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**Title: Adiposity measures as predictors of long term physical disability**

**Abbreviated title: Adiposity measures: predictors of disability**

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**Abstract: Adiposity measures as predictors of long term physical disability**

***Objective:*** To compare the predictive value of a variety of adiposity measures for the risk of disability.

***Design/Setting:*** This study used 14-year follow-up of the Melbourne Collaborative Cohort Study (MCCS; n=7142). Adiposity measures were collected at baseline and disability measures for 5 self care activities and mobility, were collected at follow-up (2003-2007).

***Methods:*** Logistic regression was used to analyse the association between each adiposity measure (body mass index (BMI), waist circumference (WC), hip circumference, waist to hip ratio, fat mass, fat free mass and percentage fat and disability. Area under the receiver operating curve ranking and comparison between nested models were used to determine the best predictor of disability.

***Results:*** For men and women, the odds for disability increased with increasing adiposity. In men, BMI was the most predictive adiposity measure for all types of disability. In women, 2 adiposity measures (BMI and WC) predicted overall and mobility disability better than only one measure, with HC the single best predictor for self-care disability.

***Conclusion:*** BMI and WC predicted disability well in men and women. Identifying individuals at high risk of future disability through simple measures of adiposity will be essential if we are to adequately cater for our ageing population.

***Keywords:*** adiposity, obesity, physical disability, predictors

**List of abbreviations and acronyms**

| | |
|---|---|
| ADL | activities of daily living |
| MCCS | Melbourne Collaborative Cohort Study |
| BMI | body mass index |
| HC | hip circumference |
| WC | waist circumference |
| WHR | waist-hip ratio |
| AUROC | Area under the receiver operating curve |
| BIC | Bayesian information criterion |

## Introduction

There is continuing controversy regarding which adiposity measure best represents the health risks associated with excess bodyweight, both at the individual and population levels. Whilst there have been studies into adiposity measures as determinants of diabetes, cardiovascular disease, cardiovascular mortality and all-cause mortality [1-3], very few studies have used non-metabolic outcome measures such as physical disability. We propose that the choice of the best adiposity predictor should be based on an overall marker of global health, such as physical disability, rather than individual obesity-related diseases. Disability is also particularly pertinent within the context of our ageing population.

Studies have shown a positive association between increased adiposity, frequently measured as body mass index (BMI) or waist circumference (WC), and physical disability as defined by impairments in performing activities of daily living (ADL) [4-10]. Studies that have directly compared the predictive value of varying adiposity measures are few and have reported mixed results. Of these studies, some compared only the adiposity measures of BMI with WC, while others compared fat mass with fat-free mass. One study compared across the spectrum of body composition measures, however, this study was only in men [9].

Our study aimed to compare the independent predictive value of a variety of adiposity and body composition measures for the long-term risk of disability in self-care and mobility activities. Firstly we aimed to find the single adiposity measure that best predicted disability. Secondly we aimed to see whether the predictive power of a model based solely on this measure was significantly improved by the addition of further adiposity measures. We used the 14-year follow-up of a large cohort of Australian adults to compare the predictive value of each of seven different adiposity measures for future disability according to 6 activities of daily living (ADLs).

**Methods**

The Melbourne Collaborative Cohort Study (MCCS) is a prospective cohort study with subjects recruited from metropolitan Melbourne through the electoral roll, advertisements and announcements in community papers, ethnic radio and churches.

Recruitment of 41 514 individuals occurred between 1990 and 1994. At baseline, 41% were male and age ranged between 27 to 81 years, with a mean of 55. The study deliberately oversampled migrants from Mediterranean countries to extend the range of lifestyle and genetic factors. The study protocol was approved by the Cancer Council Victoria's Human Research Ethics Committee and subjects gave written consent to participate. Further details of the study have been described elsewhere[11].

At 4 years post-baseline, participants were followed up with a postal questionnaire. The response rate was 87%. The questionnaire included a question on limitation of physical activity by health problems with response options of 'not at all', 'a little bit', 'moderately', 'quite a bit' and 'extremely'.

A full follow-up of MCCS participants was conducted between 2003 and 2007. Of all participants enrolled in the MCCS at baseline, 2501 participants (6%) died before the first date of follow-up in May 2003. Of the 39 013 alive at the beginning of the follow-up period, we included for our analysis only Australian born participants with available data on adiposity measures at baseline (n=10 972). We excluded those without data on ability to perform 6 activities at follow-up and we termed this group 'non-responders' as they were eligible for the analysis but did not respond to the disability questionnaire (n=3830). Overall there were 7142 participants included in our final sample population; 38% were men and the mean baseline age was 64 years. Of the 7142 participants, there were no missing confounder variables.

*Measures of disability*

The disability questions were administered at the face-to-face follow-up between 2003 and 2007, but not at baseline. Subjects were asked about difficulties performing certain activities due to their health, with responses: “none”, “some”, “a lot” and “cannot do”. Activities included bathing, dressing, eating, getting out of a chair or bed, going to or using the toilet at home, and walking about 200-300 metres (round the block). These disability questions are the same as those used in the longitudinal Dubbo Study[12] and sourced from the Supplement on Aging to the 1984 National Health Interview Survey[13]. The first five activities were classified as ‘self-care limitations ’ and the limitation to walking about 200-300 metres was considered limitation to ‘mobility activities’[14]. We defined disability for each activity as any response from “some” and above. Composite measures of having limitation to “at least one activity” and limitation to “at least one self- care activity” were also created.

*Potential confounders*

At baseline, a face-to-face interview was conducted to obtain demographic information, medical history (cardiovascular disease, diabetes, arthritis, asthma, cancer) and information regarding lifestyle factors including alcohol consumption, smoking and educational attainment. In obtaining smoking history, subjects were asked if they were never, past or current smokers. As an indicator of socio-economic status, subjects were asked their highest level of education attained (primary only, some secondary, completed secondary, completed tertiary) which was dichotomised to “completed high school and below” and “some trade/tertiary and above”.

*Adiposity measures*

Measures of height, weight, hip and waist circumferences (HC;WC) as well as bioelectric impedance analysis were performed at baseline. Height was measured with a stadiometer, weight with a digital scale and HC and WC with a metal anthropometric tape. Bioelectric impedance was measured using a BIA-101a RJL system analyser (RJL Systems, Detroit, MI). We calculated waist:hip ratio (WC divide by HC; WHR) and body mass index (weight in kg/(height in metres)$^2$; BMI). Fat-free mass was estimated from bioelectrical impedance analysis (Fat Free mass = 9.1536 +(0.4273 X height$^2$/resistance) +(0.1926 X weight) + (0.0667 X reactance) for men, and 7.7435 + (0.4542 X height$^2$/resistance) + (0.1190 X weight) + (0.0455 X reactance) for women[2]. We then calculated fat mass (body weight – fat free mass) and percentage fat (fat mass/body weight). For each of BMI, WC, HC, WHR, fat mass, fat free mass and fat percentage we created sex-specific quintile groups.

*Statistical analysis*

All statistical analyses were performed using Stata 11.1 (Stata Corp LP) and stratified by sex. Descriptive statistics (age, smoking status, medical history, and educational status) were compared across quintile groups of BMI. Logistic regression models analysed the association between each adiposity measure (in quintile categories) at baseline and the presence of disability for any of the 5 self-care activity questions or mobility at follow-up adjusted for baseline age, smoking and educational status. Reported odds ratios were referenced to the lowest quintile of the adiposity measure.

Predictive tests

To ascertain which adiposity measures were the most predictive of future disability, we first tested the comparative predictive value of models containing each of the measures in isolation, as indicated by the area under the receiver operating characteristic curve (AUROC). This area under the curve can range from 0 to 1, with 0.5 indicating poor discrimination and 1 indicating perfect discrimination. Calibration of the various models was analysed by the Hosmer-Lemeshow test. Hosmer-Lemeshow chi-square and its corresponding p-value were computed to estimate the similarity between observed and expected event rates. A p-value of less than 0.05 indicated poor calibration.

First we ranked the models with one adiposity measure by AUROC to find the model with the highest discrimination. The model with the highest discrimination by AUROC ranking without evidence of poor calibration by Hosmer-Lemeshow chi-square test was considered the single best predictor. Once we identified which adiposity measure was the single best predictor for disability, we analysed whether adding more adiposity measures would lead to a better prediction of disability status. To this end, we added one other adiposity measure at a time to the model with the single best predictor. We further ranked these two-adiposity models by AUROC to identify the model with the highest predictive ability. This highest ranked two-measure model was then compared to the model with a single best predictor and assessed for significant differences using a chi-square test of AUROC's. If the highest AUROC ranked two- measure model had significantly higher discriminative ability than the single-measure model nested within it, the process of testing the discriminative ability with an additional adiposity measure was repeated.

For each model with a single adiposity measure, the Bayesian Information Criterion (BIC) was computed as a means of ranking the models for their goodness-of-fit. The smaller the BIC, the better the fit of the model.

For these analyses, the comparative predictive ability of the adiposity measures was tested for each of the three separate outcomes of: overall disability; disability to at least one self-care activity; and mobility. All models were adjusted for age, educational attainment and smoking status.

*Sensitivity analysis*

Analyses for predictive ability of models for overall disability were repeated in a population whose physical activities were not at all limited by health problems as ascertained at the 4-year postal questionnaire (n= 4081). The MCCS data did not have baseline disability measure and this sensitivity analysis was performed to address possible reverse causation.

*Stratification by age group*

To determine if predictors of disability varied by age, we further analysed the predictors for overall disability within each gender group by age groups, under 65 years and 65 years and over.

**Results**

Comparison of those eligible for the study with available disability data (responders) and those who did not respond when eligible (non-responders) indicated that the two groups were similar in age, sex and adiposity measures (Table 1). Responders tended to be better educated and healthier, with fewer smokers and substantially less history of angina, stroke and diabetes.

Comparison of participant characteristics across increasing quintiles of BMI demonstrated lower educational level, higher prevalence of smoking and a higher prevalence of obesity related diseases such as hypertension, diabetes and arthritis with increasing BMI (Table 2). Mean and range of BMI across quintiles 1 to 5 were similar in both men and women.

*Limitation to ADLs*

Women had a higher overall prevalence of disability compared to men (35.2% and 29.1% respectively; Table 2).

Figure 1 illustrates the association between each adiposity measure and disability (adjusted for age, education and smoking status). The odds for disability increased from the lowest quintile to the highest in both sexes, and the association appeared stronger in women. Among women, a significant increase in the odds of disability was evident from the second quintile with more than 4-fold increase in the highest quintile compared to the lowest quintile for all adiposity measures except WHR ( OR 2.3, 95% CI 1.9-2.8) and fat free mass (OR 2.4, 95% CI 2.0-2.9). Among men, the association between adiposity measures and disability was significant for quintiles 4 or 5, with an approximately 2-fold increase in risk in the highest quintile compared to the lowest quintile for WC, BMI, WHR and fat mass and percentage fat. (Figure 1).

*Predictive value of adiposity measures*

In men, BMI, as a single predictor, had the highest AUROC for overall disability, self care disability only and mobility disability (Table 3). WC was the second highest ranking predictor for overall disability and mobility disability and was only slightly less predictive than BMI. Fat free mass was the second highest predictor variable for self-care disability. There was no evidence of poor calibration for any models, with all Hosmer-Lemeshow p-values >0.05. When other individual measures were added to the model already containing BMI, the difference in the AUROC was not significant, indicating that discrimination for disability was not improved with the addition of further adiposity measures.

In women, fat mass had the highest AUROC to predict overall disability, followed closely by BMI. The Hosmer-Lemeshow statistic for the model with fat mass was <0.05, indicating poor calibration, while models with all other adiposity measures showed no evidence of poor calibration. As there was evidence of poor calibration for fat mass, BMI was considered the single best predictor for overall disability as the AUROC for BMI was very similar to that for fat mass and there was no evidence of poor calibration for BMI. Adding WC to a model with BMI yielded a significantly higher AUROC compared to the model with BMI alone (Table 4). Adding a third measure to this model did not significantly increase the AUROC. For self-care disability, although HC had the highest AUROC, the AUROCs for WC and BMI were very similar (Table 3). Adding another measure to the model did not significantly increase AUROC. For mobility disability, BMI was the single best predictor but fat mass had a similar AUROC. Adding WC to the model containing BMI significantly increased the AUROC, but adding a third measure did not further increase it (Table 4).

When models with single adiposity measures were ranked by BIC, BMI remained the best fit model for predicting overall, self care and locomotion disabilities in men. In women, BMI was the best fit model for predicting overall and locomotion disabilities with a BIC marginally lower than for fat mass. WC was the best fit model in predicting self-care disabilities in women.

*Sensitivity Analysis*

In the sensitivity analysis, BMI remained the best predictor for overall disability for males and adding a second measure did not significantly increase the AUROC of the model. In women, although percentage fat had the highest AUROC, WC and fat mass were very similar in AUROC. A model with percentage fat and WC was better at predicting overall disability in women than a model with only percentage fat (Table 3).

*Stratifying by age group*

When stratified by age group, BMI remained the single predictor with the highest ranking by AUROC for predicting overall disability in males under 65 years and women aged 65 and over (Table 5). In males aged 65 and over, although WC had the highest AUROC ranking, the AUROC for the model with BMI was very similar. In this same group of older males, adding a second variable, WHR, to the model with WC only, significantly improved the predictive ability of the model (p=0.037) In women under 65 years, fat mass was the single best predictor for overall disability and there is a possibility that a more complex model with two variables, fat mass and WC, would better predict overall disability (p= 0.056).

**Discussion**

In this analysis comparing the relative predictive ability of various adiposity measures for disability, we found that in men, BMI was the best predictor regardless of the type of disability, with WC almost as good a predictor for overall and mobility disability. In women, the predictors varied by disability type, and models with 2 measures of adiposity were better than models with a single adiposity measure for predicting overall and mobility disability. BMI was the best single predictor for overall and mobility disability but adding WC improved the predictive ability of the model. To predict self care disability in women, HC was the best predictor although WC appeared to be similarly good.

There was a strong association between higher adiposity and disability, particularly in women, with the risk of overall disability in the highest BMI, WC, HC, fat mass and percentage fat quintiles being 4 times higher than the lowest quintiles of those same measures. In men the relationship was not as strong, with twice the risk of the disability in the highest quintile for all adiposity measures except fat free mass compared to the lowest quintiles of those measures. In men, the odds for disability was significant from quintile 2 for BMI and quintile 3 for WC, where the mean BMI (24.8kg/m$^2$) and WC (92.8cm) in these quintiles were high normal, below WHO criteria for overweight and increase risk for metabolic conditions(Appendix 1) . In women the odds for disability were also significant from quintiles 2 of BMI and WC and in both these quintile groups, the mean BMI (23.8kg/m$^2$) and WC (73.8cm) were high normal.

Identifying BMI, WC or fat mass as the best predictors of disability is consistent with the findings of Ramsay *et al* [9]. Ramsay *et al* compared BMI, WC, fat mass and fat-free mass for their ability to predict mobility disability, limitation to usual activities and self-care disability. Their analysis was conducted on a cohort of men, aged between 40-59 years at baseline, and found that BMI, WC and fat mass predicted disability similarly according to comparison of AUROC. Angleman *et al* compared the predictive ability of weight, WC, BMI, HC and WHR for disability. For limitation to walking 1/4mile, Angleman *et al* found that in women, weight was the best fit model whilst in men the best-fit model was with WC.  Although Angleman *et al* analysed prediction by examining the goodness of fit of the model with log likelihood ratio tests, they did not compare the models discriminative ability [7]. From a log likelihood ratio test we can determine how well the model predicts the proportion of disability in a population, but by comparing discriminative ability by AUROC, we can analyse how well an adiposity measure predicts disability in an individual.  Nevertheless, our study combined with these previous studies, suggest that simple measures of adiposity such as BMI and WC are good predictors of disability for both men and women.

Our analysis indicated a difference in the predictors for different modalities of disability among women, supporting the hypothesis of Angleman *et al*: that in women, heavier weight contributes more to mobility-type limitations whilst abdominal obesity, for which WC is a surrogate marker, is a better predictor of the metabolic chronic diseases, such as cardiovascular disease, which lie in the pathway between higher adiposity and self care disability. [1, 3]. The different adiposity predictors for men and women found in this study and others, may reflect sex differences in the clinical pathways between adiposity and disability. The relationship between greater adiposity and disability may be more complex in women and therefore a model utilising 2 measures, reflecting both general and abdominal obesity, appears to be better for predicting overall and mobility disability than a model with only one measure of general adiposity. Further stratifying by age suggests that the relative predictive strength of different adiposity measures for disability may vary by age as well as by gender. In men although BMI and WC remain good single predictors of disability, a more complex model with two variables predicted overall disability better for those 65 years and older. In women, the need for a more complex model with two adiposity variables may be restricted to the younger age group.

Our finding of apparent differences in risk of disability associated with obesity between men and women is also consistent with previous studies [7, 15]. Increased risk of disability associated with increasing adiposity in women compared to men may be due to a number of factors, including basic sex differences in disability, the fact that increased adiposity has a more disabling impact on women, or the fact that in general men are more likely to recover from disabilities [16].

*Strengths and limitations*

The strength of our study lies in the wide array of available, measured adiposity parameters at baseline and disability data at follow-up from a large cohort. The classification of ADLs in this study in terms of self-care and mobility is consistent with the WHO's harmonisation of health interview surveys [14]. The mean age at baseline for participants in this study was 64 years. when BMI may still be appropriate as a surrogate measure of adiposity [17].

Our study is limited by the lack of baseline disability data thus making it difficult to conclude on the causal relationship between adiposity and disability. However the participants were volunteers who had to attend a clinic for baseline interview and investigations and it is unlikely that anyone severely disabled would have been able to attend these sessions. The disability questions were administered after a 14-year follow-up. In our sensitivity analysis to address the possibility of reverse causation, we analysed a subpopulation that did not have any limitations to their physical activities as reported at the 4-year follow-up. The best predictor for overall disability in men did not change with BMI or WC being similar. In women, again a model with 2 measures (percentage fat and WC) was better than a model with only one measure (percentage fat). Although percentage fat yielded the highest AUROC, the AUROCs for models with WC or fat mass alone were very similar to that for percentage fat.

Another limitation in this study is the attrition rate of approximately 35% and the lack of information regarding reasons for loss to follow-up. It is possible that participants did not return to follow-up because they were too disabled to attend the clinic. Our analysis of baseline adiposity measures showed no difference in BMI between the participants who returned to follow-up and those who did not. If the loss to follow-up was due to disability, we anticipate that this would have led to an underestimation of the strength of association demonstrated in our analysis, but no impact on the relative discriminatory power of the individual adiposity measures.

*Implications*

Disability, or functional limitation, as a global health measure is commonly used as a measure of healthy ageing [18, 19]. Here we demonstrate the effect of different adiposity measurements and how these are likely to impact on our elderly population through future disability. The increased risk of disability in women from the lower quintiles suggests any increase in adiposity, across the whole continuum is a concern.

We demonstrate that simple measures of BMI and WC are better predictors of disability in both men and women than the more complex and costly body composition measures, illustrating the ease of identifying those at high risk of future disability in a clinical setting or as part of a workplace health check. Our results further support the important public health message of maintaining both a healthy weight and WC. Furthermore the overall health implications of increasing prevalence of overweight and obesity may need to be considered differently for the different sexes.

**Conclusion**

We recommend using disability or functional limitation as a global health measure above individual chronic disease outcomes when assessing adiposity measures that best represent health risks. Identifying individuals at high risk of future disability through simple measures of adiposity will be essential if we are to adequately cater for our ageing population.

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**Conflict of interest**

None

**References**

1. Lee CMY, Huxley RR, Wildman RP, Woodward M. Indices of abdominal obesity are better discriminators of cardiovascular risk factors than BMI: a meta-analysis. Journal of Clinical Epidemiology. [doi: 10.1016/j.jclinepi.2007.08.012]. 2008;61(7):646-53.
2. Simpson J, MacInnis R, Peeters A, Hopper J, Giles G, English D. A comparison of adiposity measures as predictors of all-cause mortality: the Melbourne Collaborative Cohort Study. Obesity. 2007;15(4):994-1003.
3. Ghandehari H, Le V, Kamal-Bahl S, Bassin SL, Wong ND. Abdominal obesity and the spectrum of global cardiometabolic risks in US adults. Int J Obes. 2008;33(2):239-48.
4. Alley DE, Chang VW. The changing relationship of obesity and disability, 1988-2004. JAMA. [Research Support, N.I.H., Extramural
Research Support, Non-U.S. Gov't]. 2007 Nov 7;298(17):2020-7.

5. Al Snih S, Graham JE, Kuo Y-F, Goodwin JS, Markides KS, Ottenbacher KJ. Obesity and disability: relation among older adults living in Latin America and the Caribbean. American Journal of Epidemiology. [Research Support, N.I.H., Extramural]. Jun 15;171(12):1282-8.
6. Peeters A, Bonneux L, Nusselder WJ, De Laet C, Barendregt JJ. Adult obesity and the burden of disability throughout life. Obesity Research. [Research Support, Non-U.S. Gov't]. 2004 Jul;12(7):1145-51.
7. Angleman SB, Harris TB, Melzer D. The role of waist circumference in predicting disability in periretirement age adults. International Journal of Obesity. [Research Support, N.I.H., Extramural Research Support, Non-U.S. Gov't]. 2006 Feb;30(2):364-73.
8. Houston DK, Stevens J, Cai J. Abdominal fat distribution and functional limitations and disability in a biracial cohort: the Atherosclerosis Risk in Communities Study. International Journal of Obesity. [Multicenter Study
Research Support, N.I.H., Extramural]. 2005 Dec;29(12):1457-63.
9. Ramsay SE, Whincup PH, Shaper AG, Wannamethee SG. The relations of body composition and adiposity measures to ill health and physical disability in elderly men. American Journal of Epidemiology. [Research Support, Non-U.S. Gov't]. 2006 Sep 1;164(5):459-69.
10. Visser M, Langlois J, Guralnik JM, Cauley JA, Kronmal RA, Robbins J, et al. High body fatness, but not low fat-free mass, predicts disability in older men and women: the Cardiovascular Health Study. American Journal of Clinical Nutrition. 1998 Sep;68(3):584-90.
11. Giles GG, English, D.R. The Melbourne Collaborative Cohort Study. IARC Scientific Publications. 2002;156:69-70.
12. Simons LA, Simons J, McCallum J, Powell I, Friedlander Y, Heller R. Dubbo study of the elderly: sociological and cardiovascular risk factors at entry. Australian and New Zealand Journal of Medicine. 1991;21(5):701-9.
13. Fitti JE, Kovar, M.G. The Supplement on Aging to the 1984 National Health Interview Survey. Vital and Health Statistics. 1987;Series 1: Program and Collection Procedures(21):1-115.
14. De Bruin A, Picavet, H.S.J. and Nossikov, A. Health interview surveys: towards international harmonization of methods and instruments. World Health Organization,Copenhagen. 1996.
15. Chen H, Guo X. Obesity and functional disability in elderly Americans. Journal of the American Geriatrics Society. [Comparative Study
Research Support, N.I.H., Extramural
Research Support, N.I.H., Intramural]. 2008 Apr;56(4):689-94.
16. Walter S, Kunst A, MacKenbach J, Hofman A, Tiemeier H. Mortality and disability: The effect of overweight and obesity. International Journal of Obesity. 2009;33(12):1410-8.
17. Zamboni M, Mazzli, G., Zoico, E, Harris, T.B., Meigs, J.B, Di Francesco, V., Fantin, F., Bissoli, L., Bosello, O. Healh Consequences of Obesity in the elderly: a review of four unresolved questions. International journal of obesity. 2005;29:1011-29.
18. Rowe JW, Kahn RL. Successful aging. Gerontologist. 1997 Aug;37(4):433-40.
19. Rowe JW, Kahn RL. Successful aging and disease prevention. Adv Ren Replace Ther. 2000 Jan;7(1):70-7.

Table 1: Baseline characteristics of responders versus non-responders

| Variable | Non-responders | Responders |
|---|---|---|
| n | 3830 | 7142 |
| Age (mean (SD)) | 63.3 (4.2) | 64.0 (3.3) |
| % Male | 36.7% | 38.1% |
| % Some trade/tertiary and above | 23.3 | 32.1 |
| BMI (mean(SD)) | 26.9(4.4) | 26.5 (4.0) |
| WC (mean(SD)) | 86.3(13.3) | 85.1 (12.1) |
| HC (mean (SD)) | 101.7 (9.5) | 101.1 (8.6) |
| WHR (mean (SD)) | 0.9 (0.1) | 0.8 (0.1) |
| Fat Mass (mean (SD)) | 26.4 (9.4) | 25.6 (8.7) |
| Fat Free (mean (SD)) | 46.1 (9.8) | 46.3 (9.4) |
| Percentage Fat (mean (SD)) | 36.0 (8.7) | 35.3 (8.6) |
| % Never Smoked | 57.2 | 61.7 |
| % Current Smokers | 10.2 | 5.8 |
| % Former Smokers | 32.6 | 32.5 |
| % Baseline chronic disease | | |
| Angina | 8.0 | 6.3 |
| Hypertension | 33.6 | 30.6 |
| Heart attack | 5.0 | 4.2 |
| Stroke | 2.5 | 1.5 |
| Diabetes | 4.3 | 2.4 |
| Asthma | 12.8 | 11.3 |
| Arthritis | 46.5 | 44.0 |
| Cancer | 11.8 | 12.2 |

Table 2: Comparison of baseline characteristics and disability at follow up across body mass index quintiles, stratified by sex

| | Male | | | | | |
|---|---|---|---|---|---|---|
| **Variable** | **Quintile 1** | **Quintile 2** | **Quintile 3** | **Quintile 4** | **Quintile 5** | **Overall** |
| **n** | 545 | 545 | 544 | 545 | 544 | 2723 |
| **Mean BMI (kg/m$^2$)** | 22.5 | 24.8 | 26.4 | 28.1 | 31.5 | 26.6 |
| **Age (mean (SD))** | 64.2 (3.2) | 64.3 (3.2) | 64.2 (3.4) | 64.1 (3.2) | 63.8 (3.2) | 64.1 (3.2) |
| **% Some trade/tertiary and above** | 51.0 | 47.7 | 43.6 | 39.5 | 34.7 | 43.3 |
| **%Never smoked** | 51.0 | 48.6 | 46.1 | 41.7 | 40.1 | 45.5 |
| **% Current smoker** | 7.2 | 6.6 | 4.8 | 5.9 | 4.8 | 5.8 |
| **% Former smoker** | 41.8 | 44.8 | 49.1 | 52.5 | 55.2 | 48.7 |
| **% Baseline chronic disease** | | | | | | |
| **Angina** | 9.5 | 6.2 | 10.1 | 8.4 | 12.0 | 9.3 |
| **Hypertension** | 20.7 | 25.1 | 28.3 | 30.6 | 43.2 | 29.6 |
| **Heart attack** | 6.4 | 6.8 | 8.1 | 5.9 | 9.6 | 7.3 |
| **Stroke** | 1.5 | 2.0 | 1.7 | 2.4 | 2.2 | 2.0 |
| **Diabetes** | 1.5 | 1.7 | 3.1 | 3.0 | 5.7 | 3.0 |
| **Asthma** | 9.9 | 10.8 | 8.1 | 10.1 | 7.2 | 9.2 |
| **Arthritis** | 29.5 | 29.9 | 36.6 | 35.1 | 39.2 | 34.0 |
| **Cancer** | 11.9 | 13.2 | 12.0 | 13.2 | 13.4 | 12.7 |
| **% with disability at follow-up** | 23.9 | 20.4 | 30.2 | 32.7 | 39.0 | 29.2 |

Disability defined as having limitation to at least one of self-care or mobility activities

| | Female | | | | | |
|---|---|---|---|---|---|---|
| **Variable** | **Quintile 1** | **Quintile 2** | **Quintile 3** | **Quintile 4** | **Quintile 5** | **Overall** |
| **n** | 884 | 884 | 884 | 884 | 883 | 4419 |
| **Mean BMI (kg/m$^2$)** | 21.1 | 23.8 | 25.8 | 28.1 | 33.1 | 26.4 |
| **Age (mean (SD))** | 64.1 (3.2) | 64.0 (3.4) | 64.1(3.3) | 63.8 (3.3) | 63.8 (3.3) | 64.0 (3.30) |
| **% Some trade/tertiary and above** | 29.0 | 27.6 | 23.3 | 23.3 | 22.8 | 25.19 |
| **%Never smoked** | 69.8 | 71.5 | 70.1 | 72.5 | 74.5 | 71.69 |
| **% Current smoker** | 7.8 | 6.2 | 4.9 | 6.0 | 4.0 | 5.77 |
| **% Former smoker** | 22.4 | 22.3 | 25.0 | 21.5 | 21.5 | 22.54 |
| **% Baseline chronic disease** | | | | | | |
| **Angina** | 3.3 | 2.9 | 4.2 | 5.5 | 6.5 | 4.48 |
| **Hypertension** | 21.0 | 26.0 | 30.3 | 32.5 | 46.2 | 31.21 |
| **Heart attack** | 2.5 | 2.0 | 2.7 | 1.8 | 2.4 | 2.29 |
| **Stroke** | 0.5 | 1.4 | 1.6 | 1.2 | 1.3 | 1.18 |
| **Diabetes** | 0.9 | 0.9 | 1.4 | 3.1 | 3.7 | 1.99 |
| **Asthma** | 11.3 | 10.9 | 12.9 | 13.2 | 14.3 | 12.51 |
| **Arthritis** | 42.5 | 49.3 | 49.9 | 51.7 | 56.9 | 50.06 |
| **Cancer** | 13.7 | 11.3 | 11.5 | 11.3 | 11.4 | 11.86 |
| **% with disability at follow-up** | 21.6 | 27.8 | 31.9 | 41.0 | 53.8 | 35.21 |

Disability defined as having limitation to at least one of self-care or mobility activities

Table 3: Comparison of the discriminative ability of each adiposity measure singly for the prediction of disability. Variables are ranked from highest to lowest AUROC. All models adjusted for age, education and smoking status

| | | Males | | |
|---|---|---|---|---|
| | | AUROC | Hosmer-Lemeshow p value | BIC |
| **Overall disability** | **BMI** | 0.6197 | 0.9992 | 3258.062 |
| | **WC** | 0.6173 | 0.2265 | 3258.406 |
| | **HC** | 0.6093 | 0.8111 | 3275.172 |
| | **Fat mass** | 0.6020 | 0.4184 | 3284.347 |
| | **WHR** | 0.6017 | 0.1360 | 3286.642 |
| | **Pct fat** | 0.5982 | 0.2954 | 3289.604 |
| | **Fat free** | 0.5909 | 0.0649 | 3301.920 |
| **Self-care disability** | **BMI** | 0.5755 | 0.1976 | 2591.871 |
| | **Fat free** | 0.5673 | 0.1129 | 2597.136 |
| | **Fat mass** | 0.5665 | 0.9407 | 2599.234 |
| | **WC** | 0.5653 | 0.4230 | 2595.239 |
| | **WHR** | 0.5636 | 0.1251 | 2593.742 |
| | **HC** | 0.5631 | 0.6348 | 2597.928 |
| | **Pct fat** | 0.5585 | 0.8572 | 2600.811 |
| **Mobility disability** | **BMI** | 0.6662 | 0.2235 | 2588.407 |
| | **WC** | 0.6661 | 0.4816 | 2588.580 |
| | **WHR** | 0.6528 | 0.3380 | 2617.124 |
| | **Fat mass** | 0.6494 | 0.5189 | 2612.408 |
| | **HC** | 0.6480 | 0.1691 | 2619.912 |
| | **Pct fat** | 0.6458 | 0.4969 | 2619.222 |
| | **Fat free** | 0.6368 | 0.5330 | 2641.060 |
| **Sensitivity analysis** | **BMI** | 0.6139 | 0.2074 | 1738.045 |
| | **WC** | 0.6138 | 0.2590 | 1731.752 |
| | **HC** | 0.6113 | 0.6227 | 1734.655 |
| | **Fat free** | 0.6025 | 0.2149 | 1745.887 |
| | **WHR** | 0.6018 | 0.1217 | 1746.295 |
| | **Fat mass** | 0.6009 | 0.4584 | 1744.521 |
| | **Pct fat** | 0.5989 | 0.0558 | 1747.269 |

| | | Females | | |
|---|---|---|---|---|
| | | AUROC | Hosmer-Lemeshow p value | BIC |
| Overall disability | Fat mass | 0.6630 | 0.0117 | 5478.571 |
| | BMI | 0.6617 | 0.8718 | 5477.515 |
| | WC | 0.6572 | 0.9612 | 5505.088 |
| | HC | 0.6551 | 0.9312 | 5510.748 |
| | Pct fat | 0.6545 | 0.0822 | 5508.957 |
| | Fat free | 0.6126 | 0.3506 | 5646.619 |
| | WHR | 0.6103 | 0.9559 | 5659.293 |
| Self-care disability | HC | 0.5877 | 0.3080 | 4014.104 |
| | WC | 0.5858 | 0.8780 | 4009.963 |
| | BMI | 0.5855 | 0.4823 | 4013.189 |
| | Fat mass | 0.5785 | 0.5786 | 4020.633 |
| | Pct fat | 0.5762 | 0.9700 | 4023.653 |
| | WHR | 0.5679 | 0.0469 | 4031.896 |
| | Fat free | 0.5610 | 0.5707 | 4039.441 |
| Mobility disability | BMI | 0.6903 | 0.9523 | 4883.766 |
| | Fat mass | 0.6899 | 0.8458 | 4890.019 |
| | WC | 0.6831 | 0.8183 | 4922.516 |
| | Pct fat | 0.6813 | 0.5050 | 4926.093 |
| | HC | 0.6790 | 0.9373 | 4934.346 |
| | Fat free | 0.6269 | 0.8955 | 5108.62 |
| | WHR | 0.6222 | 0.2214 | 5129.473 |
| Sensitivity analysis | Pct fat | 0.6428 | 0.3321 | 2482.589 |
| | WC | 0.6425 | 0.6869 | 2489.804 |
| | Fat mass | 0.6421 | 0.1217 | 2484.354 |
| | BMI | 0.6378 | 0.9972 | 2492.923 |
| | HC | 0.6369 | 0.2777 | 2498.680 |
| | WHR | 0.6170 | 0.7076 | 2522.866 |
| | Fat free | 0.6146 | 0.9981 | 2520.616 |

BMI: body mass index, WC: waist circumference, HC: hip circumference, WHR: waist-hip ratio, Pct fat: percentage fat

Sensitivity analysis: population whose physical activities were not at all limited by health problems as ascertained at the 4-year postal questionnaire.

Table 4: Comparison of the discriminative ability of models including more than one adiposity measure for the prediction of disability. Additional adiposity measures were added to the single best adiposity predictor identified in Table 3. Only models in which the addition of a further adiposity variable led to a significant increase in the AUROC are presented. All models are adjusted for age, education and smoking status

| **Males** | **Model** | **AUROC** |
|---|---|---|
| Overall disability | BMI | 0.6197 |
| Self-care disability | BMI | 0.5755 |
| Mobility disability | BMI | 0.6662 |
| Sensitivity analysis | BMI | 0.6139 |

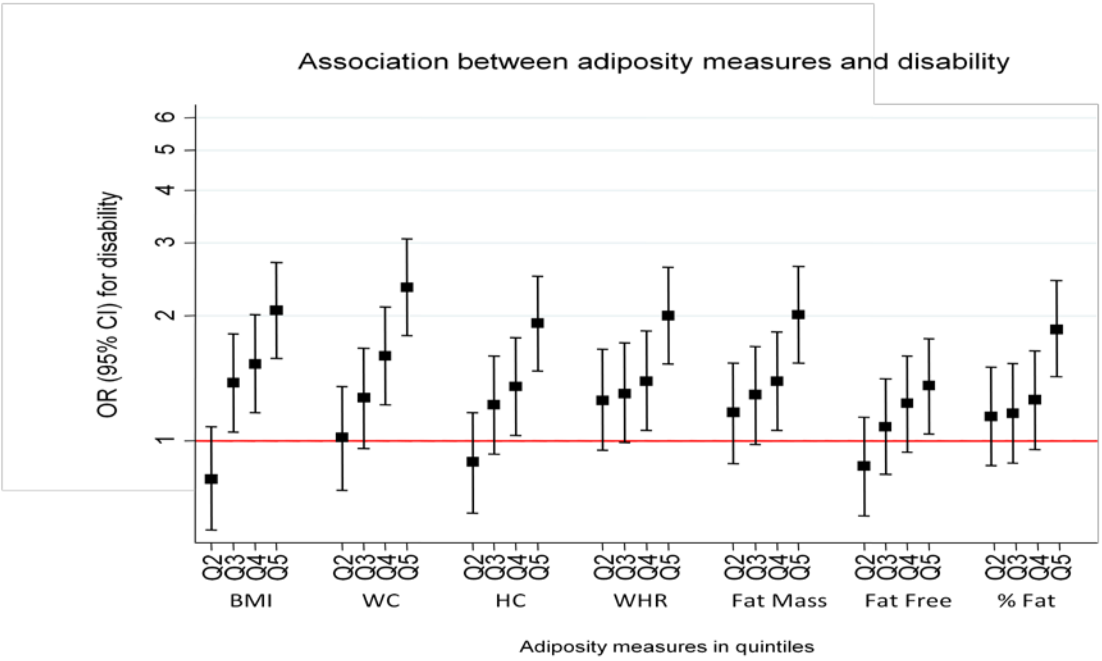
| **Females** | **Model** | **AUROC** | **(AUROC1-AUROC2 ) p-value** |
|---|---|---|---|
| Overall disability | BMI | 0.6617 | |
| | BMI + WC | 0.6679 | 0.0070 |
| Self-care disability | HC | 0.5877 | |
| Mobility disability | BMI | 0.6903 | |
| | BMI + WC | 0.6967 | 0.0046 |
| Sensitivity analysis | Percentage fat | 0.6428 | |
| | Percentage fat + WC | 0.6539 | 0.0351 |

Table 5: Comparison of the discriminative ability of each adiposity measure singly for the prediction of disability within each strata by gender and age group. Variables are ranked from highest to lowest AUROC. All models adjusted for age, education and smoking status.

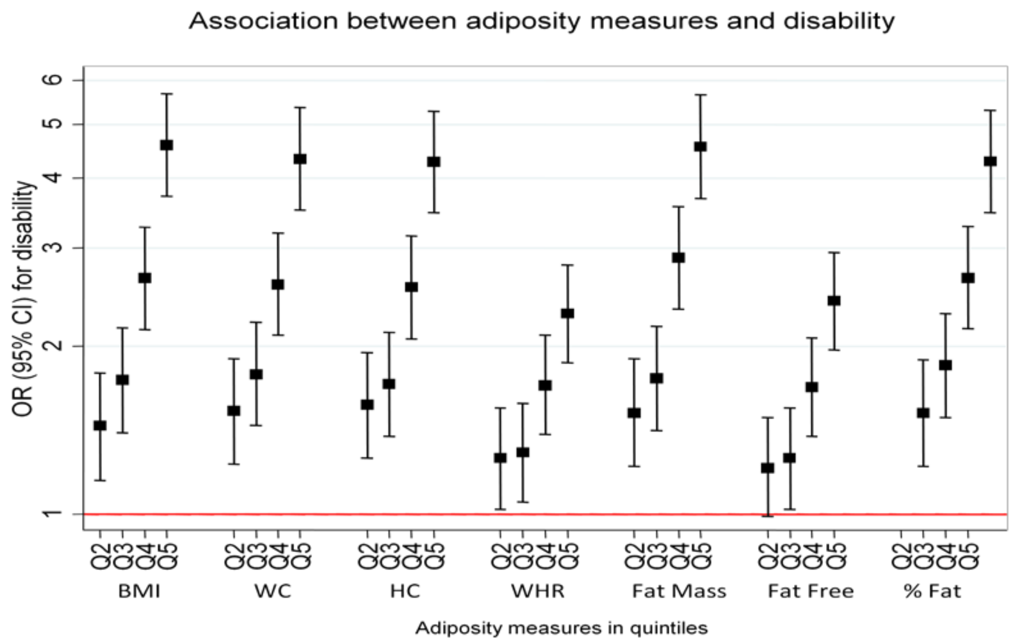
| | | | Males | |
|---|---|---|---|---|
| | | AUROC | Hosmer-Lemeshow p value | BIC |
| Under 65 n=1568 | BMI | 0.6066 | 0.8652 | 1825.804 |
| | HC | 0.5975 | 0.5152 | 1835.148 |
| | WC | 0.5957 | 0.4084 | 1832.076 |
| | Fat mass | 0.5859 | 0.7051 | 1841.894 |
| | WHR | 0.5856 | 0.5068 | 1840.507 |
| | Fat free | 0.5801 | 0.9841 | 1845.125 |
| | Pct fat | 0.5775 | 0.3036 | 1845.054 |
| 65 and over n=1155 | WC | 0.6247 | 0.3079 | 1479.640 |
| | BMI | 0.6239 | 0.4136 | 1482.281 |
| | Fat mass | 0.6131 | 0.6291 | 1492.868 |
| | WHR | 0.6103 | 0.0382 | 1492.659 |
| | HC | 0.6090 | 0.0851 | 1491.283 |
| | Fat free | 0.5998 | 0.5781 | 1500.287 |
| | Pct fat | 0.5825 | 0.8461 | 1507.508 |
| | | | Females | |
| | | AUROC | Hosmer-Lemeshow p value | BIC |
| under 65 n=2646 | Fat mass | 0.6618 | 0.1993 | 3224.427 |
| | Pct fat | 0.6568 | 0.5873 | 3233.607 |
| | BMI | 0.6543 | 0.9225 | 3242.209 |
| | WC | 0.6543 | 0.9867 | 3243.264 |
| | HC | 0.6554 | 0.8868 | 2544.468 |
| | Fat free | 0.6009 | 0.4086 | 3336.820 |
| | WHR | 0.6074 | 0.5341 | 3329.751 |
| 65 and over n=1773 | BMI | 0.6652 | 0.9812 | 2292.829 |
| | HC | 0.6551 | 0.9757 | 2312.871 |
| | Fat mass | 0.6543 | 0.8463 | 2313.468 |
| | WC | 0.6535 | 0.2562 | 2317.072 |
| | Pct fat | 0.6470 | 0.8279 | 2327.764 |
| | Fat free | 0.6243 | 0.2572 | 2362.159 |
| | WHR | 0.6070 | 0.7529 | 2381.086 |

Figure 1: Logistic regression of the association between each adiposity measure (in quintiles) at baseline and disability at follow-up. The reference category is quintile 1 of each measure (not shown). All analyses adjusted for age, education and smoking status. (A) Males, and (B) Females

A.




B.

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**Appendix 1:** Range and mean for BMI and WC in each quintile for both men and women.

| Male BMI Quintile | N | mean | min | max |
|---|---|---|---|---|
| 1 | 545 | 22.48 | 17.45 | 23.95 |
| 2 | 545 | 24.81 | 23.95 | 25.59 |
| 3 | 544 | 26.38 | 25.59 | 27.16 |
| 4 | 545 | 28.05 | 27.17 | 29.06 |
| 5 | 544 | 31.48 | 29.07 | 50.16 |

| Male WC Quintile | N | mean | min | max |
|---|---|---|---|---|
| 1 | 544 | 80.17 | 62 | 85.5 |
| 2 | 545 | 88.20 | 85.5 | 90.5 |
| 3 | 544 | 92.76 | 90.5 | 95 |
| 4 | 545 | 97.69 | 95 | 100.8 |
| 5 | 545 | 106.89 | 100.9 | 151 |

| Female BMI Quintile | N | mean | min | max |
|---|---|---|---|---|
| 1 | 884 | 21.06 | 15.45 | 22.80 |
| 2 | 884 | 23.83 | 22.81 | 24.81 |
| 3 | 884 | 25.78 | 24.81 | 26.75 |
| 4 | 884 | 28.05 | 26.75 | 29.55 |
| 5 | 883 | 33.07 | 29.55 | 57.75 |

| Female WC Quintile | N | mean | min | max |
|---|---|---|---|---|
| 1 | 883 | 66.82 | 49 | 71 |
| 2 | 884 | 73.78 | 71 | 76.1 |
| 3 | 884 | 78.92 | 76.1 | 81.5 |
| 4 | 884 | 84.86 | 81.5 | 88.9 |
| 5 | 884 | 96.36 | 88.9 | 139.5 |