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The association between BMI and health-related quality of life in the US population: Sex, age, and ethnicity matters

Short running title

The nonlinear relationship between BMI and HRQL

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Summary Box

What is already known on this subject?

- Previous studies have found that overweight and obesity are associated with reduced health-related quality of life (HQRL).
- Only a few studies have investigated the (nonlinear) relationship between body mass index (BMI) and HRQL, and none of these studies investigated sex-, age-, and ethnicity-specific differences.

What does this study add?

- This study uses representative data from the US population to describe the sex-, age-, and ethnicity-specific BMI–HRQL relationship.
- Results show that the relationship differs substantially between men and women and between white, black, and Hispanic people, and that particularly many overweight men report higher HRQL than normal weight peers.
- Findings suggest a more differentiated use of BMI cutoffs in scientific discussions and daily practice.

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Abstract

Background

Obesity is a major public health problem. Detailed knowledge about the relationship between body mass index (BMI) and health-related quality of life (HRQL) is indispensable in deriving effective and cost-effective prevention and weight management strategies. This study aims to describe the sex-, age-, and ethnicity-specific association between BMI and HRQL in the US adult population.

Methods

Analyses are based on pooled cross-sectional data from 41,459 participants in the Medical Expenditure Panel Survey (MEPS) Household Component (HC) for the years 2000–2003. BMI was calculated using self-reported height and weight, and HRQL was assessed with the EuroQol five-dimensional questionnaire. Generalized additive models (GAMs) were fitted with a smooth function for BMI and a smooth-factor interaction for BMI with sex adjusted for age, ethnicity, poverty, smoking, and physical activity. Models were further stratified by age and ethnicity.

Results

The association between BMI and HRQL is inverse U-shaped with a HRQL high point at a BMI of 22 kg/m^2 in women and a HRQL high plateau at BMI values of 22–30 kg/m^2 in men. Men aged 50 years and older with a BMI of 29 kg/m^2 reported on average 5-point higher visual analog scale (VAS) scores than peers with a BMI of 20 kg/m^2. The inverse U-shaped association is more pronounced in older people, and the BMI–HRQL relationship differs between ethnicities. In Hispanics, the BMI associated with the highest HRQL is higher than in white people and, in black women, the BMI–HRQL association has an almost linear negative slope.

Conclusions

The results show that a more differentiated use of BMI cutoffs in scientific discussions and daily practice is indicated. The findings should be considered in the design of future weight loss and weight management programs.

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Background

Excess weight is one of the major public health problems in the USA and other western countries. The most popular measure to define weight status is the body mass index (BMI). This measure relates the weight of individuals to their height (BMI=weight [kg]/height [m]^2). According to US dietary guidelines, healthy weight is defined as a BMI of 18.5–24.9, overweight as a BMI of 25–29.9, and obese as a BMI of ≥30 [1]. Using these criteria, according to the 2012 National Health and Nutrition Examination Survey (NHANES), 27.3% and 27.7% of non-institutionalized US women and 41.3% and 28.2% of US men aged >20 years are overweight or obese respectively [2].

In recent decades, a growing body of literature has described the association between BMI, risk factors, chronic diseases, health care costs, and mortality in various substrata of different populations [1–8]. There is solid evidence that the association between BMI and mortality is U- or J-shaped with lowest mortality in the healthy weight category, modestly increased risk in the overweight category, and substantially greater mortality risk for underweight and obese individuals [4, 6, 7]. Other studies have shown that the risk for cardiovascular risk factors such as hypertension, diabetes, or dyslipidemia increases almost linearly [2, 3], but that this association differs substantially among ethnicities [3, 8]. A study by Cawley and Meyerhoefer also reports substantial sex differences in the U-shaped relationship between BMI and health care costs [5].

In contrast to the intensively researched association of BMI, risk factors, mortality, and health care costs, less is known about the relationship between BMI and health-related quality of life (HRQL) in different subpopulations. HRQL is a multi-dimensional concept capturing the dimensions of physical functioning and psychological and social well-being, and is therefore a very important patient-relevant outcome [9]. Methods have been developed to transform health states to community preferences, which can be used to derive quality adjusted life years (QALYs), an established measure for burden of disease estimations and economic evaluations. Detailed knowledge about the relationship between weight and HRQL is therefore helpful in designing effective and cost-effective obesity prevention strategies. Previous studies have shown that the association between BMI and HRQL in the US

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population is inverse U-shaped with an optimum of several HRQL measures at a BMI of around 25 [10]. Studies from Germany and China have reported a similar functional relationship [11–13]; however, little is known about sex-, age, and ethnicity-specific differences.

This study aims to describe and analyze the sex-specific functional form of the nonlinear relationship between BMI and HRQL in the US population with consideration of age and ethnicity.

Methods

Data source

Analyses are based on pooled data from the MEPS Household Component (HC) for the years 2000–2003 administered by the Agency for Healthcare Research [14]. The MEPS-HC collects data from a sample of families and individuals in selected communities across the USA drawn from a nationally representative subsample of households that participated in the previous year's National Health Interview Survey [15]. The MEPS is designed as a series of overlapping panel surveys, and each year comprises data from two consecutive panels. We pooled the data from the MEPS-HC for the years 2000 (panels 4 and 5, n=23,839, participation 70.5%), 2001 (panels 5 and 6, n=32,122, participation 71.4%), 2002 (panels 6 and 7, n=37,418, participation 69.2%), and 2003 (panels 7 and 8, n=32,681, participation 68.9%) in which HRQL was comprehensively assessed. This pooled sample comprises 126,060 observations from 79,608 participants, i.e., the sample includes 33,156 participants with only one observation and 46,452 participants with two observations from consecutive years.

In a first step, we excluded 38,203 observations where the age of the participants was below 18 years, as they did not answer the HRQL questionnaire. In a second step, we excluded 17,391 observations where the self-administered questionnaire (SAQ) was answered by a proxy, as it is known that the use of proxies for QoL assessment is difficult [16]. To avoid dependency of the data, we finally omitted the second observation from participants with repeated observations (23,189). This resulted in a pooled cross-sectional sample of 47,277 unique observations. This selection procedure is illustrated in **Table 1**.

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All participants provided informed consent, and the study was approved by the Westat institutional review board (MPA M-1531).

Measures

Body Mass Index: The MEPS-HC includes questions about the individual's height and weight. The BMI was calculated by transforming feet and inches into SI units and dividing the self-reported weight in kilograms by squared self-reported height in meters (BMI=weight [kg]/height $[m]^2$).

Health-related Quality of Life: In the years 2000–2003, a self-administered and mail-back questionnaire (SAQ) was distributed to all household respondents aged 18 years and older including the EuroQol five-dimensional questionnaire (EQ-5D-3L). The EQ-5D-3L consists of a descriptive system with five dimensions (mobility, self-care, usual activities, pain/discomfort, and anxiety/depression), each of which has three response levels (no problems/some or moderate problems/extreme problems) and a visual analog scale (VAS). Health states from the descriptive system were transformed into preference-based utility values using a scoring algorithm based on time trade-off valuations in the US population [17]. Utility values range between –0.109 and 1.00 and VAS scores between 0 and 100.

Covariates: Self-reported information about age, sex, race (defined as "white", "black", Hispanic, Asian and Pacific Natives, native American), poverty status (five categories), smoking status (yes/no), physical activity (at least 30 min of moderate to vigorous physical activity per day), and history of diabetes, coronary heart disease, asthma, myocardial infarction, and stroke (yes/no) were assessed in the computer-assisted interviews. Poverty status was defined as the ratio of the family income to the corresponding federal poverty thresholds, controlling for family size and age of the head of the family and classified into five categories (<100% poverty threshold, 100–124% poverty, 125–199% poverty, 200–399% poverty, ≥400% poverty) [18].

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Statistical analyses

Sample characteristics are provided for the weight categories underweight (BMI<18.5 kg/m^2), normal/healthy weight (18.5≥BMI>25 kg/m^2), overweight (25≥BMI>30 kg/m^2), obesity class 1 (30≥BMI>35 kg/m^2), obesity class 2 (35≥BMI>45 kg/m^2), and obesity class 3 (BMI>45 kg/m^2).

The nonlinear relationship between BMI and HRQL in women and men was analyzed using generalized additive models (GAMs). A GAM with a factor-smooth interaction between sex (factor) and BMI (smooth function) was fitted. This model can be notated as

$$Y_i = \beta_0 + [f_{BMI,\ SEX}\,(BMI_i) \times \mathrm{I}(x_{sex} = 1)] + [f_{BMI,\ \overline{sex}}\,(BMI_i) \times \mathrm{I}(x_{\ sex} = 0)] + \beta_{sex}\, x_{sex} + \boldsymbol{\beta}\, \boldsymbol{x_i^T} + \varepsilon_i$$

where Y_i is the response of the individual i, f_{BMI} is the nonparametric smooth function of the covariate BMI, $\beta_{sex}\, x_{sex}$ is the main effect of the predictor variable sex, $\boldsymbol{\beta x_i^T}$ is the linear predictor of other categorical covariates, and ε_i is the error terms, which are assumed to be normally distributed. Models were adjusted for age, smoking status, race, family poverty, and physical activity. Observations with implausible BMI values (BMI<10 or BMI>60) and those with missing BMI or HRQL values or covariate values were excluded from the analyses, leading to a final analysis sample of n=41,459 observations (**Table 1**). The estimation of the additive model was carried out using the statistical software R (version 3.1.0) applying the mgcv package.

Sensitivity analyses

It is known that people systematically over- or underestimate their height and weight and that there are also systematic differences in reporting errors between men and women. We therefore repeated the analyses with sex-, race- (white, black, Hispanic), and weight category (BMI<25, 25<BMI<30, BMI>30)-specific weight and height corrections, as suggested by McAdams et al. based on data from the NHANES III study [19]. Previous studies have shown that smoking is a particularly important confounder, i.e., a factor determining weight and HRQL [4]. We therefore applied a stratified analysis for smoking status. In addition, we fitted one model in which the potential confounders or mediators

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diabetes, heart disease, asthma, myocardial infarction, and stroke were included as covariates, and one model in which all participants with these chronic conditions were excluded from the analysis.

Results

Sample characteristics

The mean age in the analysis sample of 41,459 participants is 44.8 years. Some 55.6% of participants were female and 63.3% of participants were white, 20.3% Hispanic, and 12.5% black. Mean BMI was 27.2. Overall, 1.9% were underweight, 36.5% normal weight, 35.7% overweight, 16.2% in obesity class 1, 6.2% in obesity class 2, and 3.5% in obesity class 3. Overweight was more prevalent in men and severe obesity more common in women. Obesity was more prevalent in black people and in people with low income (**Table 2**).

Relationship between BMI and HRQL in women and men

Table 3 shows the estimated regression coefficients from the overall additive model with the factor-smooth interaction sex*BMI. Older age, family poverty, smoking, and not being physically active were associated with impaired EQ-VAS and EQ-5D scores.

The estimated smooth functions in **Figure 1** show the nonlinear relationship between BMI and HRQL in women and men. In both genders, the association between BMI and HRQL is inverse U-shaped (p-values <0.0001). In women, highest VAS and EQ-5D index values are associated with a BMI of 22 kg/m^2. After this high point, HRQL declines almost linearly by ≈0.4 points (VAS) and ≈0.004 points (EQ-5D index) per BMI point. In men, a plateau of highest VAS and EQ-5D index values occurs at BMI values of 23–29 kg/m^2. The decline in VAS and EQ-5D values beyond this plateau averages ≈0.6 points and ≈0.006 points per BMI point respectively. For men with a BMI of >52 kg/m^2, HRQL seems to increase again; however, few people are in this group and confidence intervals become very large.

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Relationship between BMI and HRQL stratified by age groups

Figure 2 depicts the relationship between BMI and HRQL in different age categories. The inverse U-shaped association is more pronounced in older people. Particularly for the VAS, the curves between men and women aged 50 years and older deviate substantially. Whereas HRQL declines in women with increasing BMI values after a BMI high point of around 22 kg/m^2, HRQL has a high plateau at a BMI of 23–29 kg/m^2 in men.

Relationship between BMI and HRQL stratified by ethnicity

Figure 3 illustrates the association between BMI and HRQL in white, black, and Hispanic people. No model was fitted for Asians, as the sample size was too small to receive stable estimates. Similar to the overall model, the relationship in white people shows a clear inverse U-shaped form with highest HRQL values at a BMI of around 22 kg/m^2 in women and 22–28 kg/m^2 in men. In Hispanics, highest HRQL values are observed at a BMI of 21.5–24 kg/m^2 in women and at a BMI of 27–28 kg/m^2 in men. The functional form of the relationship in black men is also inverse U-shaped. However, in contrast, the association is almost linear in black women with a continuous negative slope.

Sensitivity analyses

The application of BMI adjustments to reduce systematic errors in height and weight self-reports according to table 3 in McAdams et al. showed an attenuated U-curve with a qualitatively similar pattern (**Appendix 1**) [19]. Adjustment for various chronic diseases (diabetes, coronary heart disease, asthma, myocardial infarction, and stroke) that can be expected to be causally influenced by weight status attenuated the nonlinear U-shaped association slightly; however, qualitatively, the BMI–HRQL association looks quite similar (**Appendix 2**). The reduction of the sample to people without a chronic comorbidity (diabetes, heart disease, asthma, myocardial infarction, and stroke) produced similar findings (**Appendix 3**). Also, the stratification for smoking status shows qualitatively similar patterns in smokers and nonsmokers (**Appendix 4**).

Discussion

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Summary

HRQL is a central patient-relevant outcome. Detailed knowledge on the association between weight status and HRQL is important for designing prevention strategies and identifying population subgroups in which weight management programs are potentially most cost-effective.

The results of this study indicate that the association between BMI and HRQL differs according to sex, age, and ethnicity. Overall, the association between BMI and HRQL is inverse U-shaped with a HRQL high point at around 22 kg/m^2 in women and a HRQL high plateau at BMI values of 22–29 kg/m^2 in men. The functional form of the BMI–HRQL relationship differs between ethnicities. Whereas the association has an almost linear negative slope in black women, the curve in black men is distinctively inverse U-shaped.

Comparison with previous findings

The results of this study add valuable information to the current body of literature on the association between BMI and HRQL. Based on data from the MEPS for the year 2000, Jia and Lubetkin showed that, compared to normal weight, underweight (–3.8 points), class 1 obesity (–3.2 points), and class 2 obesity (–4.8 points), but not overweight, are associated with decreased HRQL on the EQ5D-VAS [10]. Qualitatively similar results with varying effect sizes are known from other studies in Caucasian populations [20, 21]. Studies that used the SF-12 or the SF-36 instrument to measure HRQL indicated that obesity has a stronger negative impact on the physical component of HRQL than on the mental component of HRQL [10, 22, 23]. Authors using nonlinear modeling techniques have reported inverse U-shaped relationships between BMI and HRQL with highest EQ-5D index values at BMI values of 21 kg/m^2 (England) [13], 24.5 kg/m^2 in women and 26 kg/m^2 in men (England) [24], 23.4 kg/m^2 in women and 26.3 kg/m^2 in men (Germany) [11], and 24 kg/m^2 in women and 23 kg/m^2 in men (China) [12]. In this study, we concentrated on the EQ-5D index and the EQ-5D-VAS, which are one-dimensional HRQL valuations. Our results are similar to those from the studies in Germany and England showing that the HRQL high point in men is at a higher BMI value than in women. Bentley et al. found that the effect of obesity on EQ-5D values in black people is larger than in non-black people (USA) [22]. Our results

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based on a much larger sample do not support this finding and show that the relationship between BMI and HRQL in black people differs remarkably between women and men. Little evidence is available on the association between BMI and HRQL in different age strata. Our results indicate that the inverse U-shaped association between men and women is more pronounced in older people.

One common finding from this and other studies using a nonlinear analysis method is the steep slope of HRQL deterioration below a BMI of 20 kg/m^2 [11, 12, 24]. The slope in the lower "healthy weight" and the "underweight" categories is steeper than the slope in the "overweight" and "obesity" categories. Whether this relationship is causal or whether this finding is the subject of confounding remains unknown. However, as our models and also the models in other studies are adjusted for major chronic diseases, it can be expected that confounding explains this strong association only partially [11, 12, 24].

BMI ranges with highest HRQL and definition of "healthy weight"

Observational studies on the association between BMI and mortality have shown a mortality nadir at BMI values of 21–25 kg/m^2, indicating that the originally rather arbitrarily set cutoffs might be a reasonable choice [4, 6, 7, 25]. Mortality is a highly relevant outcome that is easy to assess; however, it is also a distant outcome and ignores people's current well-being and HRQL. As mentioned by Stevens, a good outcome to judge the applicability of weight status definitions would comprise length and quality of life [25]. As lifetime panel data that capture BMI, HRQL, and mortality are scarce, the use of cross-sectional HRQL data is of great value [26].

For women, the highest HRQL values are observed in the "healthy/normal weight" category and lower HRQL values in the underweight, overweight, and obesity categories. However, in men, we observed a HRQL high plateau at BMI values of 22–29 kg/m^2. This means that the majority of overweight men report higher or equally high HRQL as their "healthy/normal weight" peers. For example, older men report 4- to 5-point higher VAS scores and 0.025-point higher EQ-5D scores at a BMI of 29 kg/m^2 (close to the "obesity" category) than at a BMI of 20 kg/m^2 ("healthy weight" category). The reason for the observed gender differences in the association between BMI and HRQL cannot be revealed with the current approach. However, the fact that BMI often overestimates

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adiposity in men could be one reason. In a diverse Australian sample, compared with women, excess weight in men was largely attributable to greater muscle and bone tissue [27]. The reason for the differences between ethnicities also remains unknown. Differences in risk factor–disease associations or differences in the valuations of health conditions could be possible explanations [3, 8, 28, 29].

In light of our results, a more differentiated use of BMI cutoffs in research, communication, and clinical practice is indicated, particularly as the stigma associated with “overweight” or “obese” categorization can cause substantial damage [30].

Implications for the design of prevention strategies

Observational studies show that costs in men are lowest at a BMI of 30 kg/m^2 and increase substantially for normal weight and obese people [5] and that mortality is only increased modestly in the overweight category [4, 6, 7]. Our observational study shows that HRQL in the overweight category is equal to or higher than in the normal weight category in the male US population. If these found associations reflected causality, costly weight loss programs for overweight men might result in modestly decreased mortality, unchanged or lower HRQL, and higher medical costs, yielding a potential negative societal net benefit. The knowledge of sex-, age-, and ethnicity-specific associations between BMI and HRQL might therefore be useful to tailor intervention strategies.

Clinical relevance

To decide whether these results have clinical relevance, values of clinical minimal important difference (CMID) or HRQL deteriorations associated with severe conditions can be used as references. Previous studies have reported that the disease- or intervention-unspecific CMID averages 0.071 for the UK EQ-5D index [31]; however, little is known about CMID for the VAS. For the general US population, Jia and Lubetkin reported VAS deteriorations of –3.64, –5.47, –7.65, and –5.36 and EQ-5D index (UK tariff) deteriorations of –0.045, –0.042, –0.083, and –0.080 for the conditions asthma, diabetes, heart disease, and stroke respectively [10]. In light of these numbers, BMI differences of 5–10 kg/m^2 seem to be clinically relevant.

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Strengths and limitations

A significant strength of this study is the use of a large population-based data source, which approximately represents the US population. Furthermore, the use of GAMs allows efficient and flexible modeling of the nonlinear association between BMI and HRQL.

This study also has some limitations. The biggest limitation is its cross-sectional design. Although models are adjusted for a few important socio-demographic factors, the results of the analyses describe correlations. Whether these correlations describe causality remains unknown. In particular, missing information on important confounders such as cancer might have biased the effect estimates. Instrumental variable approaches that use, for example, the weight status of biological children as an instrument might be helpful in revealing causal relationships. However, the application of such methods shrinks the sample size considerably and prevents detailed sex-, age-, and ethnicity-stratified comparisons [5]. The authors of previous studies often adjusted models for various chronic disease conditions such as asthma, diabetes, heart disease, and stroke to avoid confounding [10, 11]. We think many of these conditions are rather the result of excess weight, i.e., lie on a causal chain between BMI and HRQL. We therefore did not adjust our main models for these diseases. Furthermore, all information about height and weight is self-reported, and it is known that the systematic over- and underestimation of height and weight differs among subgroups. We tried to control this bias by applying sex-, age-, and ethnicity-specific BMI corrections from a US study comparing measured and self-reported height and weight [19]. In addition, the exclusion of observations with proxy information on HRQL might limit the representativeness of our findings. As additional analyses showed that those excluded observations differ only marginally in terms of age, sex, income, and ethnicity/race, this limitation is quite small. Finally, analyses were conducted using the mgcv package in R. It is not possible to account for the cluster sampling design of MEPS participants in this package, and therefore reported adjusted means and standard errors might deviate from what can be expected in the general US population.

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Conclusions

The nonlinear association between BMI and HRQL is sex, age, and ethnicity specific. These differences should be considered in tailoring public health prevention weight management strategies. BMI values with the highest HRQL in men do not overlap with the universal BMI cutoff definitions for “healthy” weight, indicating more differentiated use of BMI cutoffs in scientific discussions and daily practice.

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Author contributions

ML was responsible for the design of the study, carried out some parts of the statistical analyses, and drafted the manuscript. CK carried out the main part of the statistical analyses and commented on drafts of the manuscript. CT and RH commented on drafts of the manuscript. All authors read and approved the final version of the manuscript.

Data availability

The MEPS data are publicly available from https://meps.ahrq.gov/data_stats/download_data_files.jsp. The R code used to produce Tables 1–3, Figures 1–3, and Appendices 1–4 can be downloaded from https://gist.github.com/krz/5be44f1128de0f326b81a1d9d325c314.

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Conflict of interest

None of the authors has any conflict of interest.

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Figure Legends

Figure 1: Relationship between BMI and HRQL in women and men

*********************************** Figure 1**************************************

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The solid curves represent the estimated smooth functions of the nonlinear association between BMI and EQ-5D-VAS and EQ-5D utility index using a thin plate regression spline function adjusted for age, income, ethnicity, smoking, and physical activity. The shaded areas represent approximate 95% pointwise confidence intervals. Vertical lines represent BMI values with highest estimated HRQL. Effective estimated degrees of freedom equal 5.05 for the EQ-5D VAS in women, 7.04 for the EQ-5D VAS in men, 6.09 for the EQ-5D utility index in women, and 6.86 for the EQ-5D utility index in men.

Figure 2: Relationship between BMI and HRQL stratified by age groups

************************************ Figure 2**************************************

The solid curves represent the estimated smooth functions of the nonlinear association between BMI and EQ-5D-VAS and EQ-5D utility index using a thin plate regression spline function, stratified for age and adjusted for income, ethnicity, smoking, and physical activity. The shaded areas represent approximate 95% pointwise confidence intervals. Vertical lines represent BMI values with highest estimated HRQL. Effective estimated degrees of freedom equal 4.71 for the EQ-5D VAS in women aged <30 years, 7.29 for the EQ-5D VAS in men aged <30 years, 4.54 for the EQ-5D utility index in women aged <30 years, 4.17 for the EQ-5D utility index in men aged <30 years, 6.72 for the EQ-5D VAS in women aged 30–50 years, 4.92 for the EQ-5D VAS in men aged 30–50 years, 4.81 for the EQ-5D utility index in women aged 30–50 years, 8.03 for the EQ-5D utility index in men aged 30–50 years, 4.10 for the EQ-5D VAS in women aged >50 years, 5.96 for the EQ-5D VAS in men aged >50 years, 6.14 for the EQ-5D utility index in women aged >50 years, and 5.07 for the EQ-5D utility index in men aged >50 years.

Figure 3: Relationship between BMI and HRQL stratified by ethnicity

************************************ Figure 3**************************************

The solid curves represent the estimated smooth functions of the nonlinear association between BMI and EQ-5D-VAS and EQ-5D utility index using a thin plate regression spline function, stratified for ethnicity and adjusted for age, income, smoking, and physical activity. The shaded areas represent approximate 95% pointwise confidence intervals. Vertical lines represent BMI values with highest estimated HRQL. Effective estimated degrees of freedom equal 5.08 for the EQ-5D VAS in white women, 6.70 for the EQ-5D VAS in white men, 6.52 for the EQ-5D utility index in white women, 5.25 for the EQ-5D utility index in white men, 2.48 for the EQ-5D VAS in black women, 4.58 for the EQ-5D VAS in black men, 2.24 for the EQ-5D utility index in black women, 6.55 for the EQ-5D utility index in black men, 3.41 for the EQ-5D VAS in Hispanic women, 4.08 for the EQ-5D VAS in Hispanic men, 3.89 for the EQ-5D utility index in Hispanic women, and 3.72 for the EQ-5D utility index in Hispanic men.

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Table 1: Description of the used data of the Medical Expenditure Panel Surveys of the year 2000-2003

	year 2000	year 2001	year 2002	year 2003	**pooled, all obs.**	**pooled, unique obs.**
Response (%)	71	71	69	69	70	-
Panel 4 (n)	13,170					
Panel 5 (n)	10,669	10,298				
Panel 6 (n)		21,824	20,890			
Panel 7 (n)			16,528	16,000		
Panel 8 (n)				16,681		
Total sample (n)	**23,839**	**32,122**	**37,418**	**32,681**	**126,060**	**79,608**
Exclusion of …						
observations aged <17 years (n)					*- 38,203*	-23,938
observations with a proxy SAQ (n)					*- 17,391*	- 8,393
Reduced sample (n)					**70,466**	**47,277**
Exclusion of …						
repeated observations (n)					*- 23,189*	
Reduced sample, unique obs. (n)					**47,277**	**47,277**
Exclusion of …						
observations with missing data* (n)					*- 5,818*	
Final analysis sample, unique obs. (n)					**41,459**	**41,459**

* participants with missing BMI, HRQL or covariate values

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Table 2: Sample characteristics

		all		underweight (BMI<18.5)		normal weight (18.5≤BMI<25)		overweight (25≤BMI<30)		obesity class 1 (30≤BMI<35)		obesity class 2 (35≤BMI<40)		obesity class 3 (BMI≥40)		
		n	%	n	%	n	%	n	%	n	%	n	%	n	%	
Total		41,459	100.0%	796	1.9%	15,146	36.5%	14,808	35.7%	6,721	16.2%	2,551	6.2%	1,437	3.5%	⊢
Gender	male	18,424	44.4%	202	25.4%	5,654	37.3%	8,091	54.6%	3,113	46.3%	950	37.2%	414	28.8%	⊣
	female	23,035	55.6%	594	74.6%	9,492	62.7%	6,717	45.4%	3,608	53.7%	1,601	62.8%	1,023	71.2%	⊣
Age	18–29 years	9,176	22.1%	337	42.3%	4,402	29.1%	2,710	18.3%	1,048	15.6%	433	17.0%	246	17.1%	⊣
	30–49 years	17,117	41.3%	228	28.6%	5,825	38.5%	6,250	42.2%	2,936	43.7%	1,190	46.6%	688	47.9%	⊣
	≥50 years	15,166	36.6%	231	29.0%	4,919	32.5%	5,848	39.5%	2,737	40.7%	928	36.4%	503	35.0%	⊣
Race/ethnicity	white	26,247	63.3%	500	62.8%	10,235	67.6%	9,272	62.6%	3,969	59.1%	1,496	58.6%	775	53.9%	⊣
	black	5,168	12.5%	90	11.3%	1,443	9.5%	1,724	11.6%	1,060	15.8%	474	18.6%	377	26.2%	⊣
	Hispanics	8,399	20.3%	125	15.7%	2,585	17.1%	3,328	22.5%	1,547	23.0%	542	21.2%	272	18.9%	⊣
	Asian	1,299	3.1%	74	9.3%	784	5.2%	352	2.4%	69	1.0%	16	0.6%	4	0.3%	⊣
	native American	346	0.8%	7	0.9%	99	0.7%	132	0.9%	76	1.1%	23	0.9%	9	0.6%	⊣
Income	<100% poverty	5,537	13.4%	140	17.6%	1,947	12.9%	1,802	12.2%	928	13.8%	426	16.7%	294	20.5%	⊣
	100–124% poverty	2,002	4.8%	57	7.2%	660	4.4%	675	4.6%	378	5.6%	143	5.6%	89	6.2%	⊣
	125–199% poverty	6,101	14.7%	147	18.5%	2,109	13.9%	2,141	14.5%	1,044	15.5%	409	16.0%	251	17.5%	⊣
	200–399% poverty	12,877	31.1%	207	26.0%	4,571	30.2%	4,649	31.4%	2,154	32.0%	848	33.2%	448	31.2%	⊣
	≥400% poverty	14,942	36.0%	245	30.8%	5,859	38.7%	5,541	37.4%	2,217	33.0%	725	28.4%	355	24.7%	⊣
Smoking	yes	9,349	22.5%	254	31.9%	3,734	24.7%	3,212	21.7%	1,368	20.4%	512	20.1%	269	18.7%	⊣
Physical activity*	yes	23,030	55.5%	408	51.3%	9,357	61.8%	8,488	57.3%	3,223	48.0%	1,059	41.5%	495	34.4%	⊣
Asthma	yes	3,805	9.2%	57	7.2%	1,200	7.9%	1,223	8.3%	719	10.7%	361	14.2%	245	17.0%	⊢
Diabetes	yes	2,815	6.8%	11	1.4%	467	3.1%	910	6.1%	745	11.1%	395	15.5%	287	20.0%	⊢
Coronary Heart Disease	yes	1,212	2.9%	20	2.5%	335	2.2%	445	3.0%	254	3.8%	99	3.9%	59	4.1%	⊢
Myocardial Infarction	yes	1,196	2.9%	18	2.3%	331	2.2%	452	3.1%	233	3.5%	107	4.2%	55	3.8%	⊢
Stroke	yes	899	2.2%	29	3.6%	278	1.8%	327	2.2%	160	2.4%	64	2.5%	41	2.9%	⊢

* moderate or vigorous physical activity of 30 min at least three times a week; ⊣ column percent; ⊢ row percent

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Table 3: Estimated regression coefficients from the overall additive model with a factor-smooth interaction

		EQ-VAS				EQ-5D index			
		ß	SE	p-value		ß	SE	p-value	
Intercept		83.0	0.4	2E-16	***	0.904	0.003	2E-16	***
Sex*BMI(smooth)	women	see figure 1		<2e-16	***	see figure 1		<2e-16	***
	men	see figure 1		<2e-16	***	see figure 1		<2e-16	***
Age (years)		-0.2	0.0	2E-16	***	-0.002	0.000	2E-16	***
Race/ethnicity	white	ref.				ref.			
	black	0.7	0.3	0.00504	**	0.003	0.002	0.24784	
	Hispanics	1.1	0.2	7.48E-07	***	0.017	0.002	2E-16	***
	Asian	-0.9	0.5	0.04131	*	0.024	0.004	3.69E-08	***
	native American	-1.3	0.9	0.14223		-0.023	0.008	0.00548	**
Income	<100% poverty	ref.				ref.			
	100–124% poverty	3.7	0.4	2E-16	***	0.028	0.004	1.37E-12	***
	125–199% poverty	4.1	0.3	2E-16	***	0.043	0.003	2E-16	***
	200–399% poverty	7.0	0.3	2E-16	***	0.065	0.002	2E-16	***
	≥400% poverty	9.4	0.3	2E-16	***	0.088	0.002	2E-16	***
Smoking	yes	-4.7	0.2	2E-16	***	-0.043	0.002	2E-16	***
Physical activity¯	yes	4.5	0.2	2E-16	***	0.035	0.002	2E-16	***
		R-sq.(adj) = 0.156, n = 41,459				R-sq.(adj) = 0.156, n = 41,459			

¯moderate or vigorous physical activity of 30 min at least three times a week, * p<0.05, ** p<0.01, *** p<0.001

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Figure 1:

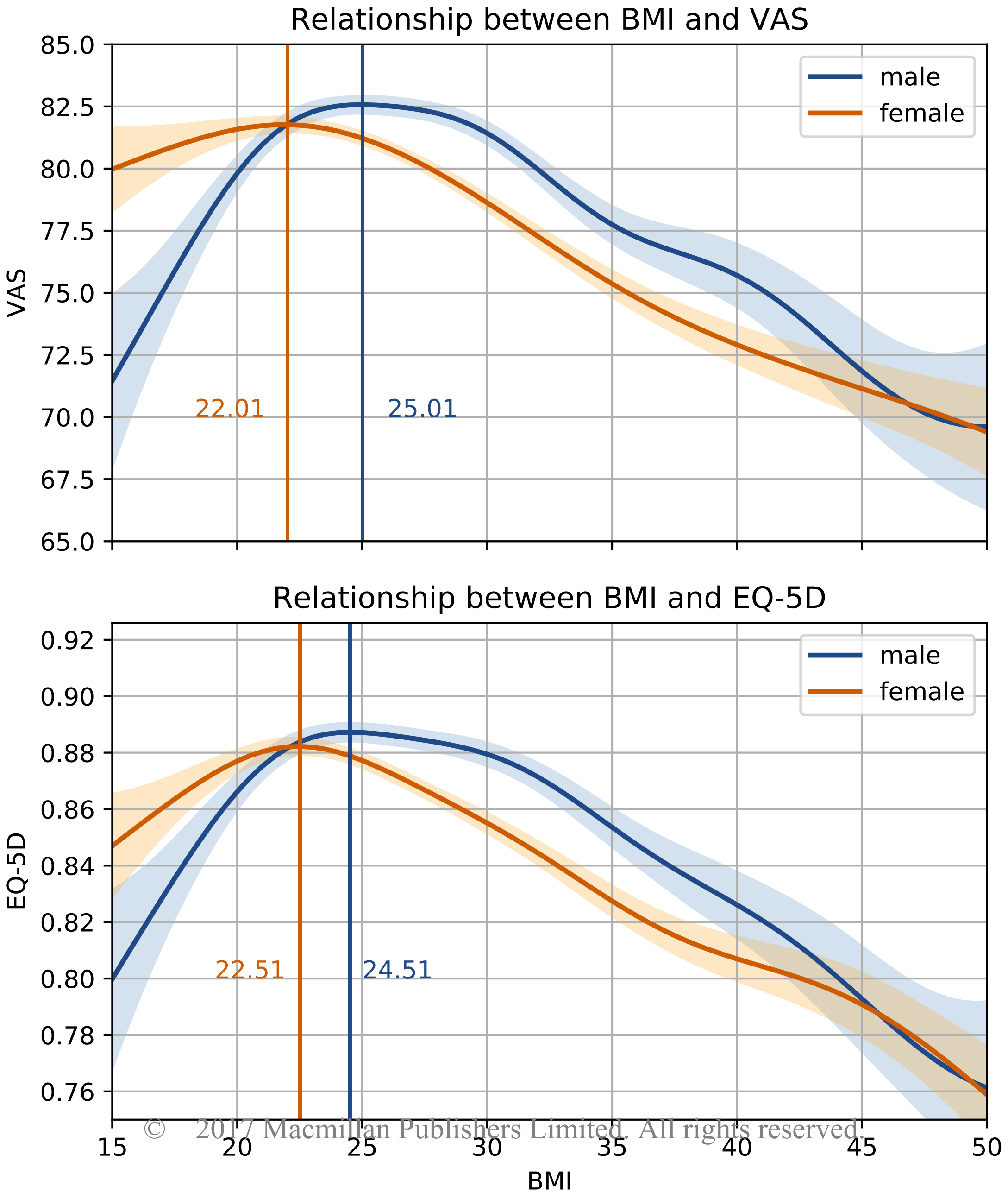

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Figure 2:

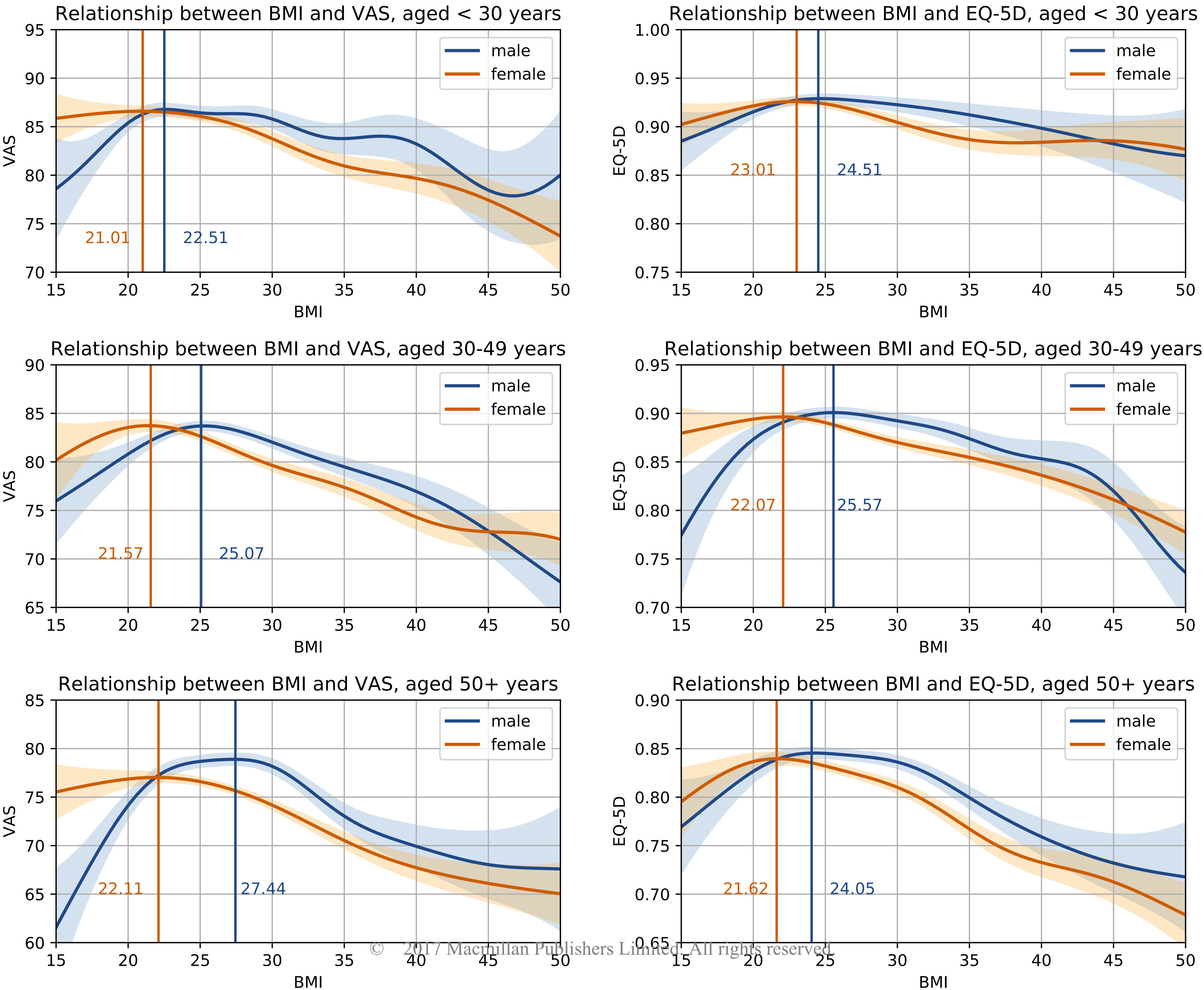

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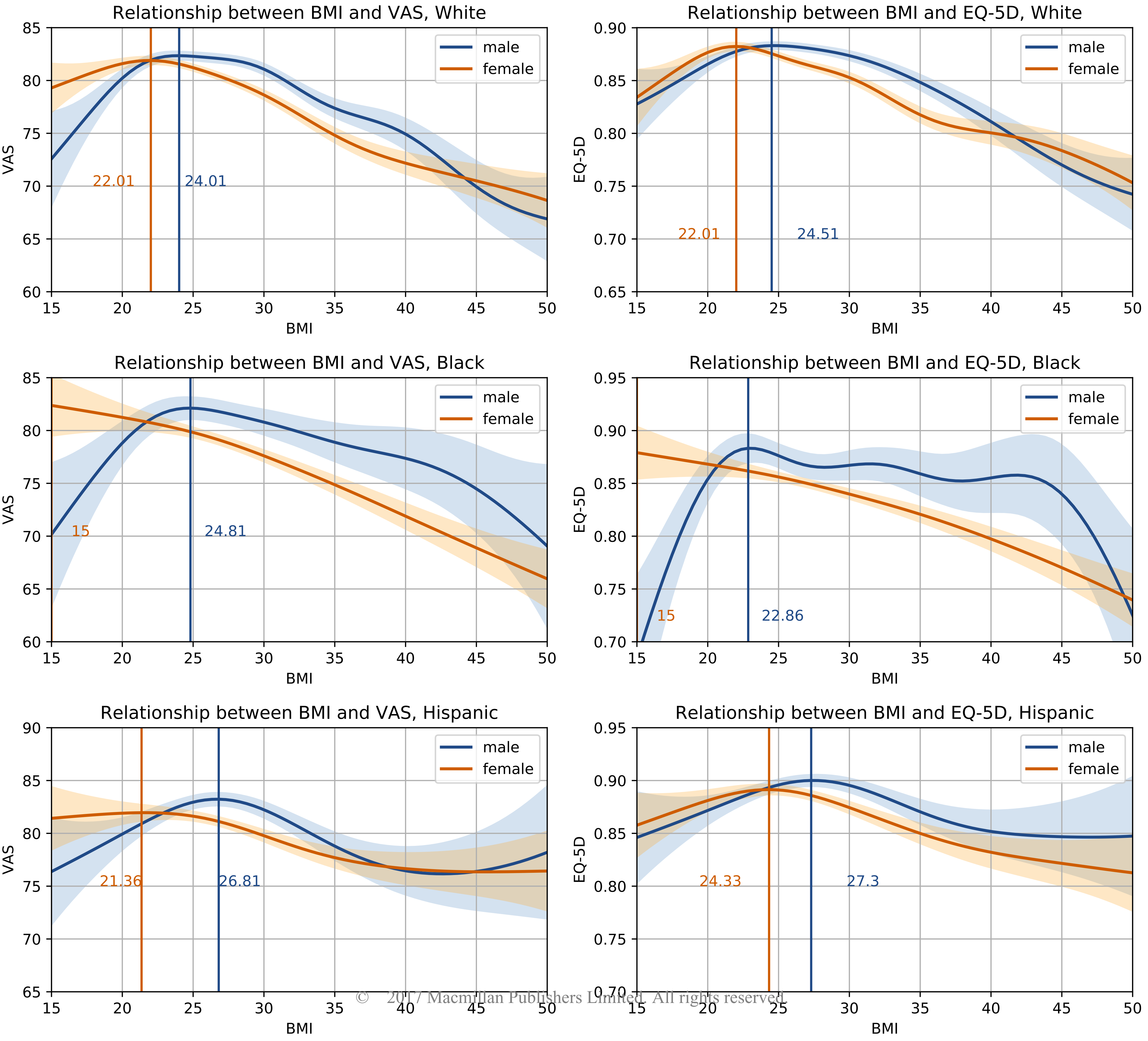
Figure 3:



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