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Indexing adult obesity by waist-to-height and weight-to-height ratios

Andrew Yatsko*

ITMS, the University of Ballarat, VIC, Australia

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Abstract

To date a vast evidence exists that the waist circumference to height ratio (WCHR) provides a better measure of obesity comparing to the body mass index (BMI). While weight and height are routinely obtained to calculate BMI, waist circumference, despite easily acquired, is often overlooked because the screening protocols, particularly for diabetes, demand BMI. This creates an obstacle for application of WCHR - a more definite measure than BMI for diagnostic of many linked to obesity metabolic disorders such as diabetes, cardiovascular disease and hypertension. This article is intended to fill the gap in the literature by providing a conversion from BMI to WCHR for five adult age categories. A strong linearity between the measures is demonstrated and equivalent to BMI WCHR thresholds are provided to identify normality, overweight as well as obesity and other points. The analysis is based on the data from National Health and Nutrition Examination Survey (NHANES). Different forms of BMI are also discussed and a strong linearity between them is demonstrated. An obesity index based on simple weight to height ratio to match the standard levels is proposed. The equivalence between the proposed and existing obesity indices is tested on the original data with promising results.

Key Words: Obesity, Body mass index, Waist circumference to height ratio, Diabetes, National Health and Nutrition Examination Survey

1. Introduction

The body mass index (BMI), attributed to Quetelet,[1] is a tool widely used for assessing risks of type two diabetes mellitus (T2DM), cardiovascular disease (CVD), hypertension (HT) and other metabolic disorders associated with the excessiveness of body weight. This universality warrants existence of the dedicated notion of obesity as a degree of unhealthy weight. BMI is calculated using measurements of body weight and height as in Equation 1:

$$BMI = \frac{[weight(kg)]}{[height(m)]^2} \quad (1)$$

The critical values of BMI to index obesity by, are found in many guidelines for diagnostic and treatment of the cardiometabolic disorders. The BMI categories recommended for general population are 18.5–24.9 as healthy, 25–29.9 as overweight, and 30 kg/m^2 or more as obese.[2] While this classification is adopted in many countries, some interpretations intended to address ethnical or racial aspects exist, notably with respect to Asian populations where the thresholds are generally lower.[3,4] Using 20 kg/m^2 instead of 18.5 kg/m^2 as a reference point for BMI transition from underweight to healthy is convenient for interval equalisation, and is conventional when the focus is on categories above the normal/healthy.[5] Besides, the prevalence of underweight is usually negligible comparing to other BMI categories,[4] particularly in the population selected for the current study,[6]

* **Correspondence:** Andrew Yatsko; Email: balunyaan@gmail.com; Address: ITMS, the University of Ballarat, VIC 3353, Australia.

probably because such an existence challenges the physiological limits, and in fact the healthy weight minimum should satisfy this criterion.[1] Instead of using 20 kg/m^2 by convention, underweight in obesity studies are often consensually included with the healthy weight category, so that no minimum for the healthy weight is set.[7,8] The critical BMI values not only define the diagnostic cut-off points, but also have a statutory meaning to justify costs associated whether with screening for, or treatment of confirmed disorders, and the costs escalate with disease progression. Particularly, if BMI is 30 kg/m^2 or more - a screening for T2DM is warranted as well as lifestyle modifications for weight loss. If BMI is 35 kg/m^2 or more - a pharmacological treatment is in order for obesity or confirmed T2DM. Once BMI has reached 40 kg/m^2 - a bariatric surgery is on the agenda.[2,9] The BMI levels of 30, 35 and 40 kg/m^2 signify the onset of obesity stages one (I), two (II) and three (III), respectively. Upon review of a large body of evidence, there is a notable increase of all-cause mortality past the first stage of obesity.[10] However, the increase is not as sharp as in the opposite direction, when crossing to the underweight space, and therefore the overweight and inner obesity categories are all equally wide.[1] On the credit side of weight gain there are the pharmaceutical expenses, and a new research shows that obese tend to spend nearly twice as much as non-obese on cures for any purpose.[11] Apart from the standard BMI, as in Equation 1, there are others forms distinguished by the power of height in the denominator of the expression. Particularly, BMI$_1$ is the simple weight to height ratio, unlike the standard BMI using squared height, of which Equations 2 is an illustration:

$$
\begin{aligned}
BMI_1 &= \frac{[weight(kg)]}{[height(m)]}, \\
BMI_2 &= \frac{[BMI_1(kg/m)]}{[height(m)]} \equiv BMI
\end{aligned}
\tag{2}
$$

If any doubt exists about a clinical decision based on BMI, it is advised to verify the result by waist circumference (WC). While BMI offers a general assessment of obesity, WC is regarded a measure of “central”, or abdominal obesity. Equations 3 introduce the gender-specific oversize/overweight ranges currently used in clinical practice[12] to classify obesity based on WC:[13]

$$
\begin{aligned}
&94 \leq [WC_m(cm)] < 102, \\
&80 \leq [WC_f(cm)] < 88
\end{aligned}
\tag{3}
$$

where the subscripts “m” and “f” identify male and female genders, respectively.

These rules are being offered as adjunct ones to the classification based on BMI. However, the rules were estimated to be responsible for additional 60% cases of obesity.[14] Obviously, WC does not have the universality of BMI taking care of the inherent differences between male and female statures, which Equations 3 reflect. At the same time, the non-linear dependence of weight on height, as in BMI (Eq. 1), seems to be adjusted for in Equations 3: men are distinguished by a larger girth, while also being taller than women, as assumed. Likewise, since the rules for men and women are different, WC should depend on height. Yet, taken by component, the rules do not convey that impression: in either gender, a variation in height does not warrant a variation in WC. The partial rules do not preclude existence of subpopulations for which weight might be proportional to height, falling short of advice in that case. In the meantime, an independent criterion assuming bald linearity of the dependence between weight and height exists,[12] whereby the upper limit of healthy weight is roughly defined as the term on the right in Equation 4 (the classic, unisex Broca’s formula):

$$
[weight(kg)] \geq [height(cm)] - 100 \tag{4}
$$

The waist circumference to height ratio (WCHR), as in Equation 5:

$$
WCHR = \frac{[WC(cm)]}{[height(cm)]} \tag{5}
$$

is used since mid-nineties under different names as an alternative measure of obesity. Recent reviews have found that WCHR performed consistently better than BMI in predicting various cardiometabolic outcomes.[3,15] By analogy with BMI, it is gender-independent and has been hypothesised to conform well to age and ethnicity differences.[15] At least, this versatility is potentiated by the dimensionless property of the measure. Also, WCHR is not as variable as, and simpler to obtain than BMI. WC can be sufficiently precise despite the existing different interpretations of how it to be measured.[3] Once a suitable procedure is determined, it is only required that it was followed to the letter for the measurements to be self-consistent, and there are contemporary non-invasive and, in a long run, inexpensive techniques, like multi-angle photography and optical scanning, that renounce any thinkable drawbacks pertaining to the tape measure. Above all, while it might be incorrectly measured, WC of a given individual does not change as much as weight within a short time frame (a day, a week).

The mentioned reviews find different state transition points by WCHR for different cardiometabolic outcomes, although close to each other, summing up with a simple “take home” message of keeping one’s waist circumference below half of one's height to stay healthy.[3,15] However, obesity as a health threatening condition exists in its own right and can be purposively treated.[16] Previously reported[5,17] WCHR cut-offs are verified in this study using a publically available collection of data.

2. Data

The required information is routinely obtained by the US ongoing National Health and Nutrition Examination Survey (NHANES).[18] Subsets corresponding to five consecutive adulthood stages, as defined in Table 1, were extracted from the latest NHANES data (2013-2014) to test the coherence between obesity indices by age group. The fifteen year age frames are meaningful. By the age of 20 years adolescents become fully formed adults.[2] Pregnancies are not recommended 35 years of age or older;[19] persons with vulnerable backgrounds 35 years of age or older are recommended to undergo a screening for diabetes.[12] The age of 50 years is an approximate age of menopause.[20] The age of 65 years is critical for diagnostic of CVD, age being a strong marker for the disease.[21] NHANES does not record age of respondents who are 80 years or older, placing them in a special 80+ years category, to better safeguard their privacy, as these participants are fewer in the number.[18]

Table 1. Adult respondent age frame descriptors and statistics

Age* Frame	Adulthood Stage	Population (n)	Females (%)
20+	Young	1,369	50
35+	Prime	1,402	54
50+	Mature	1,363	51
65+	Advanced	865	53
80+	Elderly	257	53

* Commencing the year noted and elapsing before the year on the next line

Usually, height is known virtually for all respondents, but WC is often missing. At the same time, knowledge of BMI_2 is required by screening protocols, particularly for T2DM,[12] so weight is usually also known throughout. For about 10% of the NHANES dataset WCHR or BMI_2 could not be calculated, mainly because WC results were missing. The means and one standard deviation corridors of the apropos anthropometric features through time are plotted in Figure 1 for the subset of data where the attribute values were all in supply.

As seen in Figure 1, the mean weight exhibits a pattern of slow increase as the adulthood progresses, with the maximum reached at, or before maturity, and then somewhat faster a decline. Unlike the weight, WC summits at, or after maturity. Interestingly, the mean height is steadily decreasing with age, which initially is likely due to development of the musculature, and so tightening of the joints. The added lean mass also contributes to the overall weight. On the other hand, in senescence, a drastic reduction in both weight and height, as observed, should be attributed to a loss of lean mass.[4,7] While the weight exhibits overall a declining trend, WC has a tendency to rise. The intrinsic differences between the two measures seem to be conferred onto the BMI measures and WCHR. The age frame specific means and one standard deviation ranges of obesity measures derived from the anthropometric features depicted in Figure 1 are plotted in Figure 2 to illustrate the dynamics of their change.

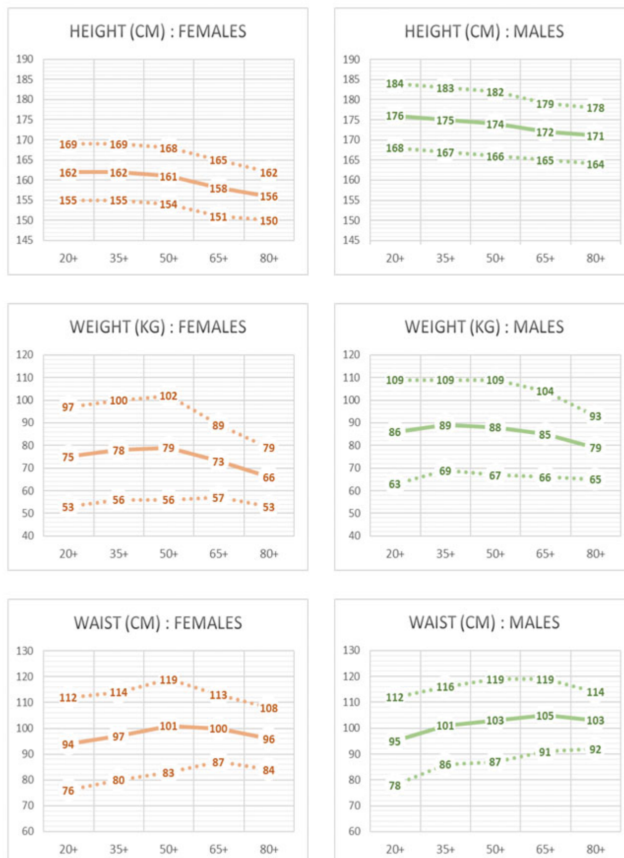


Figure 1. Means and standard deviation ranges of anthropometric features by age frame

Additionally to previously noted, the rise and fall in values of either BMI measure with age, seen in Figure 2, may be linked to the composite effect of obesity survival.[10,21–23] The simultaneous decline in weight and height, seen in Figure 1, should have a stabilising effect on BMI measures (Eqs. 2), but the declining height props WCHR more (see Figure 2) due to the delayed drop in WC values (see Figure 1), which can be interpreted as a sign of quality of WCHR as obesity measure. Obviously, the mature age adults represent the main interest as knowing the obesity cut-offs is critical for timely diagnosis and prevention of obesity related diseases which likelihood is increasing with age.

The linearity of relationship between WCHR and BMI_2 is stronger, but can be also observed between WCHR and BMI_1, prompting that BMI_1 can be a viable alternative to BMI_1.[17] For any of the age categories the standard deviation for either of the BMI measures in Figure 2 is about the same relative to the mean; for BMI_2 the deviation percent is only marginally, 6% less than for BMI_1, having compared the results of either measure relative deviation averaging over all age categories. A greater perceived stability of BMI_2 due to the uncompromising nature of height measurement could be one reason why this obesity measure historically won the popularity over BMI_1 (Eqs. 2).[7,24] By the same token, WCHR is 31% better than BMI_2.

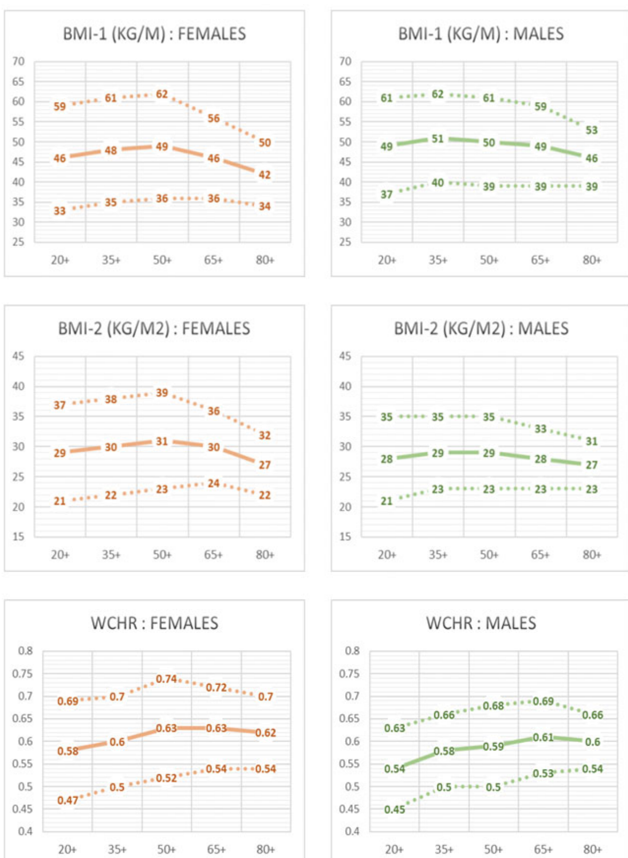


Figure 2. Means and standard deviation ranges of derived anthropometric features by age frame

3. Methods

WCHR was linearly regressed on BMI, using the least squares method,[25] on the NHANES data where both values were known, separately for men and women. The opposite was also performed, that is, BMI was regressed on WCHR by gender using the same method. Each regression and detrending allowed to identify outliers which were removed once both regression equations were evaluated. The whole procedure was repeated until outliers were no longer detected. The identification of outliers was controlled by specifying the number of standard deviations away from the detrended mean of zero, above which the data is considered non-meaningful. The number selected was 3.0, which is well in excess of 2.0 covering the 95% confidence interval. Using the same approach and the parameter setting, outliers of WCHR and BMI individual distributions were also identified and removed before regressing each one on the other, cycle after cycle. The above procedure was applied to various subsets of data arising from bootstrapping, which is a sampling with replacement technique.[25] The resampling was required to estimate mean values and confidence intervals for the regression coefficients and the coefficient of correlation between BMI and WCHR, below. For each parameter one hundred estimates were obtained.

Equations 6 and 7 represent the reciprocal linear regression expressions for WCHR and BMI:

$$WCHR = \omega_0 + \omega_1 \cdot (BMI - \beta_0) \tag{6}$$

$$BMI = \beta_0 + \beta_1 \cdot (WCHR - \omega_0) \tag{7}$$

where ω_0 and β_0 are the population WCHR and BMI means, respectively. Here, BMI is either BMI_2 or BMI_1. Note that the two equations, although similar, are not equivalent (ω_1 cannot be expressed via β_1). Each equation emphasises the best fit for the response variable of choice, assuming it is dependent on the other, explanatory variable.

Goodness of the linear fit to data is determined by the correlation coefficient (Pearson) defined by Equation 8:

$$r = \sqrt{\omega_1 \cdot \beta_1} \tag{8}$$

Similarly, the confidence to magnitude ratio (C/M) for either slope, ω_1 or β_1, in the linear regression equations can be used to assess the linearity by subtracting the result from 1. The ratio is calculated as in Equation 9:

$$C/M = 2 \cdot (CI_2 - CI_1)/(|CI_2| + |CI_1|) \tag{9}$$

where CI_1 and CI_2 denote the "from" and "to" bounds of an applicable confidence interval, and $|\cdot|$ stands for absolute values. Suppose "Integrity" I of the linear model is measured as a geometric mean of two $(1 - C/M)$ expressions for the regression line slopes as in Equation 10:

$$I = [1 - C_1/M_1]^{1/2}[1 - C_2/M_2]^{1/2} \tag{10}$$

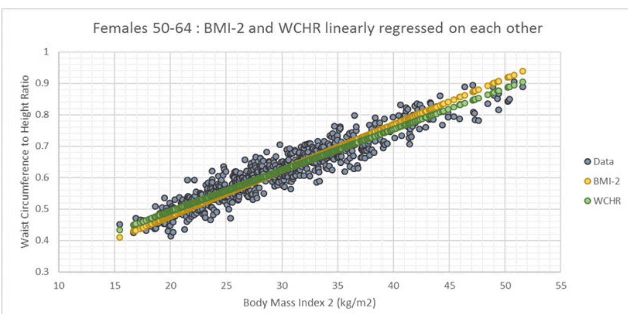
where the quantities indexed 1 and 2 are properties of ω_1 and β_1, respectively. This is a criterion resembling the regression coefficient and for the same purpose, but is an overall result of the statistical evaluation. If I = 1, the relationship between two variables is 100% linear.

4. RESULTS

4.1 Mature age adults

4.1.1 *WCHR vs BMI*$_2$

The data points in the WCHR – BMI$_2$ plane for female and male participants are plotted in Figure 3 together with the regression lines evaluated from the data. All of the data is shown except for less than 5% of the points identified as outliers. Note that the regression lines are not evaluated from all available data, but instead are based on results of resampling as described in the Methods section.



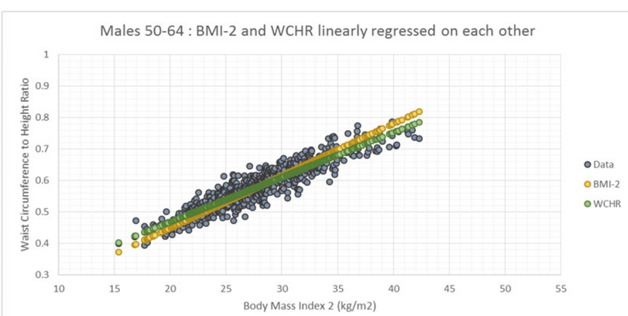


Figure 3. Evaluated linear dependences between WCHR and BMI$_2$ for mature adults

The regression coefficients (Eqs. 6 & 7) and the correlation coefficient (Eq. 8) are listed in Table 2, separately for women and men, where CI, given by its bounds CI$_1$ and CI$_2$, is the two standard deviations confidence interval, which is an inclusive approximation of the 95% interval, assuming normality of the coefficient data. The confidence to magnitude ratio C/M (Eq. 9), also in the table, is calculated for all coefficients and is expressed as a percentage.

Table 2. WCHR vs. BMI$_2$ regression coefficients for mature adults

Coefficient	Mean	CI$_1$ *	CI$_2$ *	C/M (%) **
Women				
β_0	30.03	29.41	30.64	4
β_1	68.48	66.17	70.78	7
ω_0	0.6237	0.6151	0.6323	3
ω_1	0.01305	0.01265	0.01345	6
r	0.9452	0.9348	0.9557	2
Men				
Coefficient	**Mean**	**CI$_1$ ***	**CI$_2$ ***	**C/M (%) ****
β_0	28.13	27.51	28.75	4
β_1	60.26	57.14	63.38	10
ω_0	0.5841	0.5761	0.5922	3
ω_1	0.01419	0.01369	0.01469	7
r	0.9244	0.9062	0.9426	4

* CI$_1$, CI$_2$ – confidence interval 'from' and 'to' bounds; ** C/M (%) – confidence to magnitude ratio as percentage

As seen from Table 2, the correlation coefficient r is at least 0.9 for either gender, so it is indeed approaching unity, meaning that the relation between WCHR and BMI$_2$ is close to linear. The linear model integrity (Eq. 10) is also very high; the I criterion is 94% for women and 91% for men. The slopes (ω_1, β_1) used in calculation of the criterion are expected to be more sensitive than the intercepts (ω_0, β_0), which evidently holds. The main reason for this is that much more data is available effectively for intercepts, representing means of underlying data, than for slopes of linear regression equations. Any particular point of a regression line, to establish itself, has to rely on data from the neighbouring points, which cannot be as precise as when based on repeated measurements of the same.

Table 3. Calculated WCHR for mature adult women and men corresponding to notional BMI$_2$ levels and proposed notional, unisex WCHR levels

BMI$_2$ (kg/m^2) Standard	WCHR Women	WCHR Men	WCHR Notional
18.5	0.4732	0.4475	0.455
20.0	0.4928	0.4687	0.475
25.0	0.5581	0.5397	0.545
30.0	0.6233	0.6106	0.615
35.0	0.6886	0.6816	0.685
40.0	0.7538	0.7525	0.755

After performing the paired two-tailed t-Test (Excel) on the generated parameter data, all regression coefficients in Table 2 are statistically distinct for men and women ($p < .001$). WCHR corresponding to the standard BMI_2 levels with respect to the obesity classification are given in Table 3. Even though regression coefficients are statistically different for men and women, they are close. Therefore, the expressions for men and women (using Eq. 6) are expected to produce close results, which makes possible introduction of a unified WCHR-based index of obesity.

The WCHR notional levels are obtained in the manner pertaining to the standard BMI_2 levels. Firstly, WCHR between-gender means are calculated for the overweight and first obesity thresholds and spacing between the neighbouring levels is obtained. In this case, the between-gender means are 0.5489 and 0.6170, respectively, so the overweight category width is 0.068. The category span is the same for any other category due to the linearity. It is rounded to two significant digits and then adjusted by dichotomising the least significant digit by rounding it to 0, 5 or 10, whichever is the closest. This helps to reduce the error across the threshold spectrum when the intervals are added up. In this case, the result is therefore 0.070. A required number of intervals are then added or subtracted from the first notional obesity threshold to obtain all other levels. The first obesity threshold is obtained by rounding the mean value to three significant digits and dichotomising the least significant digit, same as for intervals. In this case, the notional obesity first level is therefore 0.615 (but because the last digit is 5, the first practical WCHR value that qualifies as stage I obesity is 0.62). To sum all up, for each increase of BMI_2 by 5.0 kg/m^2, WCHR is increased by 0.070, and at BMI_2 of 30.0 kg/m^2 WCHR is 0.615, which can be used to calculate WCHR at any other BMI_2, particularly at 18.5 kg/m^2. The result is then rounded in the described manner.

4.1.2 *WCHR vs BMI*$_1$

The data points in the WCHR – BMI_1 plane for female and male participants are plotted in Figure 4 together with the regression lines evaluated from the data. There were even less outliers than for WCHR paired with BMI_2 and they are not shown.

The regression and correlation coefficients (Eqs. 6 - 8) with their confidence intervals are listed in Table 4 separately for women and men.

As seen from Table 4, the correlation coefficient r is at least 0.8 for either gender, indicating a strong linear relationship between WCHR and BMI_1. However, this relationship is not as linear as the one between WCHR and BMI_2. The linear model integrity (Eq. 10) is also not as high; the I criterion is 92% for women and 86% for men. The regression line slopes appear to be steadier for women than for men. The regression coefficients are all statistically distinct for men and women, using the paired two-tailed t-Test ($p < .001$).

Table 4. WCHR vs. BMI_1 regression coefficients for mature adults

Women				
Coefficient	**Mean**	**CI_1***	**CI_2***	**C/M(%)****
β_0	48.27	47.17	49.37	5
β_1	108.0	103.7	112.3	8
ω_0	0.6243	0.6148	0.6338	3
ω_1	0.007706	0.007397	0.008014	8
r	0.9122	0.8971	0.9273	3
Men				
Coefficient	**Mean**	**CI_1***	**CI_2***	**C/M (%)****
β_0	48.94	47.76	50.13	5
β_1	102.3	93.8	110.9	17
ω_0	0.5838	0.5750	0.5927	3
ω_1	0.007112	0.006737	0.007487	11
r	0.8527	0.8210	0.8843	7

* CI_1, CI_2 – confidence interval 'from' and 'to' bounds; ** C/M (%) – confidence to magnitude ratio as percentage

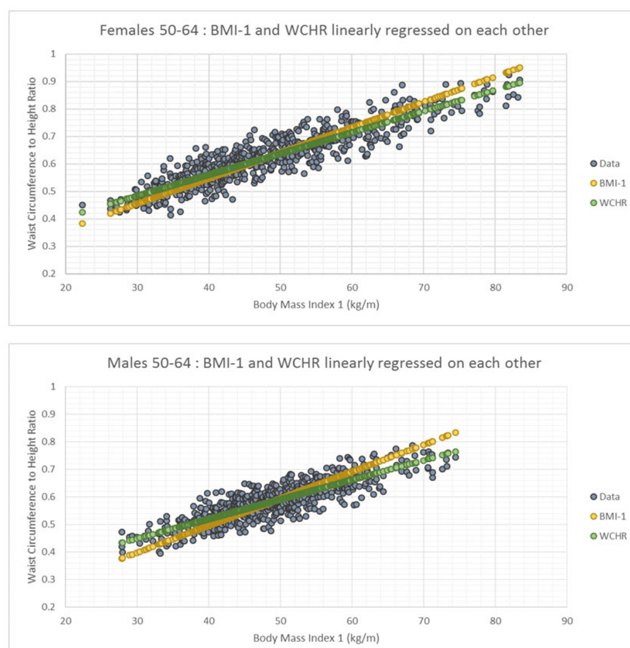


Figure 4. Evaluated linear dependences between WCHR and BMI_1 for mature adults

4.1.3 *BMI*$_1$ *vs. BMI*$_2$

The data points in the BMI_1 - BMI_2 plane for female and male participants are plotted in Figure 5 together with regression lines characterising the relationship between the two variables. There were no more outliers (less than 5%) than in other dealt with situations, and they are not shown.

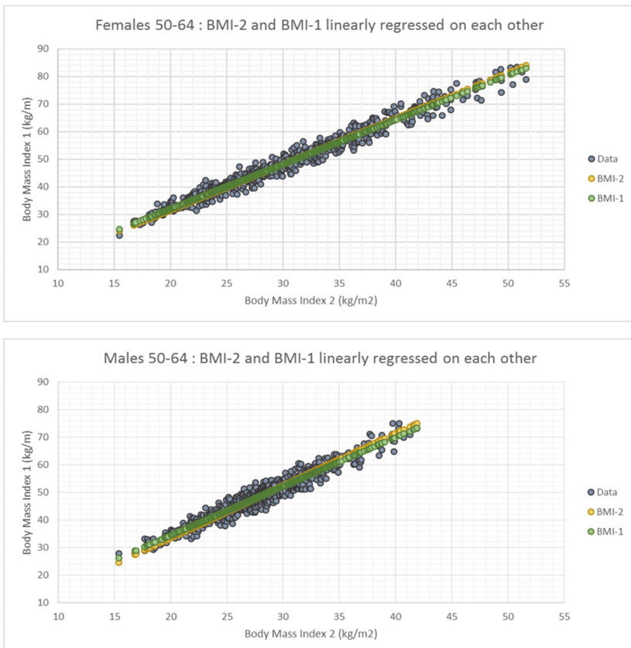


Figure 5. Evaluated linear dependences between BMI_1 and BMI_2 for mature adults

The regression and correlation coefficients (Eqs. 6 – 8) with their confidence intervals are listed in Table 5 separately for women and men, where ω symbols correspond to BMI_1 expressed via BMI_2 and, conversely, β to BMI_2 expressed via BMI_1.

As seen from Table 5, the correlation coefficient $r \cong 1.0$ for either gender, indicating that the relation between BMI_1 and BMI_2 is practically linear. The linear model integrity (Eq. 10) is exceptionally high just the same; the I criterion is 96% for either gender. The remarkable linearity is also evident from Figure 5 where the regression lines in each pane almost overlay. The regression coefficients are all statistically distinct for men and women, using the paired two-tailed t-Test ($p < .001$).

Having calculated BMI_1 corresponding to the standard BMI_2 levels using the regression expressions (Eq. 6), the results are presented in Table 6. These results, though, are not as close between genders as for WCHR regressed on BMI_2 (see Table 3). The additional division by height in BMI_2 (Eqs. 2) might have a hidden agenda of attenuating the differences as individually weight is more variable than height, which was already mentioned, and more so for a given height with different genders involved. At the same time, the differences do not exceed the "psychological" 10% of the magnitude for any stated level of BMI_2, so it is still possible to work out a notional, unisex index of obesity based on BMI_1. The proposed thresholds are as shown in Table 6. Arguably, BMI_1 is easier perceived a measure than the conventional BMI_2.

Table 5. BMI_1 vs. BMI_2 regression coefficients for mature adults

Women				
Coefficient	**Mean**	**CI_1 ***	**CI_2 ***	**C/M (%) ****
β_0	30.15	29.37	30.93	5
β_1	0.6021	0.5908	0.6135	4
ω_0	48.39	47.14	49.64	5
ω_1	1.615	1.585	1.645	4
r	0.9861	0.9835	0.9887	1
Men				
Coefficient	**Mean**	**CI_1 ***	**CI_2 ***	**C/M (%) ****
β_0	28.08	27.56	28.59	4
β_1	0.5261	0.5166	0.5357	4
ω_0	48.83	47.88	49.78	4
ω_1	1.778	1.744	1.812	4
r	0.9673	0.9597	0.9748	2

* CI_1, CI_2 – confidence interval 'from' and 'to' bounds; ** C/M (%) – confidence to magnitude ratio as percentage

Table 6. Calculated BMI_1 for mature adult women and men corresponding to notional BMI_2 levels and proposed notional, unisex BMI_1 levels

BMI_2 (kg/m^2) Standard	**BMI_1 (kg/m) Women**	**BMI_1 (kg/m) Men**	**BMI_1 (kg/m) Notional**
18.5	29.58	31.80	30.5
20.0	32.00	34.46	33.0
25.0	40.07	43.35	41.5
30.0	48.15	52.24	50.0
35.0	56.22	61.13	58.5
40.0	64.30	70.02	67.0

In this classification, BMI_1 is increased by 8.5 kg/m, to span a category, on the top of initial 33.0 kg/m, which mirrors BMI_2 rises of 5.0 kg/m^2, counting from 20.0 kg/m^2. The same arithmetic rules apply as when calculating the notional WCHR levels.

4.2 Adulthood stage summaries

The previous section dealt with mature age adults. Similar results are obtained for all other stages of adulthood. Some regression coefficients appear to be less statistically different for elderly males and females. This category, even though populous, is much smaller comparing to others (see Table

1), so the result can be on the part of t-Test sensitivity in the environment provided by bootstrapping. After having discussed the results in Tables 3 and 6 for mature adults, it becomes clear that two numbers are sufficient to determine the notional obesity indices, whether based on WCHR or BMI_1. These numbers are the notional value of a particular measure at the first obesity threshold, which is 30.0 kg/m^2 by BMI_2, and the category width, same for any of the obesity categories, and equivalent to the BMI_2 category span of 5.0 kg/m^2. The two numbers are given in Tables 7 and 8 for all five stages of adulthood. In the tables, the last significant digit is a subordinate one, a "fifty cent" adjustment to reduce the error of calculations involving the data, as detailed in the previous section.

Table 7. Notional WCHR first obesity threshold and category span by adulthood stage

Adulthood Stage	WCHR at Obesity *	Category Span **
Young	0.590	0.070
Prime	0.600	0.070
Mature	0.615	0.070
Advanced	0.635	0.070
Elderly	0.650	0.070

* WCHR at BMI_2 of 30 kg/m^2; ** WCHR any category span corresponding to 5 kg/m^2 in terms of BMI_2

Upon reviewing Table 7, there is a clear tendency to the obesity by WCHR threshold increase with age, provided BMI_2 is a trusted standard. Also, the increase is accelerating with age. All categories shift accordingly towards higher values of WCHR. The mean height is also steadily decreasing with age but with gaining in pace past the maturity (see Figure 1). Senescence, manifested in the height reduction,[4,7] may be a contributing factor for advanced age adults and elderly, but it hardly explains the steady increase of WCHR obesity threshold with age. One plausible explanation is the survival of individuals tolerant to central obesity.[10,21] Among others can be a bowel development and a weakening of muscles supporting the abdomen. People who had a bariatric surgery are known to experience inconvenience caused by flaps of skin left behind after a drastic weight loss, which may require a cosmetic surgery. A past obesity can cause a similar gut condition even among the survivors managing their weight within acceptable limits. Additionally, this can invite bloating, exacerbated by other age related gastrointestinal problems. The lack of exercise associated with more sedentary lifestyle as people grow older and "wiser", and the muscle atrophy in senescence can compound the abdominal distention.

Previously identified universally applicable spectral WCHR levels for any age older than 5 years were 0.6, 0.5 and 0.4.[5] The stage I obesity threshold by WCHR at 0.6 was "pragmatically" set after comparing obese population prevalence by BMI_2 and WCHR; whereas the overweight state was defined as reached at 0.5 based on the consensus existing in the literature;[2] the healthy state was therefore defined as reached at 0.4 (assuming the linearity). Note that a different terminology is used to describe the excess weight bands: "take action", "consider action", "OK" and "take care". It is not explicitly stated that the WCHR levels of 0.5 and 0.4 were meant to match the respective BMI_2 levels of 25 and 20 kg/m^2. Previously identified[17] WCHR cut-offs aligned to BMI_2 but for a particular set of data, unrelated to the one in the current study, were 0.600, 0.525 and 0.450, respectively. The population included adults from prime adulthood to elderly.

Instead of relying on the between-gender means to calculate notional levels, which can be traced to the assumed parity of gender frequencies in general, the results in Tables 7 and 8 are using evaluations conducted without subdividing data by gender, and so the frequencies in Table 1 apply, although the approximate parity is evident. This explains that the BMI_1 results in Table 8 for mature age adults are slightly different from those in Table 6, and this situation exists for other stages of adulthood (not shown). However, the results for WCHR in Table 7 are no different for any age frame from their variants calculated using the between-gender means (not shown).

Table 8. Notional BMI_1 first obesity threshold and category span by adulthood stage

Adulthood Stage	BMI_1 at Obesity *	Category Span **
Young	50.5	8.5
Prime	50.5	8.5
Mature	50.0	8.0
Advanced	49.0	8.0
Elderly	49.0	8.0

* BMI_1 at BMI_2 of 30 kg/m^2; ** BMI_1 any category span corresponding to 5 kg/m^2 in terms of BMI_2

BMI_1 is closely related to BMI_2 by definition (Eqs. 2), and therefore it is unsurprising that the obesity threshold and category span by BMI_1 in Table 8 change only slowly with age. The observed in Table 8 lowering of both parameters with age is related. Both weight and height decrease with age past the prime adulthood (see Figure 1) but the additional division by height in BMI_2 should increase the contrast in the rate of change with time between the two obesity measures. A reduction of lean mass, as in senescence, should render BMI_2 less powerful in exerting change of BMI_1, as going to be discussed.

5. Discussion

5.1 Adherence to existing auxiliary rules

The existing guidance on how to ascertain obesity by WC or by a linear combination of weight and height was mentioned in the introduction. While these rules are being provided as additional or rough guides, they still offer an avenue for testing of the proposed indices based on WCHR and BMI_1, and it is also interesting to see how the standard rules fare in comparison, since they are in circulation.

The standard overweight/oversize WC range for men to challenge results of assessment by BMI_2 is 94 - 102 cm, and for women it is eight upon eighty, or else 80 - 88 cm (Eqs. 3). In Figure 6, overweight bands in the WC – Height plane are shown for the standard rules, different for men and women, and the indiscriminate rule based on WCHR values for mature adults from Table 3. The rules vastly overlap, so that for a large number of realistic combinations of WC and height either approach provides identic classification into the overweight category. Nonetheless, the standard band for women seems to be especially displaced against what is projected by the proposed rule. The shaded areas in Figure 6 are intersections of common parts of the standard and proposed bands with boxes of one standard deviation around means, using the values in Figure 1, representing the data for men and women. The population is on the verge of obesity, judging by BMI_2 from Figure 2, but, as seen from Figure 6, the WC dimension is not limiting. The boxes as shown are slightly bigger to be aligned with the plot grid.

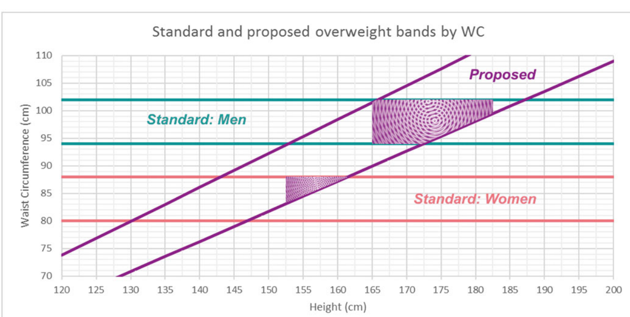


Figure 6. Standard and proposed rules using WC and height

However, the 14 cm difference in WC between men and women throughout the spectrum (Eqs. 3) is probably too large. The WC difference between genders calculated at means for the current population studied is 2 - 7 cm, depending on age (see Figure 1). The other problem is, of course, that the standard rules are not flexible enough to accommodate the variation of height in either gender group. Clearly, if WC is increasing with height then the standard band for women should be narrower than for men. However, the standard gender bands are equally wide. Otherwise, because the standard bands continue below the proposed band intended to match the standard BMI_2 classification, it is no wonder that the Equation 3 rules may attract additional population into the overweight and also obese categories comparing to the numbers based solely on BMI_2.[14] This would be an example of artificial reason for the “obesity paradox”, below, to exist.[26]

The fact of existence of a rule given by Equation 4 is important from the point of view of the argument whether BMI_1 can be a feasible alternative to BMI_2 (the conventional BMI). This rule, however, defines only the overweight boundary. Nevertheless, at the height of 200 cm the overweight state is reached at 100 kg, so BMI_2 is exactly 25 kg/m^2. This point appears to reside on the overweight boundary according to both linear and nonlinear specifications. In fact, the Broca’s boundary appears to be the tangent line at this point to the $[BMI_2(kg/m^2)] = 25$ curve in the Weight – Height plane. Using the same principle, the linear obesity boundary may be defined as the tangent line to the $[BMI_2(kg/m^2)] = 30$ curve at the height of 200 cm where the weight is 120 kg. This situation is depicted in Figure 7. The area between dotted lines in the Figure, formally defined by Equations 11, is the overweight band inspired by the Broca’s formula (Eq. 4):

$$\begin{aligned} &[height(cm)] - 100 \leq [weight(kg)], \\ &[weight(kg)] < (1.2) \cdot [height(cm)] - 120 \end{aligned} \tag{11}$$

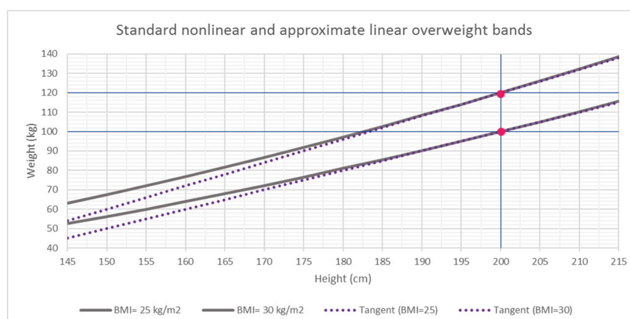


Figure 7. Standard nonlinearly and linearly related weight and height overweight band rules

Obviously, by design, the standard linear rule approximates the standard nonlinear rule most closely in the vicinity of 200 cm on the height axis, and it is more than two standard deviations away from gender means, based on the values from Figure 1, that is, very far to be practical. From Figure 7, it is clear that it will generally overstate the excessiveness of weight comparing to BMI_2. It is also clear that due to men being inherently taller than women, the standard linear rule is more accurate for men than for women. The alternative is to use the proposed obesity index based on BMI_1.

Nonetheless, as seen from Figure 8, the standard and proposed linear rules have much in common, especially around average height values seen in the population. The shaded area in the figure is an intersection of the common part of standard and proposed bands with the union of one standard deviation around means boxes, using Figure 1, representing the data for men and women. The population is on the verge of obesity, judging by BMI_2 from Figure 2, but, as seen from Figure 8, the weight dimension is not limiting. The union of boxes as shown is slightly bigger to be aligned with the plot grid.

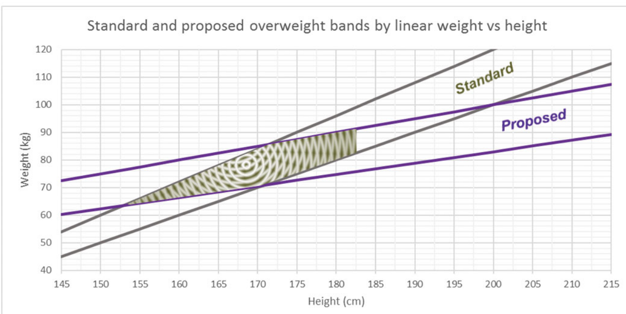


Figure 8. Standard and proposed overweight band rules using linearly related weight and height

5.2 Obesity index equivalence

The goal of this work is to estimate levels of WCHR and also BMI_1 equivalent to the standard BMI_2 levels that index obesity. This so far was not properly tested – the comparison with the existing auxiliary rules raises more questions than gives answers. One problem with the correspondence evaluation between indices is posed by borderline instances that can be classified differently by alternative indices, despite the appearance of such instances is purely circumstantial. To escape the "bracket creep", half-intervals for any involved obesity measure are introduced. For example, for BMI_2, levels from 20 to 40 by increments of 2.5 were deployed instead of the standard levels of 20 (as a proxy for 18.5), 25, 30, 35, 40 kg/m^2. Thus, for each index 10 discrete obesity levels (from 0 to 9) were defined, regarded equivalent by level index-to-index. By running a pair of indices through the data the discrepancies in classification between them can then be accounted for. To calculate the correspondence rate between indices, the absolute differences between their discrete values are found, with those of magnitude more than 1 deemed misclassifications. The runs are conducted on all available data after exclusion of outliers as explained in the sections Data and Methods. The correspondence rate as a percentage of matching classifications between indices in the described sense is shown in Table 9 by index pair and gender for different age frames.

Table 9. Correspondence rates (%) between indices derived from different obesity measures by age frame

Indices		Age	Gender		
First	Second	Frame	Female	Male	Either
BMI_2	WCHR	20+	86	89	87
		35+	87	93	90
		50+	88	92	90
		65+	83	94	88
		80+	83	94	88
BMI_1	WCHR	20+	74	76	75
		35+	74	78	76
		50+	72	76	74
		65+	69	73	71
		80+	72	73	72
BMI_2	BMI_1	20+	98	97	98
		35+	97	96	97
		50+	97	94	96
		65+	97	92	95
		80+	98	93	96

The index based on BMI_1 is produced directly from BMI_2, as otherwise it would have to rely on WCHR with a loss of precision. This to some extent explains the minor result for WCHR vs. BMI_1 comparison. Also, the relationship between WCHR and BMI_1 is less linear than between WCHR and BMI_2. Nonetheless, the correspondence between the indices can be regarded as acceptable. The close to perfect correspondence between BMI_2 and BMI_1 is expected from the high observed linearity of dependence between them and the explicit likeness of the measures: both increase with weight and decrease with height (Eqs. 2). However, it is surprising that this close relation does not translate to higher correspondence rates between WCHR and BMI_1 than the ones found in Table 9. The divergence must be additive by nature. Also, the method for index equivalence appraisal is not flexible enough to grade this divergence more sparingly. Particularly, up to half of instances that qualify with the shift of up to one half-interval in the match between BMI_2 and BMI_1 are indeed one half-interval off, but otherwise only with a "handful" of non-compliant instances (see Table 9), which then creates the unfavourable environment when comparing classifications by BMI_1 and WCHR. Ultimately, both WCHR and BMI_1 based indices are derived from BMI_2 with inevitable loss of information. However, if to allow a shift of up to two half-intervals instead of one, as previously explained, the accuracy sharply increases. This amounts to accepting misclassifications by alternative indices into neighbouring categories. The crude accuracy rates are demonstrated in Table 10 for WCHR paired with BMI_1.

Table 10. Crude correspondence rates (%) between BMI_1 and WCHR by age frame

Age Frame	Gender		
	Female	Male	Either
20+	94	94	94
35+	93	96	94
50+	92	94	93
65+	92	93	93
80+	91	96	93

After the fact, WCHR consistently assigns a higher obesity category among females than BMI_2, while the opposite is true for males. Instead, BMI_1 tends to assign a higher category for males than BMI_2 and the opposite stands for females, which can be visualised by superimposing Figure 8 onto Figure 7 and allowing that males are generally taller than females, and indeed this holds for the population (see Figure 1). This effect creates a rift in obesity classification by BMI_1 and WCHR and is reflected in the dip of correspondence rates in Table 9 between these two indices comparing to the rates for BMI_2 paired with WCHR. Essentially, this effect is due to the unisex approach to notional indexing.

At the same time, it is evident from Table 9 that the agreement between WCHR and BMI_2 and between WCHR and BMI_1 is better for males than for females. The lack of agreement seems to increase with age. While the unisex aspect can still play a role in the imbalance of joint classification rates by alternative indices, the intrinsic differences between genders should be taken into consideration. To explain the poorer performance of WCHR for females than for males it pays to return to the previously mentioned duality of WC measurement.[3] There is nothing wrong with the alternative definitions: the circumference midway below the ribs and above the hips (if not the smallest than the largest), or by the navel. While the first method is the standard one,[2] it is generally accepted that the second method would produce similar results.[2] However, the second method has also demonstrated certain advantages applicable to women.[3] For women who gave birth, a larger WC can correlate with complications at the time of labour. To size this up, an estimated quarter of births in California, US have to be delivered via the caesarean section.[19] This may be related to obesity, miscalculated or imbalanced diet, albeit at the time of pregnancy. The obesity at the time of pregnancy can lead to macrosomia; particularly, women who had the gestational diabetes mellitus (GDM) may be affected.[27] The maternal trauma of relevance is not as much related to the labour and the method of delivery, as it is to the abnormal pressure sustained over a long time by muscles and supplying nerves of the abdomen. However, this type of damage can be caused not only by large newborns but also twins. Generally, soft tissue conditions are very common. They complicate about 40% of pregnancies with normal delivery and aggravate 50% of pregnancies with delivery via the caesarean section among women younger than 35 years, with rates for older women even higher: 50% and 60%, respectively.[19] Obviously, consecutive pregnancies provoke the risk in general. It has been also reported that women who experienced GDM are predisposed to the non-alcoholic fatty liver disease some years after their pregnancy. The enlargement of liver associated with the disease can cause abdominal distention at moderate BMI_2.[28] The ethnical/racial aspect in the migrational pattern context needs to be also considered. It had been shown, for example, that fatness of Asian-American women, but not men, is underestimated by their BMI_2.[29] Associated with the weight gain with age is also the gluteal-femoral deposition of fat in women before menopause,[20] which unlike all previous would render a larger BMI_2 whilst a smaller WCHR.

5.3 Distribution of weight

The utility of BMI_2 suggests a quadratic dependence of weight on height (Eq. 2). Another mentioned criterion admits weight dependence merely on height (Eq. 4), thus justifying BMI_1 (Eq. 2). Both seem extraordinary as the cylindrical model of human body, if proportions were preserved, prompts a cubic dependence of weight on height.[24] Of note, in some cultures fatness of women is regarded an attribute of married status, or this is a refraction of the population genetic propensity to obesity. Generally, if the amount of accumulated fat becomes extremely high then the cubic model may indeed suit better.[30] For example, while the proportion of obese in the US population is about 30% in either gender, in some island nations in the Pacific it is much higher: roughly 50% among men and 70% among women in Tonga and Samoa.[31] In absence of such extremes, for the dependence to be quadratic, the vertical dimension must account for most of the weight change with height - a trait indeed common to vertebrates - with an auxiliary role given to the dimension orthogonal to the vertical one in the frontal plane. The anterior-to-posterior dimension ought to hardly play a role. By this theory, taller people tend to be also broader in the chest, which is evidently true. From the biological perspective, the amount of oxygen acquired per unit of square per unit of time by alveoli is fixed; so, to deliver more oxygen to make a bigger musculature work can only be achieved with bigger lungs. In obesity, the distribution of additional weight, although perceived as concentrated around the waist, also has a major subcutaneous component,[32] as seen in people who are successful in their efforts to lose the excessive weight. It is therefore unsurprising that the sagittal abdominal diameter might provide a better measure of adiposity than WC[33] – this dimension is the one least correlated with height. The diameter is an emergent marker in connection to medical imagery but can be clinically measured.

In biology, the distribution of fat along the body surface is considered an evolutional adaptation by creating a protective layer enhancing mechanical and thermal insulation.[23] Embracing the same principle, a spherical shape is more economical than any other, which may explain thickening of the layer around the waist. At least, if surface minimisation is the goal then the space around waist offers an ideal storage depot. The thermal insulation may play a role in improving CVD outcomes in certain population cohorts surviving cold seasons by reducing vasoconstriction required to avert the hypothermia. A number of studies observed that being somewhat overweight improves the survival statistics, known as the "obesity paradox".[10,21] Yet, this perception may be ill-informed due to a widespread disregard of major methodological issues.[26] Nonetheless, apart from the mentioned, and the mere effect of survival, there are other valid reasons in support of the protective property of being somewhat overweight against odds of various cardiometabolic disorders. First of all, the storage and dispensation of excess fat, as well excess glucose converted to fat, are quintessential for the mechanism by which the homeostasis of glucose is perpetuated. These "metabolic reserves" especially count when patients are faced with some wasting condition, that is, survive an acute "catabolic state".[21] It must be stressed that an abundant diet not only may provide surplus amounts of glucose or triglycerides, but replenish, even though only to full capacity, other critical nutrients such as essential amino acids, vitamins and minerals. Then, there is the epigenetic connection - in absence of exercise, methylation of DNA (the deoxyribonucleic acid) deactivates some genes.[34] There is a view that the overweight subjects get involuntarily exercised, provided they live sufficiently busy lives.[21,23] Also, through an exercise the metabolic reserves more genuinely evolve. A NHANES study described the metabolically healthy obese as people consistently engaged in a light-to-moderate physical activity, particularly the "active transportation".[22] However, methodological issues do exist. For example, the "pear-shaped" body, typical of women, is regarded health-protective due to redistribution of fat away from the abdomen and towards lower extremities.[20] This should be discarded, as should genetic variations which allow for accumulation of more fat without deleterious consequences for health. This sort of protection is not caused by accumulation of fat.

It is tenable that the visceral fat starts to build up when the capacity for surficial storage becomes exhausted, or if earlier then due to a genetic propensity, a maternal diabetes at the time of gestation, or an adverse environment exposure in childhood.[15,27,35] The visceral fat deposits are regarded "ectopic" and unhealthy,[23,35] although "visceral" has a connotation of abdominal and "ectopic" of other internal locations. The epidemiological evidence so far points clearly in the direction of faster accumulation of visceral than subcutaneous fat in diabetic/prediabetic subjects comparing to the euglycemic controls, by 67% on average.[36] In this connection, while the treatment by liposuction can provide aesthetic benefits, it is generally ineffective against T2DM, unless accompanied by lifestyle changes. The reason is that only the subcutaneous fat can be removed through this procedure.[32] The surficial capacity for fat storage is anyhow much larger than the internal capacity. On average, no more than 20% of total body fat in men and 10% in women is located in the abdominal cavity.[35] Therefore, the additional weight due to adiposity should be well correlated with the squared height.

Regardless of what disease adiposity connection is studied, the best measure of BMI type should correlate with weight as much as possible and correlate with height as little as possible. There had been a consistent reporting that, using this principle, the optimal exponent of height (Eqs. 2) is lower for women than for men; particularly, a NHANES based analysis[37] found that BMI_1 was optimal for women and BMI_2 for men. Based on the results in Tables 4 and 2, BMI_1 might indeed be more appropriate for women and BMI_2 for men than the other index, although the ascription is tentative. WCHR vs BMI_1 regression coefficients in Table 4 are more certain for women than for men, whereas in the WCHR vs BMI_2 regression the parameters for different genders in Table 2 vary less and to a similar extent. Also, it does not escape notice that the slope ω_1 in the BMI_1 expressed via BMI_2 relation (Eq. 6 where WCHR is a place holder for BMI_1), with values found in Table 5, is steeper (see Figure 5) for men than for women, which signifies a looser control of BMI_2 over BMI_1 in women - BMI_2 has to change more to effect a desired change in BMI_1. Returning therefore to the previously discussed point, the "masculinity" of men has historically evolved, but the weight gain associated with adiposity blurs the gender differences. Despite the better correlation of WCHR with BMI_2 than BMI_1, the linearity of either relationship is sufficiently strong. Thus, using BMI_1 instead of BMI_2 is not without a merit. Moreover, small WCHR are probably better aligned with BMI_1, larger WCHR with BMI_2, and perhaps even larger WCHR with BMI_3 (weight divided by cubic height) – a trait discernable in Figures 3 and 4.

5.4 Advantage of WCHR

The reported success of WCHR[3,15,17,38] is in many respects explained by inadequacies of BMI_2. Firstly, WCHR varies less than BMI_2, given an individual. Weight and so BMI_2, while can be precisely measured at any particular time, invariably change. Specifically, the body weight is regulated by cycles of digestion, and fluids are much involved in maintaining homeostasis of temperature and pressure. The discrepancies between self-reported and measured BMI_2 can to some extent be explained by this ever changing nature of the measured body weight, the changes gaining in amplitude with BMI_2.[8] Therefore, it is unsurprising that patients are allowed to stay in light indoors clothing while their weight is being measured, only shoes are removed.[7] Clearly, the type of clothes worn and also hairstyle are additional contributors of the weight variation through the procedure. Height is much less misperceived than weight, when self-reported.[7] One possible explanation of the second division by height in the widely adopted BMI_2 (Eqs. 2) is that this helps to "tame" the effect of weight variation, granted that height is much more stable a measure than weight.[24] The lack of guidance as to "how and when", may partly be behind the spread arrangement whereby weight, instead of being measured, is simply elicited from the subjects of screening or, equivalently, transferred from other databases. This kind of information is often obsolete. With age people tend to gain weight or, in frailty, become shorter.[4,7] Also, people like to be if not healthier then at least appear slimmer and taller, or they are socially pressured into understating their weight and overstating height.[8,39]

The above would be sufficient to opt for WCHR in BMI_2 stead, but adiposity is also more squarely explained by WCHR. BMI_2 is a poor measure of adiposity because it involves the total weight, that is, not only that of fat but also of the lean mass. However, it is adiposity, not weight as such, that is contributing to a range of cardiometabolic disorders and other diseases.[23,35] Additionally, a larger WCHR may be indicative of visceral deposits of fat thereby also being able to relate to the diabetic phenotype, although this phenotype is only partially explained by the genetic variation. A reprogramming into this phenotype can occur at the time of gestation due to a maternal diabetes, even if it is only transient.[27] There are also reports that a major contributor of this phenotype is unfavourable environmental conditions during certain phases of childhood that both stall the growth and lead to metabolism reprogramming towards accumulation of fats.[15] This reprogramming, apart from the body surface reduction to conserve energy, possibly also involves elongation of the digestive tract for a more thorough extraction of nutrients from food, as well as activation of adipocytes in the visceral area. Inevitably, the toxicity levels due to food processing and activity of microflora are also bound to increase with this scenario. This conjecture is particularly hinged on the effectiveness of bariatric surgery, often involving an intestinal bypass,[9,16] against weight gain and T2DM. Analytical reviews of many trials reveal that this treatment achieves on average a 65% reduction of the excess weight in T2DM subjects, is 99% protective against T2DM, and is responsible for 80% – 90% reversal rate in patients with T2DM.[16]

5.5 Overweight state by WCHR as a precursor of T2DM

The current view of obesity is that it contributes to cardiometabolic disorders such as T2DM, CVD and HT, but there is no reverse causation, although some medicines may increase the glucose conversion rate to triglycerides.[16,38] Evidently, T2DM is linked to obesity much closer than HT or CVD. One of the earlier mentioned reviews[3] estimated the optimal WCHR value for predicting T2DM in adults, derived from a selection of studies, as 0.56 for non-Asians (0.51 for Asians). This is encouraging, as this level for mature adults should be higher than the overweight level of 0.545 and approach the obesity level of 0.615 (see Table 3). Although, it is difficult to be any more specific due to the observed threshold value increase with age (see Table 7), while this aspect is not watched in the review entirely. An optimal level of WCHR recently reported was 0.58[17] for rural Australia prime age adults or older, including elderly. In this connection, the standing guidelines do not exclude a bariatric surgery for people who have contracted T2DM and have poor prospects of managing it, and also are at increased CVD risk, as soon as the first obesity threshold is reached, that is, already at BMI_2 of 30 kg/m^2.[2] Normally, the surgery is only recommended on reaching the third stage of obesity, or the second stage for people with comorbidities. In a different review, pooling of Asian and non-Asian adult populations produced a lower mean value for the optimal cut-off for T2DM (0.53).[15] Clearly, this creates a foothold to deny the obesity paradox but is a methodological issue just the same.[26] All the quoted WCHR cut-off points for T2DM are gender-independent. The proposed in Table 7 WCHR obesity thresholds are for the general population, same as the BMI_2 levels they are based on. Populations that significantly depart from the "general population" specification will have different WCHR thresholds to match their unique, applicable BMI_2 levels for obesity indexation.

To ascertain predictive power of a variable in respect of a specified diagnostic condition, a ROC (Receiver Operating Characteristic) analysis is often performed, whereby two aspects of predictive accuracy are probed at various cut-off points. The area under the resulting curve in the sensitivity – specificity space, albeit a transformed one, is the criterion characterising the overall predictive power of the variable. Using this approach, WCHR more often than not appeared to outperform BMI_2 in predicting T2DM, as one review found.[15] The best cut-off point is usually determined by maximising an aggregate criterion (the Youden's index) equivalent to the mean value of sensitivity and specificity.[17] The mean, or balanced accuracy at its highest can be independently used for comparing predictive powers of different variables. Again, more often than not, WCHR appeared to predict T2DM better than BMI_2, using this approach, which another review, non-intersecting with the aforementioned, found.[3]

WCHR is a better predictor of T2DM than BMI_2, overall, but sensitivity and specificity appear to be contrasting in the two. Particularly, in a previous report, after maximising the balanced accuracy, WCHR was found to be more accurate on the T2DM-yes side and BMI_2 on the T2DM-no side than the other feature.[17] This is in line with perceived properties of either measure. For healthy individuals, BMI_2 within limits is reassuring (74% specific), but higher values are ambivalent about the opposite (51%). For individuals with T2DM, WCHR over a limit is consistent with the ill status (71% sensitive), but lower values are inconclusive of the contrary (63%). Nonetheless, in diagnostics, the sensitivity is more valuable than the specificity, but what is the main aspect of diagnostic accuracy fails BMI_2 especially. Evidently, obesity precipitates T2DM.[23,35] Even though a reverse causation from T2DM to obesity is inconceivable, one might think of a hidden factor influencing both. This risk factor ought to be the sprung-out central/visceral adiposity which gives a boost to WCHR and triggers T2DM. By contrast, BMI_2 is steadily increasing.

5.6 Uses of BMI_2

Unlike BMI_2, BMI_1 appears to be equally sensitive and specific (63%),[17] but this offers no advantage one way or the other and the balanced accuracy is low. A high specificity can be a desirable property, and what is sensitivity or otherwise depends on how the problem is approached. If it was tendered to identify persons not suited for screening for T2DM then BMI_2 is obviously a better choice than WCHR.

Again, BMI_2 is an obvious choice in relation to pain in weight-bearing joints because it characterises the pressure in a joint,[24] which was probably another historical reason behind the wide acceptance of BMI_2 as a universal measure of excessive weight. However, it is unnecessary that the extra weight was associated with adiposity, it can refer to a burden of any kind, even related to carrying loads. Moreover, a history of obesity or physical exertion can negatively impact on the joint ability to self-repair.[40] This particularly holds for osteoarthritis - a highly prevalent degenerative condition affecting all joints. It onsets with age, the incidence being higher among women than among men, and is exacerbated by excessive body weight.[40] Its origins are thought to be metabolic and hormonal. Particularly, obesity is known to be responsible for creating a chronic state of systemic low-grade inflammation, provoking an autoimmune response.[23,35] Independently, a high BMI_2 may aggravate the condition in weight-bearing joints, like the ones in knees.[40] Under the circumstances, BMI_2 might indeed appear being more relevant to the problem than WCHR.

6. Conclusion

In this paper linear regressions from BMI to WCHR and in reverse were evaluated to enable WCHR estimation since WC measurements are often neglected in favour of BMI routinely used as an obesity index despite the mounting evidence that WCHR is a better measure. Even though regression coefficients are statistically different for men and women, the expressions produce close results, inspiring a unified WCHR-based index of obesity. It has been claimed that WCHR is also age independent. In this study the population spans five age categories from young adults to elderly. The data was sourced from the NHANES collection. There is a modest, but clear tendency to the obesity threshold accelerating increase with age, so long as BMI is a trusted standard. Age amplifies hazards posed by various diseases and correlates with the weight gain in obesity. The effects of survival and senescence change the population. Also, WCHR is not flawless in assessing obesity in women past the young adulthood. A minor result in this study is that BMI_2 (the conventional BMI) was compared to BMI_1 – the simple weight to height ratio. Using BMI_1 is more convenient for self-assessment, and it appears that it aligns very closely with BMI_2 by gender. Although the equations for different genders are notably different, it was still possible to work out a single obesity index based on BMI_1, and it is highly correspondent with the standard one based on BMI_2 (at the 95% - 100% level). This addresses certain lack of information in various related to the healthy weight guidelines and is supported by findings of related research. However, there is a much higher correspondence between WCHR and BMI_2 (at the 85% - 90% level) than between WCHR and BMI_1 (at the 70% - 75% level). Different measures to different extents explain the weight gain in obesity, and in that respect BMI_2 is better than BMI_1, or at least BMI_2 is widely adopted. Yet, time and again WCHR was demonstrated to be even more relevant to obesity than BMI_2. Therefore, some misclassification of data by alternative indices is generally unavoidable.

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