International Journal of Obesity (2009) 33, 1410–1418
 0307-0565/09 $32.00
www.nature.com/ijo

ORIGINAL ARTICLE

Mortality and disability: the effect of overweight and obesity

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Context: Prevalence of obesity is increasing globally. The effect of obesity on mortality and morbidity and its implication on the future prevalence of disability in the older population has not been conclusively analyzed.
Objective: To determine the influence of overweight and obesity on mortality and disability by quantifying the effect in terms of disability-free life expectancy and years lost to disability (YLD) in the older people.
Design, Setting and Participants: For 5980 participants from the Rotterdam Study cohort, regression techniques were used to estimate the association of body mass index (BMI) and waist circumference (WC) separately with mortality, incident disability and recovery from disability. Disability was assessed using the Stanford Health Assessment Questionnaire Disability Index, an activity of daily living scale. Multistate life table methodology was used to calculate life expectancies.
Main Outcome Measures: In total, 15-year mortality risk, 6-year disability incidence, total life expectancy, healthy life expectancy and years of disabled life expectancy.
Results: We observed 2388 deaths. Our analysis revealed no association between body mass index, or WC and mortality in the healthy population. Body mass index and WC were related to disability (‘overweight’ $25 \leqslant \mathrm{BMI} < 30$, odd ratio (OR) = 1.33, 95% confidence interval (CI) (1.10; 1.61), ‘obesity I’ $30 \leqslant \mathrm{BMI} < 35$, OR = 2.03, 95% CI (1.55; 2.65)) and negatively to recovery from disability. We observed an increase of years lost to disability with increasing weight for men (‘normal weight’—4.69 years, ‘overweight’—5.87 years and ‘obesity I’—7.06 years) and for women (‘normal weight’—10.95 years, ‘overweight’—12.82 years, ‘obesity I’—15.17 years and ‘obesity II/III’—13.13 years).
Conclusion: Results do not support the hypothesis that an increased body weight reduces total life expectancy in the older people. Although increased body weight was associated with a higher risk of becoming and remaining disabled. These results remained using WC.
International Journal of Obesity (2009) **33,** 1410–1418; doi:10.1038/ijo.2009.176; published online 29 September 2009

Keywords: mortality; waist circumference; disability; population-based; gender

Overweight and obesity are important determinants of mortality and disability. The increasing prevalence of obesity contributes to a reduction in quality of life. In Europe, more than half of all adults are overweight.[1] Obesity prevalence in the Netherlands has increased dramatically in the last decades and effective strategies to alleviate the societal burden of obesity are needed.[2,3]

Although the literature agrees on the inverse association of obesity and overweight on mortality in young adulthood and middle age,[4–7] consensus is limited when focusing on the older population.[8–11] Research showed an association between increased body mass index (BMI) and the incidence and prevalence of disability.[12,13]

Depending on the balance between mortality and disability risks due to increased body weight, obesity could result in compression or expansion of disability (that is, more or less time spent with disability). Compression of disability toward the end of life is believed to reduce overall costs to society of an aging population.[14] Research that evaluated obesity in relation to both mortality and disability risks by means of multistate life tables yielded contradicting results. The estimates of years lost to disability (YLD) because of overweight and obesity vary between 6 and 10 years depending on age at baseline and sex.[9,11,12,15–17] No difference in YLD attributed to increased mortality risks among obese participants in the adult population in one

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Received 30 January 2009; revised 20 July 2009; accepted 26 July 2009; published online 29 September 2009

study[15] is contrasted by investigations that showed increased total and disability-free life expectancy (DFLE) among obese participants as compared with the normal weight population in other studies.[9,11,12,16,17] Some authors argue that there is a recent change in the relationship between excess body weight, disability and mortality because of the improvements in treating cardiovascular conditions. This suggests that presently the disabling effects of obesity outweigh the mortality effects resulting in expansion of morbidity.[18,7]

Most of the studies mentioned above used BMI as an indicator for overweight and obesity. Particularly in the older population waist circumference (WC) might be a better measure when evaluating obesity-related health risks and all-cause mortality.[19–21]

The aim of this study is to estimate the risk of overweight and obesity on mortality and disability and to quantify the effect in terms of DFLE and YLD in the older people. Using $n = 5980$ participants of 55 years and older from the Rotterdam Study cohort we analyzed the state-specific mortality risk, disability incidence, as well as recovery from disability as a function of BMI and WC adjusting for major confounders. Subsequently, we estimated transition probabilities using a Markov modelling approach and derived DFLE and YLD using a multistate life table. Among the strengths of this investigation is the clinical assessment of outcomes and covariates and the long mortality follow-up.

Data and methods

The Rotterdam Study is a population-based longitudinal study designed to analyze diseases and risk factors for diseases among the older population of 55 years and older in the Ommoord district of Rotterdam, The Netherlands. From June 1990 to August 1993 trained research assistants collected data on health, medication use, medical and family history, and life style factors for $n = 7983$ participants (78% of 10 215 invited to participate) in extensive home interviews. Participants subsequently visited the research center for a clinical examination. Detailed information on the design of the Rotterdam Study has been published elsewhere.[22]

The Rotterdam Study has been approved by the institutional review board (medical ethics committee) of the Erasmus Medical Center and by the review board of the Netherlands Ministry of Health, Welfare and Sports. All participants provided written informed consent.

Data analyzed in this study comprised $n = 5980$ participants from the Rotterdam Study. We excluded participants that did not visit the research center and had no anthropometric measurements ($n = 1073$), that had a BMI <18.5 ($n = 78$) or had not answered the questions regarding smoking behavior ($n = 162$). In addition, we excluded participants who unintentionally lost more than 3.5 kg in the 18 months before baseline measurements ($n = 690$) to account for disease-related weight loss before death.

Anthropometric measures rely on clinical measurements from the baseline investigation in our research center. Height and weight were measured in participants without shoes and heavy clothing and BMI was calculated as kg m^{-2}. We modelled BMI as categorical variable with four categories. 'Normal weight' ranging from $18.5 \leqslant$ BMI <25, 'overweight' $25 \leqslant$ BMI <30, 'obesity I' $30 \leqslant$ BMI <35 and 'obesity II/III' $35 \leqslant$ BMI according to WHO cutoff criteria.[23] WC was measured midway between the lower rib margin and the iliac crest with the participant breathing out gently. We classified WC using different cutoffs for males and females. We constructed three classes for males (WC <94 cm, WC <102 cm and WC $\geqslant 102$ cm) and females (WC <80 cm, WC <88 cm and WC $\geqslant 88$ cm) using clinical cut-points.[24]

We analyzed the influence of BMI and WC on two outcome variables, 15-year mortality and 6-year disability incidence. All participants of the Rotterdam Study were under continuous surveillance; general practitioners' and hospital records as well as death certificates were used for follow-up of deceased participants till the 1 January 2006. Disability status was assessed at baseline and follow-up center visit after 6 years by the Activities of Daily Living from the Stanford Health Assessment Questionnaire Disability Index (HAQ-DI).[25]

The HAQ-DI has proven to be a valid, effective and sensitive tool for the assessment of health status.[26] The HAQ-DI consists of eight categories: *dressing, arising, eating, hygiene, walking, reach, grip and outside activity*. Each of these categories consists of two to four questions inquiring regarding the ability to perform a task 'Are you able to…'. The status of the participant was evaluated as able to perform without difficulty (0), with some difficulty (1), with much difficulty (2) or unable to perform/requiring assistance (3). The highest scoring item determined the overall category score. The mean score of all categories was equivalent to the HAQ-DI ranging from 0.00 to 3.00. In accordance with the literature we used a HAQ-DI $\geqslant 0.5$ to define a participant as at least mildly disabled.[13]

We used Cox proportional hazard regression to estimate the influence of BMI and WC on mortality. The associations between BMI, WC and incidence of disability and recovery from disability 6 years after baseline were estimated using logistic regression. The analysis revealed a significant interaction between BMI and sex ($P < 0.001$), as well as WC and sex ($P \sim 0.03$) in the logistic regression analysis of recovery from disability. We therefore decided to stratify the life table estimations by sex.

The overall effect of overweight and obesity on a persons life in terms of YLD and DFLE can only be assessed taking into consideration the risk of disability and the chances of recovery. We modelled a three-state illness-death model in R (R Foundation for Statistical Computing: Vienna, Austria, 2008) using the Broyden–Fletcher–Goldfarb–Shanno variable metric algorithm in the *R* msm package to account for competing risks between disability and mortality.[27,28]

To increase comparability, we used the following covariates in all regression models. Education was grouped into four categories 'elementary education', 'lower secondary education', 'higher secondary education' and 'tertiary education'. We assessed living situation as a dichotomous variable describing whether the participant lived alone or not. We adjusted for income as the equivalent household income in 1000 Euro per month. Missing values were accounted for by defining a binary variable describing whether or not information on income was available. If the information was not available, the continuous income variable was set to '0' otherwise the income was included. This method of treating missing data is adequate when controlling for limited confounding and if interpretation of the risk estimates of the confounders is no objective of the study.[29,30] A similar approach was taken for the continuous measure of alcohol consumption. Drinking behavior was similarly modelled as 'unknown', 'yes', 'no' and supplemented with information on the daily intake of alcohol in gram. Smoking status was accounted for through the states 'current smoker', 'former smoker' and 'never smoker' accompanied by a continuous measure of smoked pack years of cigarettes.

We constructed a hypothetical Rotterdam Study participant attributing the mean and modal values of the covariates used earlier in the regression models to this participant. The transition probabilities from the disability-free (healthy) to the disabled state or death state and from the disabled state to disability-free or death were derived from this model and used as input for the multistate life table. Empirical 95% confidence intervals (CIs) for the life table measures were calculated using a 250 replicate bootstrap procedure. Unless otherwise indicated all analysis are based on SAS V9.1.3 by the SAS Institute Inc., Cary, NC, USA.

Results

Table 1 shows the baseline characteristics of the overall population as well as stratified by baseline disability status as measured by activities of daily living (ADL). In all, 4620 participants were classified as 'healthy', that is, non-disabled, and 1360 as disabled at baseline. In total, we observed 2388 deaths in our study population over 15 years of follow-up. Out of these, 1530 deaths were registered among the non-disabled population and 858 among the disabled population. People disabled at baseline were older, showed higher measures of anthropometry, and had a lower socioeconomic status as measured by education and income.

Table 2 shows the results of the Cox-regression analysis of body weight, as measured by BMI or WC, and mortality stratified by baseline ADL-disability status. In the population healthy at baseline, the hazard ratios across the categories of BMI or WC lacked statistical significance. The hazard ratio for the overweight population as classified by a BMI between 25 and 30 indicates slightly and nonsignificantly reduced hazards in comparison with the normal weight population (hazard ratio 0.96, 95% CI (0.86; 1.07)). Among disabled participants, overweight (hazard ratio 0.82, 95% CI (0.70; 0.96)) and obesity I (hazard ratio 0.73, 95% CI (0.60; 0.90)) were negatively associated with mortality indicating protective effects. Among the severely obese participants the hazard ratio suggested increased mortality albeit lacking statistical significance. No statistically significant effect on mortality could be observed using WC as underlying measure to classify participants.

Table 3 shows the results of the logistic regression analysis for 6-year disability incidence and recovery from disability. For a healthy obese person the odds of being disabled 6 years later were roughly twice as high as compared with a person of normal weight (OR = 2.03, 95% CI (1.55; 2.65)). The analysis similarly indicated negative associations for BMI and recovery. Being 'overweight' reduced the odds of recovery by one-third (OR = 0.66, 95% CI (0.41; 1.07)). Obesity cut the odds of recovery by more than half (OR = 0.42, 95% CI (0.22; 0.80)). When we applied WC instead of BMI a similar association with disability incidence was observed. Results for the association between WC and recovery from disability were statistically significant only in the highest WC group indicating a strong reduction of the odds of recovery for overweight and obese participants (OR = 0.47, 95% CI (0.27; 0.83)). Modelling the obesity—mortality or obesity—disability relationship using WC was more appropriate than applying the BMI categories according to the Akaike Information Criterion.

The results from the life table analysis were based on the 'normal' Rotterdam study participant and refer to a healthy, that is, non-disabled, 55-year-old population at baseline. Figure 1 shows the joint analysis of BMI on mortality and ADL disability stratified by sex. Overall life expectancy remained largely constant except in the obesity II/III category. DFLE decreased with increasing BMI. At the same time YLD increased gradually over the BMI categories reaching its peak in the 'obesity I' category. Owing to the small sample size in the obesity II/III category among male participants, reliable estimates could not be obtained. Figure 2 shows the same analysis for WC. The influence of overweight and obesity when measured by WC on total life expectancy was negligible. DFLE decreased with increasing WC while YLD increased. Table 4 shows the life table estimations numerically.

Discussion

The general objective of this study was to quantify the effect of overweight and obesity on DFLE and YLD. These analyses showed a limited effect of overweight and obesity on mortality but a significant effect on morbidity as described by incident and persistent ADL disability. As the disabling effects of overweight and obesity exceeded the mortality effects, YLD increased among overweight and obese participants compared with normal weight participants. This finding was valid independent of the approach used to classify overweight and obese individuals.

Table 1 Baseline characteristics of the study population

Label	*Entire population Mean (s.d.)/frequency*	*Non-disabled (ADL) Mean (s.d.)/frequency*	*Disabled (ADL) Mean (s.d.)/frequency*
Population			
n	5980	4620	1360
Female sex	58.63%	54.03%	74.26%
Age at interview (years)	68.85 (8.63)	66.76 (7.40)	75.07 (9.42)
Anthropometry			
BMI (kg m^{-2})	26.55 (3.63)	26.29 (3.41)	27.41 (4.17)
Normal (BMI 18.5–24.9)	34.88%	36.43%	29.63%
Overweight (BMI 25.0–29.9)	48.90%	49.85%	45.66%
Obesity I (BMI 30.0–34.9)	13.80%	12.01%	19.85%
Obesity II (BMI 35.0+)	2.42%	1.71%	4.85%
WC (cm)	90.94 (10.91)	90.15 (10.65)	93.72 (11.40)
WC 1 male: 79 cm $\leqslant$ WC $<$ 94 cm, female: 68 $\leqslant$ WC $<$ 80	30.92%	34.73%	17.61%
WC 2 male: 94 cm $\leqslant$ WC $<$ 102 cm, female: 80 $\leqslant$ WC $<$ 88	30.50%	31.97%	25.35%
WC 3 male: 102 cm $\leqslant$ WC, female: 88 $\leqslant$ WC	38.59%	33.29%	57.04%
Social economic status			
Living situation			
Alone	27.81%	22.86%	44.63%
Partner	64.92%	70.15%	47.13%
Other/unknown	7.27%	6.99%	8.24%
Education			
Elementary	37.34%	32.34%	54.34%
Lower secondary	27.27%	28.98%	21.47%
Higher secondary	26.67%	28.94%	18.97%
Tertiary	8.71%	9.74%	5.22%
Income			
Income not known	14.00%	11.06%	23.97%
Income known	86.00%	88.94%	76.03%
Household equivalent income (1000 Euro/month)	2.19 (1.01)	2.27 (1.03)	1.91 (0.88)
Lifestyle variables			
Smoking			
Smoking current	22.72%	23.66%	17.57%
Smoking former	42.71%	44.89%	35.29%
Smoking never	35.02%	31.45%	47.13%
Pack years of cigarettes smoked (20 cigarettes = pack per day)	16.19 (22.82)	17.06 (22.76)	13.25 (22.79)
Alcohol			
Alcohol unknown	18.70%	13.87%	35.07%
Alcohol no	16.34%	15.30%	19.85%
Alcohol yes	64.97%	70.82%	45.07%
Daily alcohol consumption g/day	10.52 (15.27)	11.10 (15.58)	7.89 (13.49)

Abbreviations: ADL, activity of daily living; BMI, body mass index; WC, waist circumference.

Strength and limitations

Before we discuss our findings, several limitations must be pointed out. In total, 776 participants refused to participate in the follow-up interview. Our non-response analyses showed that these persons had on average a higher BMI. We could not assess their functional status, but if the non-response was related to disability, which is not unlikely, this selection effect could have led to an underestimation of the true effect of obesity and overweight on disability in our analyses. Although the estimation using MSM modelling takes into account arbitrary observation times and unknown states directly before a known transition, for example, death, these participants did not contribute to the estimation of the transition probabilities to the disabled or non-disabled state.

We modelled disability incidence after 6 years. It is likely that we missed incident disability cases and recoveries within this time window. Using the Markov modelling approach we partially accounted for these missed events.[27] Sample size was another limitation especially when we estimated the hazard ratios for recovery from disability. It would have been interesting to distinguish participants in the obesity II/III category (BMI $\geqslant$ 35). However, severely obese participants were rare at baseline.

Further we lacked data on physical activity. The bias resulting from this should be negligible for the mortality

Table 2 Adjusted hazard ratios for the 15-year mortality stratified by disability status[a]

Effect	15 year-mortality—non-disabled			15 year-mortality—disabled		
	Hazard ratio	95% Confidence limits		Hazard ratio	95% Confidence limits	
BMI						
Age	1.118	1.11	1.127	1.14	1.101	1.126
Sex (female vs male)	0.559	0.488	0.64	0.599	0.487	0.736
Normal weight BMI (18.5;25)	1.000			1.000		
Overweight BMI (25;30) vs (18.5–25)	0.962	0.862	1.074	0.818	0.698	0.958
Obesity I BMI (30;35) vs (18.5–25)	1.056	0.89	1.252	0.734	0.601	0.897
Obesity II/III BMI (35+) vs (18.5–25)	1.309	0.86	1.994	1.115	0.795	1.565
AIC	23 645.19			21 096.51		
SBC	23 741.18			21 185.40		
WC						
Age	1.118	1.109	1.126	1.113	1.1	1.127
Sex (female vs male)	0.570	0.493	0.66	0.584	0.465	0.732
WC 1 male: 79⩽WC<94, female: 68⩽WC⩽80	1.000			1.000		
WC 2 male: 94⩽WC<102, female: 80⩽WC<88	1.052	0.923	1.199	1.014	0.803	1.281
WC 3 male:102⩽WC, female: 88⩽WC	1.048	0.914	1.202	1.052	0.846	1.307
AIC	10 813.73			9335.02		
SBC	10 899.31			9413.56		

Abbreviations: AIC, akaike information criterion, BMI, body mass index; SBC, Schwarz Bayesian criteria; WC, waist circumference. [a]All analyses were additionally adjusted for smoking status, pack years of cigarettes smoked in the past, alcohol consumption, alcohol consumption in g day^{-1}, education, income and living situation.

Table 3 Adjusted odds ratios for the 6-year incidence of disability[a]

Effect	6-year—Disability incidence			6-year—Recovery from disability		
	Odds ratio	95% Confidence limits		Odds ratio	95% Confidence limits	
BMI						
Age	1.122	1.106	1.138	0.908	0.879	0.938
Sex (female vs male)	2.095	1.672	2.625	0.548	0.310	0.968
Normalweight BMI (18.5;25)	1.000			1.000		
Overweight BMI (25;30) vs (18.5–25)	1.329	1.095	1.613	0.660	0.406	1.074
Obesity I BMI (30;35) vs (18.5–25)	2.026	1.550	2.648	0.416	0.217	0.797
Obesity II/III BMI (35+) vs (18.5–25)	2.143	1.156	3.972	0.324	0.088	1.201
AIC	3332.26			682.20		
SBC	3448.86			686.69		
WC						
Age	1.119	1.109	1.135	0.906	0.875	0.938
Sex (female vs male)	2.019	1.590	2.566	0.636	0.348	1.160
WC 1 male: 79⩽WC<94, female: 68⩽WC⩽80	1.000			1.000		
WC 2 male: 94⩽WC<102, female: 80⩽WC<88	1.477	1.175	1.857	0.897	0.500	1.609
WC 3 male:102⩽WC, female: 88⩽WC	1.814	1.446	2.277	0.472	0.270	0.828
AIC	3086.75			565.03		
SBC	3195.73			644.09		

Abbreviations: AIC, akaike information criterion, BMI, body mass index; SBC, Schwarz Bayesian criteria; WC, waist circumference. [a]All analyses were additionally adjusted for smoking status, pack years of cigarettes smoked in the past, alcohol consumption, alcohol consumption in g day^{-1}, education, income and living situation.

analysis as overweight and obesity were equally predictive of mortality across different levels of physical activity level in an earlier study.[31] Physical activity is associated with disability independent of overweight or obesity.[32]

Common shortcomings in this type of research are mostly related to improper consideration of confounders such as smoking, sudden, disease-induced weight loss and comorbidities.[33,34] We carefully adjusted for smoking by using

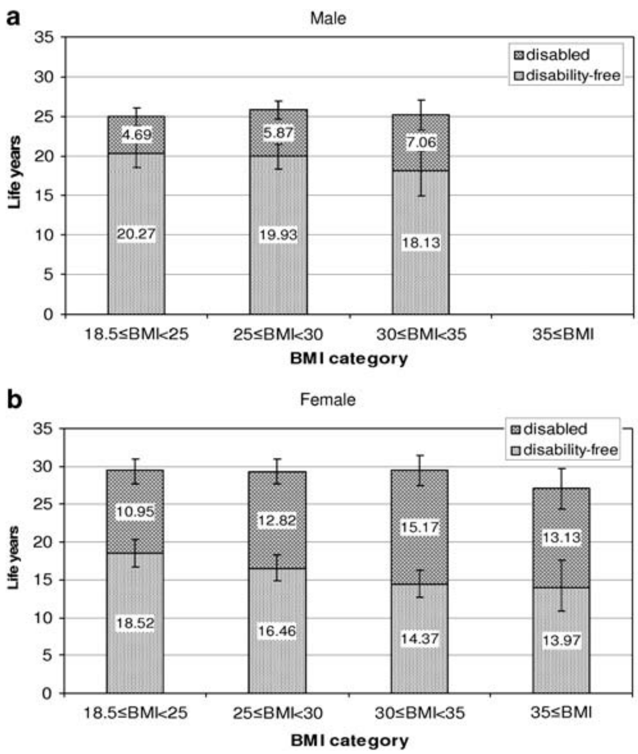

Figure 1 Life expectancies at age 55 by BMI category for the average and non-disabled Rotterdam Study participant stratified by sex.

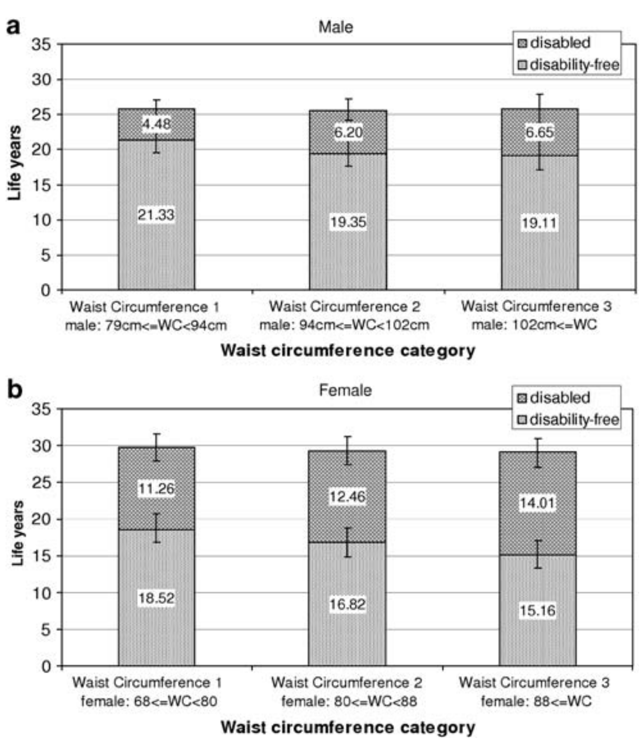

Figure 2 Life expectancies at age 55 by waist circumference category for the average and non-disabled Rotterdam Study participant stratified by sex.

smoking status and the pack years of cigarettes smoked till assessment at baseline and similarly accounted for alcohol consumption, education and socioeconomic status in our analysis. We also excluded $n = 690$ participants that reported unintentional weight loss of more than 3.5 kg in the 18 months before baseline measurements to forestall the effects of disease-induced weight loss on our analysis. We did not control for disease prevalence because diseases are intermediaries in and not confounders to the association between obesity and disability and mortality.

Among the strengths of our study is the assessment of the determinant. Our measurements do not rely on self-reported information but on clinical measurements of BMI and WC in our research center.

Mortality

Our analysis of the association between BMI and mortality in the older people corroborated findings already presented by others in the literature. The negative effects of overweight and obesity on survival are well documented among the young, and working-age population.[35] Among the older population an increase in BMI is not consistently correlated with an increase in mortality risk.[8–10,18] Overweight and obesity have been attributed with protective effects even in the healthy, older population[11] but another study concluded that increased BMI had a hazardous effect on survival. However, participants suffering from chronic disease showed a weaker, maybe even protective association between increased BMI and mortality.[36] Our analysis did not reveal protective effects of an increased BMI or increased WC in the healthy population. People disabled at baseline although seemed to benefit from overweight and even obesity when considering survival.

Why is excess body weight in the older people not detrimental and in the disabled even protective? One hypothesis is related to medical progress. Optimized medical care for chronic diseases and in the treatment of cardiovascular conditions might have halted the negative health effect of increased levels of body fat.[7,18] This could explain our analyses, why overweight and obesity I showed no negative effects on survival, but it cannot serve as an explanation as to why we observed a positive effect on overall survival in the disabled population. It has been argued that overweight and obesity serve as a general nutritional reserve in times of stress and disease.[37,38] In addition, several studies showed that increased BMI is positively associated with survival after critical care,[39,40] but others did not observe this association,[41] or even attribute higher mortality to an increased BMI.[42]

The relationship between WC and mortality is often described a *J*-shaped.[43–45] Increased WC was found to be an independent risk factor for all-cause mortality suggesting that fat distribution might be equally or more important than total body fat.[43] In one study, the authors did not report on a higher likelihood of mortality because of

Table 4 Life table estimates for a normal 55-year-old Rotterdam Study participant stratified by sex

Determinant	*Males*						*Females*					
	TLE	*95% CI*	*DFLE*	*95% CI*	*YLD*	*95% CI*	*TLE*	*95% CI*	*DFLE*	*95% CI*	*YLD*	*95% CI*
BMI												
Normal weight BMI (18.5;25)	24.96	23.41–26.37	20.27	18.58–22.00	4.69	3.54–5.83	29.47	28.16–30.76	18.52	16.75–20.35	10.95	9.20–12.50
Overweight BMI (25;30) vs (18.5–25)	25.80	24.39–27.20	19.93	18.41–21.51	5.87	4.75–7.05	29.28	28.08–30.52	16.46	14.89–18.30	12.82	11.22–14.50
Obesity I BMI (30;35) vs (18.5–25)	25.19	22.87–27.60	18.13	15.65–21.34	7.06	5.19–8.99	29.54	28.04–31.11	14.37	12.67–16.28	15.17	13.14–17.07
Obesity II/III BMI (35+) vs (18.5–25)	Not applicable		Not applicable		Not applicable		27.10	24.85–29.80	13.97	10.84–17.58	13.13	10.34–15.77
WC												
WC 1 male: 79⩽WC<94, female: 68⩽WC⩽80	25.81	24.09–27.73	21.33	19.55–23.16	4.48	3.17–5.79	29.78	28.18–31.44	18.52	16.78–20.68	11.26	9.40–13.12
WC 2 male: 94⩽WC<102, female: 80⩽WC<88	25.56	23.81–27.17	19.35	17.61–21.54	6.20	4.78–7.81	29.29	27.62–30.86	16.82	14.86–18.79	12.46	10.62–14.40
WC 3 male:102⩽WC, female: 88⩽WC	25.76	23.53–27.76	19.11	17.16–21.30	6.65	4.60–8.68	29.17	27.59–30.56	15.16	13.35–17.07	14.01	11.87– 15.80

Abbreviations: BMI, body mass index; DFLE, disability free life expectancy; TLE, total life expectancy; WC, waist circumference; YLD, years lost to disability. A 'normal' participant was defined as a person with mean and modal values of covariates. TLE, DFLE and YLD could not be estimated for obesity II/III among male participants because of limited sample size in this category.

increased WC and increased mortality[46] or only found this association in subgroups.[19,37] We could not confirm a higher risk of mortality with increased WC in our study after stratifying for disability status. This might be because of the categorization of WC in other studies. Most of the literature attributing an additional mortality risk to increased WC categorized WC according to study-specific cutoffs. We decided to adhere to the clinical cutoffs that are included in guidelines on weight management.[24,47]

Disability

Our analysis indicated that overweight and obesity, whether assessed by BMI or WC, increased the odds of disability. As a consequence, more time was spent with disability throughout life. Although it is beyond the scope of this paper to show the effect of obesity on disease-specific outcomes, it is important to realize that different diseases contribute to disability as measured by ADL.[48] Obesity is related to several musculoskeletal conditions that favor disability.[49] Among these conditions are osteoarthritis, low back pain, diffuse idiopathic skeletal hyperostosis, gait disturbance, soft tissue conditions, osteoporosis, gout, fibromyalgia and connective tissue disorders.

Some authors analyzed the association between BMI and upper- and lower limb disability.[12] They concluded that disability risk was higher for obese persons but not consistently so for overweight individuals. Our results differed and indicated a significant increase in disability risk with increasing BMI and WC. In addition, we observed multiplicative interaction between BMI, WC and sex when analyzing recovery from disability. ADL disability is more common among women than men.[50] This is probably because of increased survival and disadvantages in recovery from disability as compared with men.[50,51] Sex differences in mortality, morbidity and physical function have been the focus of scientific investigations. Men are physically stronger than women even at advanced ages and thus more likely to recover from mild disability.[52] The finding that overweight and obesity have a more pronounced effect among the recovery from disability among females could indicate that excess body weight paired with less muscle mass is the most hazardous phenotype.

Life table estimation

In our analysis overweight was associated with early disability but not with early death and there were indications that severe obesity was strongly associated with both mortality and disability. Earlier research showed that obesity was associated with a higher proportion of life spent under ADL disability in adults 70 years and older.[16] Al Snih *et al.*[9] noted that 'overweight' was associated with the highest DFLE in older persons. We found a consistent increase in disabled life years in the overweight and obese category and could not confirm the 'overweight' category to have the highest life expectancy free of ADL disability.

A previous study suggested that declining mortality effects of obesity due to cardiovascular improvements were not accompanied by a reduction in ADL disability among the obese population.[18] Our results similarly indicated that total life expectancy at age 55 for the average Rotterdam Study participant whether male or female remained largely unaffected by overweight and obesity while the YLD increased. An exception to this was found only among severely obese female participants with a BMI $\geqslant$35.

It is an intriguing finding that although there is an average difference of 5 years in total life expectancy between men and women, the same difference cannot be observed when focusing on disease-free life expectancy. Together with the observation of a sex interaction with BMI and WC in the analysis of recovery from disability there is an indication that women are more prone to become (at least) mildly disabled state and that excess bodyweight might adversely affect recovery and increase the duration of disability among females more than among males.

Conclusion

Our analysis consistently showed that the risk of an increased body weight cannot be found in the domain of overall survival but rather in the onset and duration of disability. Using WC to approximate overweight and obesity might be preferable to BMI but it did not change our conclusions. Overweight and obesity were associated with early, and extended periods of disability. In addition, women might be disproportionally affected by the disability risk induced by excess body weight. If the obesity epidemic continues, we could observe an increased burden of disability among the older people in the future. This underlines the importance of preventive actions to halt the obesity epidemic, including among the baby-boom cohorts.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

The Rotterdam Study is supported by the Erasmus Medical Center and Erasmus University Rotterdam, the Netherlands Organisation of Scientific Research (NWO), the Netherlands Organisation for Health Research and Development (ZonMw), the Research Institute for Diseases in the Elderly (RIDE), the Ministry of Education, Culture and Science, the Ministry of Health, Welfare and Sports and the European Commission (DG XII). Stefan Walter is funded by NETSPAR and the NETSPAR theme 'Living Longer in Good Health'. The sponsors had no role in the design or conduct of the study; in the collection, management, analysis or interpretation of the data; or in the preparation, review or approval of the paper.

Author Contributions

Stefan Walter had full access to all data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Walter, Kunst, Tiemeier. Acquisition of the data: The Rotterdam Study Investigators. Analysis and interpretation of the data: Walter, Kunst, Mackenbach, Hofman, Tiemeier. Critical revision of the paper for important intellectual content: Walter, Kunst, Mackenbach, Hofman, Tiemeier. Statistical analysis: Walter. Obtained funding: Mackenbach, Hofman. Study supervision: Kunst, Tiemeier. Additional contributions: Wilma Nusselder, PhD (Department of Public Health, Erasmus MC), Caspar Looman (Department of Public Health, Erasmus MC), and Istvan Majer (Department of Public Health, Erasmus MC) provided technical assistance in the statistical analysis.

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