700 (1332; 1368) | 44 | 243 |
| 60-64y | 1816 (872; 944) | 29 | 390 |
| 68-69y | 1777 (860; 917) | 485 | 158 |

[a] A total of 3426 MRC NSHD participants were included in the main analyses. Participant's data could be included at a specified age if there was complete information on back pain, BMI, waist circumference and all covariates at that age
BMI: Body mass index; WC: waist circumference

**Table S2: Characteristics of the MRC National Survey of Health and Development sample included in analysis [a]**

| | Male | Female |
|---|---|---|
| **Highest education level achieved by age 26y, N (%)** | | |
| A-level/equivalent or above | 706 (41.0) | 463 (27.2) |
| O-level/equivalent or below | 357 (20.7) | 587 (34.5) |
| None | 660 (38.3) | 653 (38.3) |
| **Own occupational class at age 53y, N (%)** | | |
| High (I/II) | 853 (49.5) | 593 (34.8) |
| Middle (IIINM/IIIM) | 662 (38.4) | 740 (43.5) |
| Low (IV/V) | 208 (12.1) | 370 (21.7) |
| **Time varying covariates[b]** | | |
| **Height (cm), mean (SD), at age:** | | |
| 36y | 175.4 (6.5) | 162.4 (6.0) |
| 43y | 175.2 (6.6) | 162.4 (6.2) |
| 53y | 174.7 (6.5) | 161.6 (5.9) |
| 60-64y | 174.8 (6.5) | 161.9 (5.9) |
| 69y | 174.0 (6.4) | 160.7 (5.9) |
| **Smoking status, N (%), at age:** | | |
| 36y | | |
| Current | 530 (34.4) | 524 (33.7) |
| Ex | 617 (40.1) | 518 (33.4) |
| Never | 393 (25.5) | 511 (32.9) |
| 43y | | |
| Current | 460 (31.0) | 417 (28.6) |
| Ex | 522 (35.2) | 373 (25.6) |
| Never | 501 (33.8) | 667 (45.8) |
| 53y | | |
| Current | 323 (24.3) | 315 (23.0) |
| Ex | 544 (40.8) | 391 (28.6) |
| Never | 465 (34.9) | 662 (48.4) |
| 60-64y | | |
| Current | 97 (11.1) | 105 (11.1) |
| Ex | 410 (47.0) | 322 (34.1) |
| Never | 365 (41.9) | 517 (54.8) |
| 68-69y | | |
| Current | 76 (8.8) | 65 (7.1) |
| Ex | 411 (47.8) | 314 (34.2) |
| Never | 373 (43.4) | 538 (58.7) |
| **Leisure time physical activity, N (%), at age:** | | |
| 36y | | |
| Inactive | 475 (30.8) | 651 (41.9) |
| Less active | 407 (26.4) | 376 (24.2) |
| Most active | 658 (42.7) | 526 (33.9) |
| 43y | | |

| | | | |
|---|---|---|---|
| | Inactive | 714 (48.2) | 805 (55.3) |
| | Less active | 354 (23.9) | 338 (23.2) |
| | Most active | 415 (28.0) | 314 (21.6) |
| 53y | | | |
| | Inactive | 627 (47.1) | 689 (50.4) |
| | Less active | 252 (18.9) | 227 (16.6) |
| | Most active | 453 (34.0) | 452 (33.0) |
| 60-64y | | | |
| | Inactive | 557 (63.9) | 585 (62.0) |
| | Less active | 118 (13.5) | 142 (15.0) |
| | Most active | 197 (22.6) | 217 (23.0) |
| 68-69y | | | |
| | Inactive | 491 (57.1) | 520 (56.7) |
| | Less active | 101 (11.7) | 141 (15.4) |
| | Most active | 268 (31.2) | 256 (27.9) |
| **Symptoms of anxiety and depression, N(%), at age:** | | | |
| 36y | | | |
| | No | 1482 (96.2) | 1420 (91.4) |
| | Yes | 58 (3.8) | 133 (8.6) |
| 43y | | | |
| | No | 1350 (91.0) | 1233 (84.6) |
| | Yes | 133 (9.0) | 224 (15.4) |
| 53y | | | |
| | No | 1147 (86.1) | 1035 (75.7) |
| | Yes | 185 (13.9) | 333 (24.3) |
| 60-64y | | | |
| | No | 765 (87.7) | 739 (78.3) |
| | Yes | 107 (12.3) | 205 (21.7) |
| 69y | | | |
| | No | 781 (90.8) | 764 (83.3) |
| | Yes | 79 (9.2) | 153 (16.7) |

SD: Standard Deviation; y: years

[a] Maximum N=3426 (this includes participants with a valid measure of back pain, BMI, waist circumference and each covariate for at least one age)

[b] See number of participants with valid data at specified age in Supplementary Table S1

**Table S3: Coefficients from the multilevel models for standardised BMI and waist circumference with back pain across adulthood (N=3426)**

| | BMI | | | |
|---|---|---|---|---|
| | Model 1 | | Model 2[a] | |
| | Log-odds (SE) | P value | Log-odds (SE) | P value |
| BMI (per SD) | 0.119 (0.071) | 0.03 | 0.112 (0.056) | 0.05 |
| Sex (female) | 0.221 (0.072) | 0.002 | 0.500 (0.102) | <0.001 |
| Age 43 | 0.683 (0.073) | <0.001 | 0.674 (0.074) | <0.001 |
| Age 53 | 1.008 (0.074) | <0.001 | 0.993 (0.076) | <0.001 |
| Age 60-64 | 0.869 (0.083) | <0.001 | 0.895 (0.087) | <0.001 |
| Age 68 | 0.786 (0.084) | <0.001 | 0.876 (0.088) | <0.001 |
| Age 43*BMI | -0.019 (0.071) | 0.8 | -0.009 (0.071) | 0.9 |
| Age 53*BMI | 0.037 (0.072) | 0.5 | 0.045 (0.072) | 0.5 |
| Age 60-64*BMI | 0.148 (0.082) | 0.07 | 0.148 (0.081) | 0.07 |
| Age 68*BMI | -0.040 (0.084) | 0.6 | -0.046 (0.084) | 0.6 |

| | Waist circumference | | | |
|---|---|---|---|---|
| | Model 1 | | Model 2[a] | |
| | Log-odds (SE) | P value | Log-odds (SE) | P value |
| WC (per SD) | 0.160 (0.057) | 0.005 | 0.129 (0.057) | 0.02 |
| Sex (female) | 0.221 (0.071) | 0.002 | 0.442 (0.102) | <0.001 |
| Age 43 | 0.684 (0.073) | <0.001 | 0.674 (0.074) | <0.001 |
| Age 53 | 1.010 (0.074) | <0.001 | 0.990 (0.076) | <0.001 |
| Age 60-64 | 0.875 (0.083) | <0.001 | 0.896 (0.087) | <0.001 |
| Age 68 | 0.787 (0.084) | <0.001 | 0.867 (0.088) | <0.001 |
| Age 43*WC | -0.048 (0.072) | 0.5 | -0.049 (0.072) | 0.5 |
| Age 53*WC | -0.011 (0.073) | 0.9 | -0.009 (0.073) | 0.9 |
| Age 60-64*WC | 0.076 (0.083) | 0.4 | 0.063 (0.083) | 0.5 |
| Age 68*WC | -0.050 (0.084) | 0.6 | -0.058 (0.084) | 0.5 |

*Note.* BMI: body mass index; WC: waist circumference; SE: standard error; SD: Standard Deviation

As BMI and WC are standardised and so have a mean of 0 and SD of 1, the main effects of age represent the estimate at the mean BMI

[a] Model 2: model 1 + education, occupational class and time-varying covariates (height, cigarette smoking status, physical activity and symptoms of anxiety and depression)

**Table S4: Associations between body composition measures[a] at age 60-64 and back pain at age 68 (n=1186)**

| Sex-standardised body composition measures | Model 1[b] Odds ratio (95%CI) | Model 1[b] P value | Model 2[c] Odds ratio (95%CI) | Model 2[c] P value |
|---|---|---|---|---|
| Lean mass index | 0.93 (0.79, 1.10) | 0.4 | 0.91 (0.77, 1.08) | 0.3 |
| Fat mass index | 1.23 (1.04, 1.45) | 0.01 | 1.24 (1.04, 1.47) | 0.02 |

[a]Assessment of body composition measures has been described in detail by Bann et al[1]

[b] Model 1: includes sex, lean mass index and fat mass index

[c] Model 2: model 1 + education at age 26, occupational class at age 53 and the following covariates (assessed at age 60-64): height, cigarette smoking status, physical activity and symptoms of anxiety and depression

**Table S5: Odds Ratios (OR) of back pain at each age per 1 kg/m$^2$ increases in BMI and 1 cm increases in waist circumference at the same age estimated from multilevel logistic models (12 326 observations nested within 3426 individuals)**

| | BMI | | | |
|---|---|---|---|---|
| | Model 1[a] | | Model 2[b] | |
| Per kg/m$^2$ BMI at: | OR (95% CI) | P value | OR (95% CI) | P value |
| 36y | 1.03 (1.00,1.07) | 0.04 | 1.03 (1.00,1.06) | 0.05 |
| 43y | 1.02 (1.00,1.05) | 0.06 | 1.03 (1.00,1.05) | 0.05 |
| 53y | 1.04 (1.01,1.06) | 0.002 | 1.04 (1.01,1.06) | 0.002 |
| 60-64y | 1.06 (1.03,1.08) | <0.001 | 1.05 (1.03,1.08) | <0.001 |
| 68y | 1.02 (0.99,1.04) | 0.2 | 1.02 (0.99,1.04) | 0.2 |
| | Waist circumference | | | |
| | Model 1[a] | | Model 2[b] | |
| Per cm WC at: | OR (95% CI) | P value | OR (95% CI) | P value |
| 36y | 1.014 (1.004,1.023) | 0.005 | 1.011 (1.001,1.020) | 0.03 |
| 43y | 1.011 (1.002,1.020) | 0.01 | 1.008 (0.999,1.017) | 0.07 |
| 53y | 1.013 (1.005,1,021) | 0.002 | 1.011 (1.002,1,019) | 0.01 |
| 60-64y | 1.019 (1.009,1.030) | <0.001 | 1.016 (1.006,1.026) | 0.002 |
| 68y | 1.009 (0.999,1.019) | 0.07 | 1.006 (0.996,1.015) | 0.3 |

*Note.* BMI: body mass index; OR: Odds Ratio; y: years

[a] Model 1: Includes age as a categorical variable, BMI or WC and an age by BMI or age by WC interaction (as appropriate), adjusted for sex (as there was no evidence of a sex by BMI (p=0.5) or sex by WC (p=0.7) interaction)

[b] Model 2: Includes age as a categorical variable, BMI or WC and an age by BMI or age by WC interaction (as appropriate), adjusted for sex, education, occupational class and time-varying covariates (height, cigarette smoking status, physical activity and symptoms of anxiety and depression)

**Table S6: Odds Ratios (OR) of back pain at each age per 1 kg/m$^2$ increase in BMI and 1 cm increase in waist circumference at the previous age estimated from multilevel logistic models (8 595 observations nested within 3044 individuals)**

| | | BMI | | | |
|---|---|---|---|---|---|
| | | Model 1[a] | | Model 2[b] | |
| Per kg/m$^2$ BMI at age: | Back pain at age: | OR (95% CI) | P value | OR (95% CI) | P value |
| 36y | 43y | 1.02 (0.99, 1.05) | 0.1 | 1.02 (0.99, 1.05) | 0.2 |
| 43y | 53y | 1.04 (1.02, 1.07) | 0.002 | 1.04 (1.02, 1.07) | 0.004 |
| 53y | 60-64y | 1.06 (1.03, 1.09) | <0.001 | 1.05 (1.02, 1.08) | <0.001 |
| 60-64y | 68y | 1.02 (0.99, 1.05) | 0.2 | 1.02 (0.99, 1.05) | 0.3 |
| | | Waist circumference | | | |
| | | Model 1[a] | | Model 2[b] | |
| Per cm WC at age: | Back pain at age: | OR (95% CI) | P value | OR (95% CI) | P value |
| 36y | 43y | 1.012 (1.002,1.021) | 0.01 | 1.009 (0.999, 1.018) | 0.07 |
| 43y | 53y | 1.015 (1.006, 1.025) | 0.001 | 1.013 (1.004, 1.022) | 0.005 |
| 53y | 60-64y | 1.019 (1.009, 1.030) | <0.001 | 1.016 (1.005, 1.026) | 0.003 |
| 60-64y | 68y | 1.007 (0.996, 1.019) | 0.2 | 1.004 (0.993, 1.015) | 0.5 |

*Note.* BMI: body mass index; SD: Standard Deviation; OR: Odds Ratio; y: years
[a] Model 1: Includes age as a categorical variable, BMI or WC and an age by BMI or age by WC interaction (as appropriate), adjusted for sex (as there was no evidence of a sex by BMI (p=0.7) or sex by WC (p=0.9) interaction)
[b] Model 2: Includes age as a categorical variable, BMI or WC and an age by BMI or age by WC interaction (as appropriate), adjusted for sex, education, occupational class and time-varying covariates (height, cigarette smoking status, physical activity and symptoms of anxiety and depression)

**References**

1. Bann D, Kuh D, Wills AK, et al. Physical activity across adulthood in relation to fat and lean body mass in early old age: Findings from the Medical Research Council National Survey of Health and Development, 1946–2010. *Am J Epidemiol.* 2014;179:1197-207.

**STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cohort studies***
**Checklist completed for: Do the associations of body mass index and waist circumference with back pain change as people age? 32 years of follow-up in a British birth cohort**

| Section/Topic | Item # | Recommendation | Reported on page # |
|---|---|---|---|
| **Title and abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract | 1; 2 |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | 2 |
| **Introduction** | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | 4-5 |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | 5 |
| **Methods** | | | |
| Study design | 4 | Present key elements of study design early in the paper | 5-10 |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 5-6 |
| Participants | 6 | (*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up | 5-10 |
| | | (*b*) For matched studies, give matching criteria and number of exposed and unexposed | n/a |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 6-9 & Suppl methods |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 6-9 |
| Bias | 9 | Describe any efforts to address potential sources of bias | 9-10, 14 |
| Study size | 10 | Explain how the study size was arrived at | 9, Table S1 |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 6-9, Table 1, Table S2 |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | 9-10 |
| | | (*b*) Describe any methods used to examine subgroups and interactions | 9-10 |
| | | (*c*) Explain how missing data were addressed | 9-10, table S1 |
| | | (*d*) If applicable, explain how loss to follow-up was addressed | n/a |

| | | | |
|---|---|---|---|
| | | (*e*) Describe any sensitivity analyses | 10 |
| **Results** | | | |
| Participants | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed | 5-6, 9-10, footnotes to tables |
| | | (b) Give reasons for non-participation at each stage | 5-6 |
| | | (c) Consider use of a flow diagram | See Stafford et al 2013 |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | Table 1 and Table S2 |
| | | (b) Indicate number of participants with missing data for each variable of interest | Table S1 and Table S2 |
| | | (c) Summarise follow-up time (eg, average and total amount) | n/a |
| Outcome data | 15* | Report numbers of outcome events or summary measures over time | Tables |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | 10-11, Tables 2-3 |
| | | (*b*) Report category boundaries when continuous variables were categorized | Tables 1-3 |
| | | (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | - |
| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses | 11-12 |
| **Discussion** | | | |
| Key results | 18 | Summarise key results with reference to study objectives | 12 |
| **Limitations** | | | |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 12-15 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | 14 |
| **Other information** | | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based | 16 |

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.