



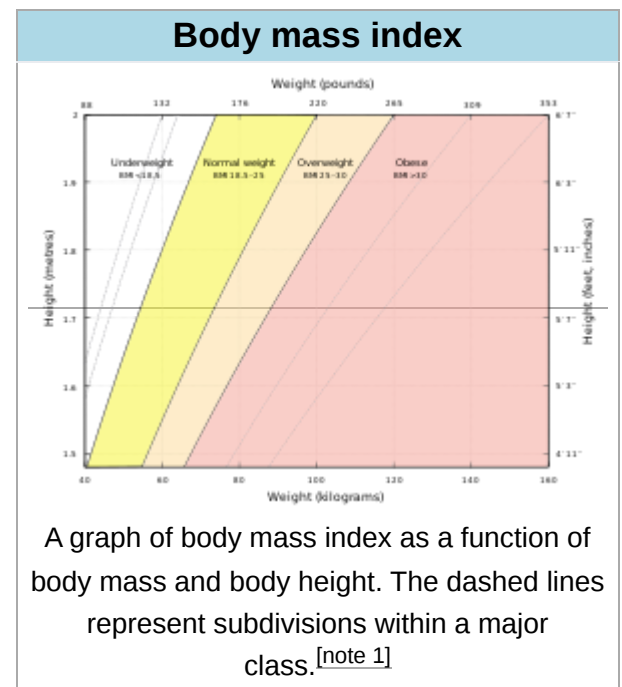
Body mass index

⚠ This is an old revision of this page, as edited by Yurell (talk | contribs) at 11:47, 23 September 2017 (→ *Surface-based body shape index: Added SBSI-star*). The present address (URL) is a permanent link to this revision, which may differ significantly from the current revision.

The **body mass index (BMI)** or **Quetelet index** is a value derived from the mass (weight) and height of an individual. The BMI is defined as the body mass divided by the square of the body height, and is universally expressed in units of kg/m^2 , resulting from mass in kilograms and height in metres.

The BMI may also be determined using a table^[note 2] or chart which displays BMI as a function of mass and height using contour lines or colours for different BMI categories, and which may use other units of measurement (converted to metric units for the calculation).^[note 3]

The BMI is an attempt to quantify the amount of tissue mass (muscle, fat, and bone) in an individual, and then categorize that person as *underweight*, *normal weight*, *overweight*, or *obese* based on that value. However, there is some debate about where on the BMI scale the dividing lines between categories should be placed.^[2] Commonly accepted BMI ranges are underweight: under 18.5 kg/m^2 , normal weight: 18.5 to 25 , overweight: 25 to 30 , obese: over 30 . People of Asian descent have different associations between BMI, percentage of body fat, and health risks than those of European descent, with a higher risk of type 2 diabetes and cardiovascular disease at BMIs lower than the WHO cut-off point for overweight, 25 kg/m^2 , although the cutoff for observed risk varies among different Asian populations.^[3]



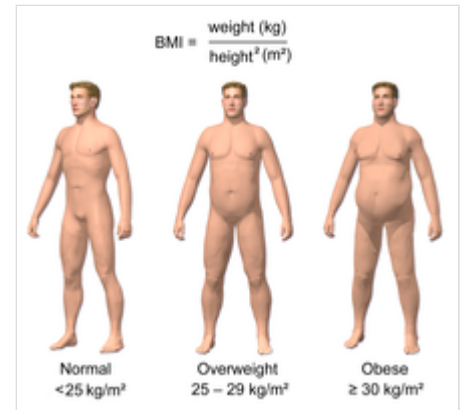
History

The basis of the BMI was devised by Adolphe Quetelet, a Belgian astronomer, mathematician, statistician and sociologist, from 1830 to 1850 during which time he developed what he called "social physics".^[4] The modern term "body mass index" (BMI) for the ratio of human body weight to squared height was coined in a paper published in the July 1972 edition of the *Journal of Chronic Diseases* by Ancl Keys and others. In this paper, Keys argued that what he termed the BMI was "...if not fully satisfactory, at least as good as any other relative weight index as an indicator of relative obesity"^{[5][6][7]}

The interest in an index that measures body fat came with increasing obesity in prosperous Western societies. BMI was explicitly cited by Keys as appropriate for *population* studies and inappropriate for individual evaluation. Nevertheless, due to its simplicity, it has come to be widely used for preliminary diagnosis.^[8] Additional metrics, such as waist circumference, can be more useful.^[9]

The BMI is universally expressed in kg/m², resulting from mass in kilograms and height in metres. If pounds and inches are used, a conversion factor of 703 (kg/m²)/(lb/in²) must be applied. When the term BMI is used informally, the units are usually omitted.

$$\text{BMI} = \frac{\text{mass}_{\text{kg}}}{\text{height}_{\text{m}}^2} = \frac{\text{mass}_{\text{lb}}}{\text{height}_{\text{in}}^2} \times 703$$



Obesity and BMI

BMI provides a simple numeric measure of a person's *thickness* or *thinness*, allowing health professionals to discuss weight problems more objectively with their patients. BMI was designed to be used as a simple means of classifying average sedentary (physically inactive) populations, with an average body composition.^[10] For these individuals, the current value recommendations are as follow: a BMI from 18.5 up to 25 kg/m² may indicate optimal weight, a BMI lower than 18.5 suggests the person is underweight, a number from 25 up to 30 may indicate the person is overweight, and a number from 30 upwards suggests the person is obese.^{[8][9]} Some athletes, such as football linemen, have a high muscle to fat ratio and may have a BMI that is misleadingly high relative to their body fat percentage.^[9]

Scalability

BMI is proportional to the mass and inversely proportional to the square of the height. So, if all body dimensions double, and mass scales naturally with the cube of the height, then BMI doubles instead of remaining the same. This results in taller people having a reported BMI that is uncharacteristically high, compared to their actual body fat levels. In comparison, the Ponderal index is based on the natural scaling of mass with the third power of the height.

However, many taller people are not just "scaled up" short people but tend to have narrower frames in proportion to their height. Nick Korevaar (a mathematics lecturer from the University of Utah) suggests that instead of squaring the body height (as the BMI does) or cubing the body height (as the Ponderal index does), it would be more appropriate to use an exponent of between 2.3 and 2.7^[11] (as originally noted by Quetelet). (For a theoretical basis for such values see MacKay.^[12]) Carl Lavie has written that, "The B.M.I. tables are excellent for identifying obesity and body fat in large populations, but they are far less reliable for determining fatness in individuals."^[13]

Categories

A frequent use of the BMI is to assess how much an individual's body weight departs from what is normal or desirable for a person's height. The weight excess or deficiency may, in part, be accounted for by body fat (adipose tissue) although other factors such as muscularity also affect BMI significantly (see discussion below and overweight).

The WHO regards a BMI of less than 18.5 as underweight and may indicate malnutrition, an eating disorder, or other health problems, while a BMI equal to or greater than 25 is considered overweight and above 30 is considered obese.^[1] These ranges of BMI values are valid only as statistical categories.

Category	BMI (kg/m ²)		BMI Prime	
	from	to	from	to
Very severely underweight		15		0.60
Severely underweight	15	16	0.60	0.64
Underweight	16	18.5	0.64	0.74
Normal (healthy weight)	18.5	25	0.74	1.0
Overweight	25	30	1.0	1.2
Obese Class I (Moderately obese)	30	35	1.2	1.4
Obese Class II (Severely obese)	35	40	1.4	1.6
Obese Class III (Very severely obese)	40		1.6	

BMI in children (aged 2 to 20)

BMI is used differently for children. It is calculated in the same way as for adults, but then compared to typical values for other children of the same age. Instead of comparison against fixed thresholds for underweight and overweight, the BMI is compared against the percentile for children of the same sex and age.^[14]

A BMI that is less than the 5th percentile is considered underweight and above the 95th percentile is considered obese. Children with a BMI between the 85th and 95th percentile are considered to be overweight.^[15]

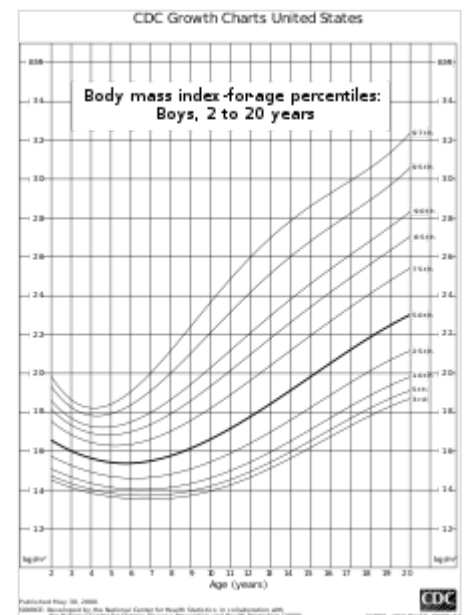
Recent studies in Britain have indicated that females between the ages 12 and 16 have a higher BMI than males of the same age by 1.0 kg/m² on average.^[16]

International variations

These recommended distinctions along the linear scale may vary from time to time and country to country, making global, longitudinal surveys problematic.

Hong Kong

The Hospital Authority of Hong Kong recommends the use of the following BMI ranges:^[17]



BMI for age percentiles for boys 2 to 20 years of age.

Category	BMI (kg/m ²)	
	from	to
Underweight		18.5
Normal Range	18.5	23
Overweight—At Risk	23	25
Overweight—Moderately Obese	25	30
Overweight—Severely Obese	30	

Japan

Japan Society for the Study of Obesity (2000):^[18]

Category	BMI (kg/m ²)	
	from	to
Low		18.5
Normal	18.5	25
Obese (Level 1)	25	30
Obese (Level 2)	30	35
Obese (Level 3)	35	40
Obese (Level 4)	40	

^[19]

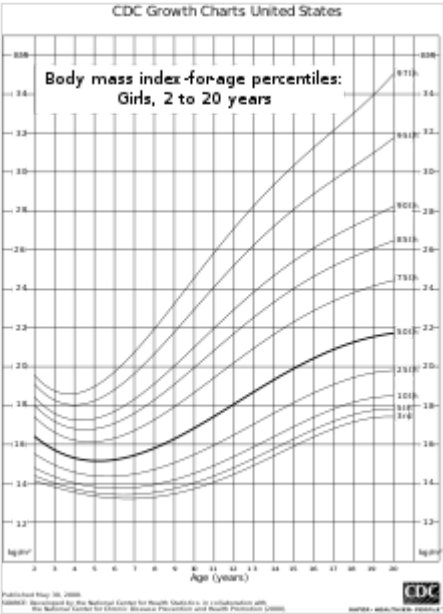
Singapore

In Singapore, the BMI cut-off figures were revised in 2005, motivated by studies showing that many Asian populations, including Singaporeans, have higher proportion of body fat and increased risk for cardiovascular diseases and diabetes mellitus, compared with Caucasians at the same BMI. The BMI cut-offs are presented with an emphasis on health risk rather than weight.

Health Risk	BMI (kg/m ²)
Risk of developing problems such as nutritional deficiency and osteoporosis	under 18.5
Low Risk (healthy range)	18.5 to 23
Moderate risk of developing heart disease, high blood pressure, stroke, diabetes	23 to 27.5
High risk of developing heart disease, high blood pressure, stroke, diabetes	over 27.5

United States

In 1998, the U.S. National Institutes of Health and the Centers for Disease Control and Prevention brought U.S. definitions in line with World Health Organization guidelines, lowering the normal/overweight cut-off from BMI 27.8 to BMI 25. This had the effect of redefining approximately 29 million Americans, previously *healthy*, to *overweight*.^[20]



BMI for age percentiles for girls 2 to 20 years of age.

This can partially explain the increase in the *overweight* diagnosis in the past 20 years, and the increase in sales of weight loss products during the same time. WHO also recommends lowering the normal/overweight threshold for South East Asian body types to around BMI 23, and expects further revisions to emerge from clinical studies of different body types.

The U.S. National Health and Nutrition Examination Survey of 1994 showed that 59.8% of American men and 51.2% of women had BMIs over 25.^[21] Morbid obesity—a BMI of 40 or more—was found in 2% of the men and 4% of the women. A survey in 2007 showed 63% of Americans are overweight or obese, with 26% in the obese category (a BMI of 30 or more). As of 2014, 37.7% of adults in the United States were obese, categorized as 35.0% of men and 40.4% of women; class 3 obesity (BMI over 40) values were 7.7% for men and 9.9% for women.^[22]

There are differing opinions on definition of underweight in females; doctors quote anything below 18.5 to 20 as underweight. The most frequently stated is 19. A BMI nearing 15 is usually defined as starvation and a BMI less than 17.5 as an informal criterion for the diagnosis of anorexia nervosa.

Body Mass Index values for males and females aged 20 and over, and selected percentiles by age: United States, 2011–2014.									
Source: "Anthropometric Reference Data for Children and Adults: United States" from CDC DHHS ^[23]									
Age	Percentile								
	5th	10th	15th	25th	50th	75th	85th	90th	95th
	Men BMI (kg/m ²)								
20 years and over (total)	20.7	22.2	23.0	24.6	27.7	31.6	34.0	36.1	39.8
20–29 years	19.3	20.5	21.2	22.5	25.5	30.5	33.1	35.1	39.2
30–39 years	21.1	22.4	23.3	24.8	27.5	31.9	35.1	36.5	39.3
40–49 years	21.9	23.4	24.3	25.7	28.5	31.9	34.4	36.5	40.0
50–59 years	21.6	22.7	23.6	25.4	28.3	32.0	34.0	35.2	40.3
60–69 years	21.6	22.7	23.6	25.3	28.0	32.4	35.3	36.9	41.2
70–79 years	21.5	23.2	23.9	25.4	27.8	30.9	33.1	34.9	38.9
80 years and over	20.0	21.5	22.5	24.1	26.3	29.0	31.1	32.3	33.8
Age	Women BMI (kg/m ²)								
20 years and over (total)	19.6	21.0	22.0	23.6	27.7	33.2	36.5	39.3	43.3
20–29 years	18.6	19.8	20.7	21.9	25.6	31.8	36.0	38.9	42.0
30–39 years	19.8	21.1	22.0	23.3	27.6	33.1	36.6	40.0	44.7
40–49 years	20.0	21.5	22.5	23.7	28.1	33.4	37.0	39.6	44.5
50–59 years	19.9	21.5	22.2	24.5	28.6	34.4	38.3	40.7	45.2
60–69 years	20.0	21.7	23.0	24.5	28.9	33.4	36.1	38.7	41.8
70–79 years	20.5	22.1	22.9	24.6	28.3	33.4	36.5	39.1	42.9
80 years and over	19.3	20.4	21.3	23.3	26.1	29.7	30.9	32.8	35.2

Consequences of elevated level in adults

The BMI ranges are based on the relationship between body weight and disease and death.^[24] Overweight and obese individuals are at an increased risk for the following diseases:^[25]

- Coronary artery disease
- Dyslipidemia
- Type 2 diabetes
- Gallbladder disease
- Hypertension
- Osteoarthritis
- Sleep apnea
- Stroke
- At least 10 cancers, including endometrial, breast, and colon cancer.^[26]
- Epidural lipomatosis ^[27]

Among people who have never smoked, overweight/obesity is associated with 51% increase in mortality compared with people who have always been a normal weight.^[28]

Applications

Public health

The BMI is generally used as a means of correlation between groups related by general mass and can serve as a vague means of estimating adiposity. The duality of the BMI is that, while it is easy to use as a general calculation, it is limited as to how accurate and pertinent the data obtained from it can be. Generally, the index is suitable for recognizing trends within sedentary or overweight individuals because there is a smaller margin of error.^[29] The BMI has been used by the WHO as the standard for recording obesity statistics since the early 1980s.

This general correlation is particularly useful for consensus data regarding obesity or various other conditions because it can be used to build a semi-accurate representation from which a solution can be stipulated, or the RDA for a group can be calculated. Similarly, this is becoming more and more pertinent to the growth of children, due to the fact that the majority of children are sedentary.^[30]

Clinical practice

BMI categories are generally regarded as a satisfactory tool for measuring whether sedentary individuals are *underweight*, *overweight*, or *obese* with various exceptions, such as: athletes, children, the elderly, and the infirm. Also, the growth of a child is documented against a BMI-measured growth chart. Obesity trends can then be calculated from the difference between the child's BMI and the BMI on the chart. In the United States, BMI is also used as a measure of underweight, owing to advocacy on behalf of those with eating disorders, such as anorexia nervosa and bulimia nervosa.

Legislation

In France, Israel, Italy and Spain, legislation has been introduced banning usage of fashion show models having a BMI below 18.^[31] In Israel, a BMI below 18.5 is banned.^[32] This is done in order to fight anorexia among models and people interested in fashion.

Limitations

The medical establishment^[34] and statistical community^[35] have both highlighted the limitations of BMI.

Mathematician Keith Devlin and the restaurant industry association Center for Consumer Freedom argue that the error in the BMI is significant and so pervasive that it is not generally useful in evaluation of health.^{[36][37]} University of Chicago political science professor Eric Oliver says BMI is a convenient but inaccurate measure of weight, forced onto the populace, and should be revised.^[38]

Scaling

The exponent in the denominator of the formula for BMI is arbitrary. The BMI depends upon weight and the *square* of height. Since mass increases to the *3rd power* of linear dimensions, taller individuals with exactly the same body shape and relative composition have a larger BMI.^[39]

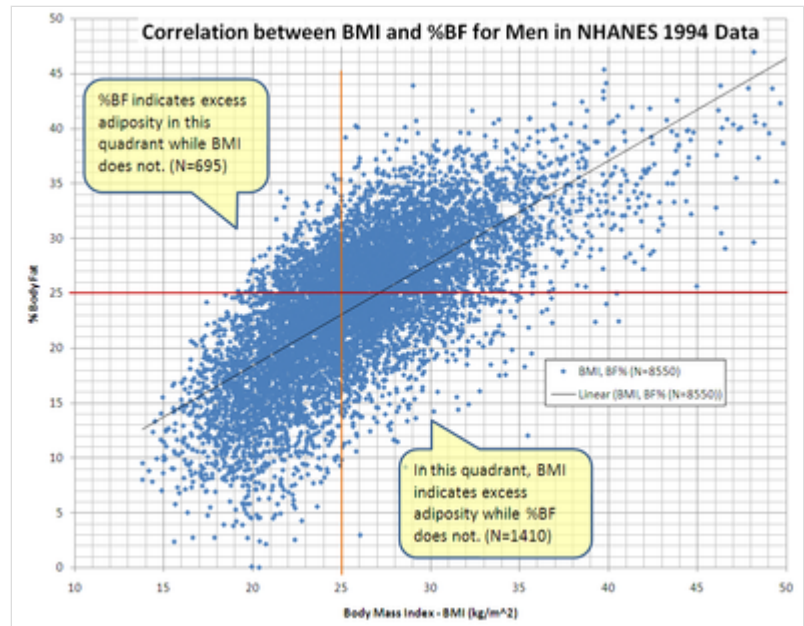
The mathematician Prof Nick Trefethen, who observed this said, “BMI divides the weight by too large a number for short people and too small a number for tall people. So short people are misled into thinking that they are thinner than they are, and tall people are misled into thinking they are fatter.”^[40]

Sports medicine doctor Sultan M. Babar has shown that corpulence index is a better measure.^[41]

An analysis based on data gathered in the US suggested an exponent of 2.6 would yield the best fit for children aged 2 to 19 years old.^[11] For US adults, exponent estimates range from 1.92 to 1.96 for males and from 1.45 to 1.95 for females.^{[42][43]}

Ignores variation in physical characteristics

The BMI adds roughly 10% for a large (or tall) frame and subtracts roughly 10% for a smaller frame (short stature). In other words, persons with small frames would be carrying more fat than optimal, but their BMI reflects that they are *normal*. Conversely, large framed (or tall) individuals may be quite healthy, with a fairly low body fat percentage, but be classified as *overweight* by BMI.^[44]



This graph shows the correlation between body mass index (BMI) and percent body fat (%BF) for 8550 men in NCHS' NHANES 1994 data. Data in the upper left and lower right quadrants suggest the limitations of BMI.^[33]

For example, a chart may say the ideal weight for a man 5 ft 10 in (178 cm) is 165 pounds (75 kg). But if that man has a slender build (small frame), he may be overweight at 165 pounds (75 kg) and should reduce by 10%, to roughly 150 pounds (68 kg). In the reverse, the man with a larger frame and more solid build can be quite healthy at 180 pounds (82 kg). If one teeters on the edge of small/medium or medium/large, common sense should be used in calculating one's ideal weight. However, falling into one's ideal weight range for height and build is still not as accurate in determining health risk factors as waist/height ratio and actual body fat percentage.^[45]

Accurate frame size calculators use several measurements (wrist circumference, elbow width, neck circumference and others) to determine what category an individual falls into for a given height.^[46] The BMI also fails to take into account loss of height through aging. In this situation, BMI will increase without any corresponding increase in weight.

Does not differentiate between muscle mass and fat mass

Assumptions about the distribution between muscle mass and fat mass are inexact. BMI generally overestimates adiposity on those with more lean body mass (e.g., athletes) and underestimates excess adiposity on those with less lean body mass. A study in June 2008 by Romero-Corral et al. examined 13,601 subjects from the United States' third National Health and Nutrition Examination Survey (NHANES III) and found that BMI-defined obesity (BMI > 30) was present in 21% of men and 31% of women.

Using body fat percentages (BF%), however, BF-defined obesity was found in 50% of men and 62% of women. While BMI-defined obesity showed high specificity (95% for men and 99% for women), BMI showed poor sensitivity (36% for men and 49% for women). Despite this undercounting of obesity by BMI, BMI values in the intermediate BMI range of 20–30 were found to be associated with a wide range of body fat percentages. For men with a BMI of 25, about 20% have a body fat percentage below 20% and about 10% have body fat percentage above 30%.^[33]

BMI is particularly inaccurate for people who are very fit or athletic, as their high muscle mass can classify them in the *overweight* category by BMI, even though their body fat percentages frequently fall in the 10–15% category, which is below that of a more sedentary person of average build who has a *normal* BMI number. Body composition for athletes is often better calculated using measures of body fat, as determined by such techniques as skinfold measurements or underwater weighing and the limitations of manual measurement have also led to new, alternative methods to measure obesity, such as the body volume index.

Variation in definitions of categories

It is not clear where on the BMI scale the threshold for overweight and obese should be set. Because of this the standards have varied over the past few decades. Between 1980 and 2000 the U.S. Dietary Guidelines have defined overweight at a variety of levels ranging from a BMI of 24.9 to 27.1. In 1985 the National Institutes of Health (NIH) consensus conference recommended that overweight BMI be set at a BMI of 27.8 for men and 27.3 for women.

In 1998 a NIH report concluded that a BMI over 25 is overweight and a BMI over 30 is obese.^[47] In the 1990s the World Health Organization (WHO) decided that a BMI of 25 to 30 should be considered overweight and a BMI over 30 is obese, the standards the NIH set. This became the definitive guide for determining if someone is overweight.

The current WHO and NIH ranges of *normal* weights are proved to be associated with decreased risks of some diseases such as diabetes type II; however using the same range of BMI for men and women is considered arbitrary, and makes the definition of underweight quite unsuitable for men.^[48]

One study found that the vast majority of people labelled 'overweight' and 'obese' according to current definitions do not in fact face any meaningful increased risk for early death. In a quantitative analysis of a number of studies, involving more than 600,000 men and women, the lowest mortality rates were found for people with BMIs between 23 and 29; most of the 25–30 range considered 'overweight' was not associated with higher risk.^[49]

Variation in relationship to health

A study published by *Journal of the American Medical Association* (JAMA) in 2005 showed that *overweight* people had a death rate similar to *normal* weight people as defined by BMI, while *underweight* and *obese* people had a higher death rate.^[50]

A study published by *The Lancet* in 2009 involving 900,000 adults showed that *overweight* and *underweight* people both had a mortality rate higher than *normal* weight people as defined by BMI. The optimal BMI was found to be in the range of 22.5–25.^[51]

High BMI is associated with type 2 diabetes only in persons with high serum gamma-glutamyl transpeptidase.^[52]

In an analysis of 40 studies involving 250,000 people, patients with coronary artery disease with *normal* BMIs were at higher risk of death from cardiovascular disease than people whose BMIs put them in the *overweight* range (BMI 25–29.9).^[53]

One study found that BMI had a good general correlation with body fat percentage, and noted that obesity has overtaken smoking as the world's number one cause of death. But it also notes that in the study 50% of men and 62% of women were obese according to body fat defined obesity, while only 21% of men and 31% of women were obese according to BMI, meaning that BMI was found to underestimate the number of obese subjects.^[33]

A 2010 study that followed 11,000 subjects for up to eight years concluded that BMI is not a good measure for the risk of heart attack, stroke or death. A better measure was found to be the waist-to-height ratio.^[54] A 2011 study that followed 60,000 participants for up to 13 years found that waist-hip ratio was a better predictor of ischaemic heart disease mortality.^[55]

Alternatives

BMI Prime

BMI Prime, a modification of the BMI system, is the ratio of actual BMI to upper limit optimal BMI (currently defined at 25 kg/m²), i.e., the actual BMI expressed as a proportion of upper limit optimal. The ratio of actual body weight to body weight for upper limit optimal BMI (25 kg/m²) is equal to BMI Prime. BMI Prime is a dimensionless number independent of units. Individuals with BMI Prime less than 0.74 are underweight; those

with between 0.74 and 1.00 have optimal weight; and those at 1.00 or greater are overweight. BMI Prime is useful clinically because it shows by what ratio (e.g. 1.36) or percentage (e.g. 136%, or 36% above) a person deviates from the maximum optimal BMI.

For instance, a person with BMI 34 kg/m² has a BMI Prime of 34/25 = 1.36, and is 36% over their upper mass limit. In South East Asian and South Chinese populations (see § international variations), BMI Prime should be calculated using an upper limit BMI of 23 in the denominator instead of 25. BMI Prime allows easy comparison between populations whose upper-limit optimal BMI values differ.^[56]

Waist circumference

Waist circumference is a good indicator of visceral fat, which poses more health risks than fat elsewhere. According to the U.S. National Institutes of Health (NIH), waist circumference in excess of 102 centimetres (40 in) for men and 88 centimetres (35 in) for (non-pregnant) women, is considered to infer a high risk for type 2 diabetes, dyslipidemia, hypertension, and CVD. Waist circumference can be a better indicator of obesity-related disease risk than BMI. For example, this is the case in populations of Asian descent and older people.^[57] 94 centimetres (37 in) for men and 80 centimetres (31 in) for women has been stated to pose "higher risk", with the NIH figures "even higher".^[58]

Waist-to-hip circumference ratio has also been used, but has been found to be no better than waist circumference alone, but more complicated to measure.^[59]

A related indicator is waist circumference divided by height. The values indicating increased risk are: greater than 0.5 for people under 40 year of age, 0.5 to 0.6 for people aged 40–50, and greater than 0.6 for people over 50 years of age.^[60]

Surface-based body shape index

The Surface-based Body Shape Index (SBSI) is far more rigorous and is based upon four key measurements: the body surface area, vertical trunk circumference, waist circumference and height. Data on 11,808 subjects from the National Health and Human Nutrition Examination Surveys (NHANES) 1999–2004, showed that SBSI outperformed BMI, waist circumference, and A Body Shape Index (ABSI), an alternative to BMI.^{[61][62]}

$$\text{SBSI} = \frac{(H^{7/4})(WC^{5/6})}{\text{BSA VTC}}$$

A simplified, dimensionless form of SBSI, known as SBSI*, has also been developed.^[62]

$$\text{SBSI}^* = \frac{(H^2)(WC)}{\text{BSA VTC}}$$

Modified body mass index

Within some medical contexts, such as familial amyloid polyneuropathy, serum albumin is factored in to produce a modified body mass index (mBMI). The mBMI can be obtained by multiplying the BMI by serum albumin, in grams per litre.^[63]

See also


- Allometry
- Body adiposity index
- Body Shape Index
- Body volume index
- Body water
- Corpulence index
- List of countries by Body Mass Index (BMI)
- Obesity paradox
- Pignet Index
- Sagittal Abdominal Diameter (SAD)

Notes

1. For instance, the "Underweight" classification is further divided into "severe", "moderate", and "mild" subclasses.^[1]
2. e.g., the Body Mass Index Table (http://www.nhlbi.nih.gov/guidelines/obesity/bmi_tbl.htm) Archived (https://web.archive.org/web/20100310114919/http://www.nhlbi.nih.gov/guidelines/obesity/bmi_tbl.htm) 2010-03-10 at the Wayback Machine from the National Institutes of Health's NHLBI.
3. For example, in the UK where people often know their weight in stone and height in feet and inches, – see "Archived copy" (https://web.archive.org/web/20121111002050/http://newsimg.bbc.co.uk/media/images/42028000/gif/_42028890_bmi_gra_416x314.gif). Archived from the original (http://newsimg.bbc.co.uk/media/images/42028000/gif/_42028890_bmi_gra_416x314.gif) on 2012-11-11. Retrieved 2013-07-29. {{cite web}}: Unknown parameter |deadurl= ignored (|url-status= suggested) (help)

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Further reading

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- Samaras, Thomas T., ed. (2007). *Human Body Size and the Laws of Scaling: Physiological, Performance, Growth, Longevity and Ecological Ramifications*. New York: Nova Science. ISBN 978-1-60021-408-0.
- Sothorn, Melinda S.; Gordon, Stewart T.; von Almen, T. Kristian, eds. (2006). *Handbook of Pediatric Obesity: Clinical Management* (illustrated ed.). CRC Press. ISBN 978-1-4200-1911-7.

External links

- U.S. National Center for Health Statistics:
 - BMI Growth Charts for children and young adults (<https://www.cdc.gov/growthcharts/>)
 - BMI calculator ages 20 and older (https://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/english_bmi_calculator/bmi_calculator.html)

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