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Anthropometric Assessment: Height, Weight, Body Mass Index (Adults)

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Historical Perspective

Quetelet

Lambert-Adolf-Jacques Quetelet is credited with the concept of the body mass index (BMI).[1] The proposal was made in a monograph in 1835 on the development of the human body. As Freudenthal says, "With Quetelet's work in 1835 a new era in statistics began … The work gave a description of the average man as both a static and dynamic phenomenon."[2] It was Quetelet who introduced the concept of quantitation in measurement of the human being, thus providing a framework for progess in epidemiology and statistics. Quetelet, with his mathematical background, took statistical methods into new arenas. He was a pioneer in the application of statistics to human biology, anthropology, and criminology.

Quetelet was interested in the underlying factors that determined the distribution of such events as births, marriages, deaths, and the prevalence of various types of crime. In his work he noted the seasonal distribution of births, deaths, and marriages. He also noted a seasonal distribution of crime, and that crimes against property appeared more frequently in cold months while crimes against the person were more common in the summer. Commenting on the constancy of crimes from year to year, he said, "Thus we pass from one year to another with the sad perspective of seeing the same crimes reproduced in the same order and calling down the same punishments in the same proportions. Sad condition of humanity …".[1] Fortunately, the human being has been able to change this apparent constancy by education, laws, and better government. Much of the work in the volume *Sur l'Homme* deals with means and distributions of the measurements he made. It was not until a later publication in 1845 in the *Bulletin de la Commission de Statistique (de Belgique)* that he dealt with the concept of the binomial distribution in detail. In his work, Quetelet devoted a significant amount of space to the issues of height and weight. The concept of the "average man" originated with Quetelet, and is one of his seminal contributions. To quote from Chapter 2 of his work, Quetelet says:

> If man increased equally in all his dimensions, his weight at different ages would be as the cube of his height. Now, this is not what we really observe. The increase in weight

is slower, except during the first year after birth; then the proportion which we have just pointed out is pretty regularly observed. But after this period, and until near the age of puberty, the weight increases nearly as the square of the height. The development of the weight again becomes very rapid at the time of puberty, and almost stops at the 25th year. In general, we do not err much when we assume that, during development, the square of weight at different ages are as the fifth powers of the height; which naturally leads to this conclusion, in supposing the specific gravity constant, that the transverse growth of man is less than the vertical.

However, if we compare two individuals who are fully developed and well-formed with each other, to ascertain the relations existing between the weight and stature, we shall find that the weight of developed persons, of different heights, is nearly as the square of the stature. Whence it naturally follows, that a transverse section, giving both the breadth and thickness, is just proportioned to the height of the individual. We furthermore conclude that, proportion still being attended, width predominates in individuals of small stature.[1]

These two paragraphs succinctly summarize the concept of the body mass according to Quetelet, and the rationale on which he developed his concept.

Life Insurance

Nearly 70 years after Quetelet, the life insurance industry in the United States began to weigh in on the importance of excess weight as a risk for early death.[3] It was also noted that a central distribution of weight was important. The 1922 *Statistical Bulletin of the Metropolitan Life Insurance Company*[4] says:

It is generally recognized that weight of the human body in relation to its height plays a part in determining the health and longevity of the individual. It is only recently, however, that the long experience of the insurance companies has made possible the crystallization of this impression into a series of definite propositions. We know now, for example, that overweight is a serious impairment among insured lives, the gravity increasing with the excess in weight over the average for the height and age. But, even this statement has its exceptions because, at younger ages, a limited amount of overweight is apparently an advantage. Such persons have uniformly lower death rates from tuberculosis. It is after the age of 35 that overweight, even in relatively small amounts, begins to be dangerous. The seriousness increases with advancing age and with the amount of overweight.

From this point forward until the last decade of the 20th century, there were "weight tables" of appropriate, desirable, or ideal weight proposed by the life insurance industry. The Framingham Study, which was the first American effort at a long-term population-based evaluation of health risks, used the Metropolitan Life Insurance Table of 1959 as the basis for comparing the weights of people living in Framingham with some standard. The term came to be called the Metropolitan Relative Weight, which was the weight for height of an individual to the expected weight for height from the Metropolitan Life Insurance Table median frame grouping.

Various Indices

Several indices relating height to weight were proposed in the middle of the 20th century. The BMI, or what might be appropriately called the Quetelet Index (QI), was compared against several other indices by Keys et al.[5] They evaluated three indices of weight and height: the Wt/Ht, the $Wt/[Ht]^2$ (QI), and the $Ht/[Wt]^{1/3}$ (Ponderal Index) against skinfold estimates of fat. Of these three, the QI had a slightly better correlation with fatness than Wt/Ht. The Ponderal Index was clearly the worst.

Gradual Adoption of the BMI

Benn reopened this question again in 1971.[6] He showed that a simple index of weight/$(Ht)^p$ could be derived for each population, in which p was a power where weight had the lowest relation to height for that population. For most populations this number is between 1 and 2. The ratio that Quetelet proposed in 1835 had a power of 2 $[wt/(Ht)^2]$. Lee, Kolonel, and Hinds,[7] in an effort to apply a weight/height index to a variety of populations in Hawaii, found different indices useful for ranking the different populations. However, these authors did not measure fatness, and since all of these weight-to-height indices are strongly related to weight,[8] their data are not helpful in resolving the value of the QI versus the Benn Index as estimates of fat. Keys et al.[5] examined the relationship of weight-to-height indices in 12 populations. The best correlations with body fat as estimated from skinfolds were found with $[wt/(Ht)^2]$. He found that the QI had correlations ranging between .611 and .850 when related to skinfold thickness. In a detailed evaluation of four large study populations, Garn and Pesick [8] showed a strong correlation between any index and weight which approximated $r = 0.90$. In this study, the population-specific indices, as proposed by Benn $[wt/(Ht)^2]$, ranged between 1.18 and 1.83. These population-specific indices provided no advantage over the $Wt/(Ht)^2$ when related to skinfolds.

Garrow and Webster[9] have examined the QI as a measure of fatness in a group of obese subjects. Fat was measured by three separate techniques including densitometry, measurement of total body water, and measurement of total body potassium using γ-emission from naturally occurring ^{40}K. As Garrow and Webster point out, there is considerable variation in estimating fat between the methods that they selected for this study.[9] The accuracy for measuring fat was greater for men than for women by all methods used by Garrow and Webster. The standard deviations for estimating fat by the QI, however, were only slightly larger than those for density, body water, and body potassium. The relationship of $FAT/(Ht)^2$ plotted against $[wt/(Ht)^2]$ yielded very similar slopes for men (0.715) and women (0.713). This indicates that men and women of similar height differ in weight by tissue which is approximately 75% fat and 25% non-fat. In their data analysis there was an important difference in the fatness between men and women, such that a woman with 0 (zero) body fat would have a QI of 13.7 kg/m^2, whereas a man with 0 body fat would have a QI of 16.9 kg/m^2. Garrow and Webster thus conclude that "Quetelet's Index has been underrated as a measure of obesity in adults. It … provides a measure of fatness not much less accurate than specialized laboratory methods." As they point out, this index can be applied over the entire weight range, while such measurements as skinfold thickness are severely limited in obese individuals and nearly useless in very obese individuals.

An additional feature of the QI is the similarity of the mortality and morbidity curves plotted against QI for men and women. Whether related to excessive deaths or to morbidity from various disease entities, the minimum QI (BMI) is similar for both sexes at comparable ages. Yet at all ages, the quantity of body fat in women is higher than men for any given height/weight combination. This implies that the extra fat in women (the zero fat BMI values noted above) is not associated with increased risk of excess morbidity or mortality. A similar conclusion, ushering in the era of studies in body fat distribution,[1] suggests that for comparable increases in risk indices such as blood pressure, women have approximately 20 kg more adipose tissue stores of fat than men.[2]

In summary, the relationship between height and weight [$wt/(Ht)^2$] proposed by Quetelet in 1835 has stood the test of time. In tribute to his contribution and its validation from a number of sources, it would be appropriate to refer to it as the Quetelet Index, or QI, and replace the frequently used body mass index, or BMI, with this new nomenclature.

Measurement of Weight

Recommended Technique

During infancy, a leveled pan scale with a beam and movable weights is used to measure weight. The pan must be at least 100 cm long so that it can support a 2-year-old infant at the 95th percentile for recumbent length. A quilt is left on the scale at all times, and the scale calibrated to zero and across the range of expected weights when only a quilt is on it, using test objects of known weights. Calibration is performed monthly and whenever the scales are moved. Similar procedures are used to calibrate the scales used for older individuals. When the scales are not in use, the beam should be locked in place or the weights shifted from zero to reduce wear.

The infant, with or without a diaper, is placed on the scales so that the weight is distributed equally on each side of the center of the pan. Weight is recorded to the nearest 10 g with the infant lying quietly, which may require patience. When an infant is restless, it is possible to weigh the mother when holding the infant and then weigh the mother without the infant, but this procedure is unreliable, partly because the mother's weight will be recorded to the nearest 100 g. It is better to postpone the measurement and try later. The measurement is repeated three times, and the average recorded after excluding any clearly erroneous value. If a diaper is worn, the weight of the diaper is subtracted from the observed weight, because most reference data for infants are based on nude weights.

In a clinic, the measured weight is recorded in tabular form in addition to being plotted. This plotting is done while the subject is present. Irregularities may be noted in the serial data for a subject or there may be major discrepancies between the percentile levels for highly correlated variables. When this occurs, the measurer checks the accuracy of the plotting and remeasures the subject if the plotting is correct.

A subject able to stand without support is weighed using a leveled platform scale with a beam and moveable weights or an electronic balance. The beam on the scale must be graduated so that it can be read from both sides and the scale positioned so that the measurer can stand behind the beam, facing the subject, and can move the beam weights without reaching around the subject. The movable tare is arranged so that a screwdriver is needed to shift it. The subject stands still over the center of the platform with the body weight evenly distributed between both feet. Light indoor clothing can be worn, excluding shoes, long trousers, and sweater. It is better to standardize the clothing, for example, a disposable paper gown. The weight of this clothing is not subtracted from the observed weight when the recommended reference data are used. Weight is recorded to the nearest 100 g.*

Handicapped subjects, other than infants, who cannot stand unsupported can be weighed using a beam chair scale or bed scale. If an adult weighs more than the upper limit on the beam, a weight can be suspended from the left-hand end of the beam, after

* For electronic scales, the subject stands in the center of the platform in appropriate clothing and the weight is recorded when stable.

which the measurer must determine how much weight must be placed on the platform for the scale to record zero when there is no weight on the platform. This weight is added to the measured value when a scale modified in this fashion is used. In studies to assess short-term changes, weights must be recorded at times standardized in relation to ingestion, micturition, and defecation, but for single weight this is not necessary.

Purpose

Weight is the most commonly recorded anthropometric variable, and generally is measured with sufficient accuracy. Accuracy can be improved, however, by attention to details of the measurement technique. Strictly, this measurement is of mass rather than weight, but the latter term is too well established to be replaced easily. Weight is a composite measure of total body size. It is important in screening for unusual growth, obesity, and undernutrition.

Literature

There is general agreement that weight should be measured using a beam scale with movable weights or a calibrated electronic balance. A pan scale is needed for measurements made during infancy. The use of a spring scale is not recommended, despite its greater mobility, except in field conditions where there may be no practical alternative. Automatic scales that print the weight directly onto a permanent record are available but expensive. The scale should be placed with the platform level and in a position where the measurer can see the back of the beam without leaning around the subject. Scales with wheels to facilitate movement from one location to another are not recommended because they need calibration every time they are moved.

Weight is best measured with the subject nude, which is practical during infancy.[10] At older ages, nude measurements may not be possible.[10] If not, standardized light clothing, for example, a disposable paper gown, should be worn in preference to "light indoor clothing."[10]

There are diurnal variations in weight of about 1 kg in children and 2 kg in adults. Therefore, recording the time of day at which measurements are made is necessary.[10] Usually it is not practical to measure at a fixed time, but a narrow range may be achievable.

Reliability

Intermeasurer differences (M) from the Fels Longitudinal Study are as follows:[10]

M = 1.2 g (SD = 3.2 g) at 5 to 10 years
M = 1.5 g (SD = 3.6 g) at 10 to 15 years
M = 1.7 g (SD = 3.8 g) at 15 to 20 years
M = 1.5 g (SD = 3.6 g) for adults

In the Health Examination Survey by the National Center for Health Statistics, the intermeasurer and intrameasurer technical errors were about 1.2 kg, when pairs of measurements were made 2 weeks apart.[10] About 10% of the observed error would have been due to growth.

Measurement of Stature (Standing Height)

Recommended Technique

Measurement of stature requires a vertical board with an attached metric rule and a horizontal headboard that can be brought into contact with the most superior point on the head. The combination of these elements is called a stadiometer. Fixed and portable models are available, and plans for fabrication of a stadiometer by an investigator are available from the Field Services Branch, Division of Nutrition, Centers for Disease Control, Atlanta, Georgia 30333.

The subject is barefoot or wears thin socks and little clothing so that the positioning of the body can be seen. The subject stands on a flat surface that is at a right angle to the vertical board of the stadiometer. The weight of the subject is distributed evenly on both feet, and the head is positioned in the Frankford Horizontal Plane. The arms hang freely by the sides of the trunk, with the palms facing the thighs. The subject places the heels together, with both heels touching the base of the vertical board. The medial borders of the feet are at an angle of about 60°. If the subject has knock knees, the feet are separated so that the medial borders of the knees are in contact but not overlapping. The scapulae and buttocks are in contact with the vertical board. The heels, buttocks, scapulae, and the posterior aspect of the cranium of some subjects cannot be placed in one vertical plane while maintaining a reasonable natural stance. These subjects are positioned so that only the buttocks and the heels or the cranium are in contact with the vertical board.

The subject is asked to inhale deeply and maintain a fully erect position without altering the load on the heels. The movable headboard is brought onto the most superior point on the head with sufficient pressure to compress the hair. The measurement is recorded to the nearest 0.1 cm, and the time at which the measurement was made is noted.

Recumbent length is measured in place of stature until the age of two years. Between two and three years, recumbent length or stature can be measured, and the choice made between these variables must be noted because they differ systematically. Two measurers are needed to measure stature in children aged two to three years. One measurer places a hand on the child's feet to prevent lifting of the heels and keep the heels against the vertical board, and he or she makes sure that the knees are extended with the other hand. The second measurer lowers the headboard and observes its level.

When there is lower limb anisomelia (inequality of length), the shorter side is built up with graduated wooden boards until the pelvis is level, as judged from the iliac crests. The amount of the buildup is recorded because it can alter the interpretation of weight-stature relationships.

Purpose

Stature is a major indicator of general body size and bone length. It is important in screening for disease or malnutrition and in the interpretation of weight. Variations from the normal range can have social consequences, in addition to their association with disease.

When stature cannot be measured, recumbent length can be substituted and, depending on the purpose of the study, adjustments for the systematic differences between these highly correlated measurements may be desirable.[10] Arm span may be used in place of stature when stature cannot be measured and it is not practical to measure recumbent length. The measurement of arm span is described in the section on segment lengths. Also, stature can be estimated from knee height, as described in the section on recumbent anthropometry.

Literature

Stature can be measured using a fixed or movable anthropometer. An anthropometer consists of a vertical graduated rod and a movable rod that is brought onto the head. An anthropometer can be attached to a wall or used in a free-standing mode, utilizing a base plate to keep the vertical rod properly aligned. Measurements of stature with a movable anthropometer tend to be less than those with a stadiometer.[10] It is not recommended that stature be measured against a wall, but if this must be done, a wall should be chosen that does not have a baseboard, and the subject should not stand on a carpet. An apparatus that allows stature to be measured while the subject stands on a platform scale is not recommended.

Some workers do not ask subjects to stretch to the appropriate extent. This is likely to lead to less reproducible positioning and less reliability than the recommended procedure. Some workers ask the subjects to assume a position of military attention; this is inappropriate for young children and for the elderly. In one alternative technique, a measurer exerts upward force under the mastoid processes to keep the head at the maximum level to which it was raised when the subject inhaled deeply. A second measurer lowers the headboard and observes its level, while a third person records the value. The need for three measurers reduces the practicality of this technique, but when it is applied the diurnal variation in stature is reduced.[10]

Some workers place the head in a "normal" position, with the eyes looking straight ahead; this is less precise than positioning in the Frankfort Horizontal Plane. Others tilt the head backwards and forwards and record stature when the head is positioned so that the maximum value is obtained. It is difficult to apply the latter procedure while the subject maintains a full inspiration.

It is general practice to place the subject's heels together, but the angle between the medial borders has varied from study to study. If these borders are parallel, or nearly so, many young children and some obese adults are unable to stand erect.

Reliability

Intermeasurer differences (M) for large samples in the Fels Longitudinal Study are as follows:[10]

M = 2.4 mm (SD = 2.1 mm) at 5 to 10 years

M = 2.0 mm (SD = 1.9 mm) at 10 to 15 years

M = 2.3 mm (SD = 2.4 mm) at 15 to 20 years

M = 1.4 mm (SD = 1.5 mm) at 20 to 55 years

M = 2.1 mm (SD = 2.1 mm) at 54 to 85 years

Comments

BMI and Gender

Women are fatter than men at any BMI. On average, this number is 11-12% higher for the same BMI and age group. Yet this extra fatness in women is not associated with extra risk to health. Thus, because the component units of the BMI, height, and weight can be measured with great reliability compared to total body fat, measuring body fat is not recommended. Rather, BMI is preferred because it is gender neutral. Table 33.1 shows BMI.

BMI and Ethnic Groups

A recent study compared percent body fat at different ages in men and women of three ethnic groups (Table 33.2). Ethnic differences are obvious, and imply that using the BMI to evaluate risk requires an adjustment related to ethnic differences. This is one of many adjustments to BMI in arriving at the risk from obesity for individuals.[11]

BMI Curves and Children

BMI curves have been developed for children by the Centers for Disease Control and Prevention (www.CDC.gov). The principle behind this table for children was to take the height for BMI 25 and 30 for 18-year-olds and then take corresponding height deviations at various ages. The BMI of 30 for children is close to the 95th percentile of height for weight. The BMI of 25 in children is close to the 85th percentile of weight for height in children.

Misclassification

Since BMI measures height and weight, it is an imperfect tool for evaluating fat. Correlations of fat with BMI vary from <0.1 to >0.8 depending on initial percent of fat, level of physical training, and age. Older people tend to lose height, and this elevates the BMI inappropriately. Body builders, Sumo wrestlers, and professional athletes will have high BMI values for low body fat. However, the purpose and value of the BMI is not to assess athletes, but to provide a starting point in risk assessment of overweight in sedentary people.

BMI and Central Fat

Body fat and visceral fat are related, but BMI as an index of body fatness cannot assess central fat. A measure of waist circumference can be a valuable addition in the assessment of risk. To have a clear picture of the steps in this process, it would be helpful to examine the natural history of the change in BMI. Figure 33.1 shows the increasing percentage of the population with a BMI >25 (top line) or >30 (lower line). Both lines rise until age 50 to 60 years. This means that an increasing percentage of the population is moving from the pre-overweight category with a BMI <25 to overweight or obese. Thus, the natural history of overweight is a gradual transition of the potentially or pre-overweight into overweight or clinical overweight categories. In addition, there appears to be about 25% of the population who will never become overweight. This is shown in Figure 33.1.

Risk Evaluation — Know Your BMI

The BMI is a useful tool in assessing the risk from overweight. In epidemiological studies, the risk of many diseases increases as BMI increases. This is shown in Figure 33.2, along with the cut points used for determining overweight and clinical overweight.

The curvilinear relationship shown is for overall mortality. The steepness of the curve varies for different diseases. For diabetes mellitus there is a very steep relationship. For

TABLE 33.1

Body Mass Index (BMI) Values

	Good Weights							Overweight					Obese									
											BMI											
Height	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
4′10″	91	96	100	105	110	115	119	124	129	134	138	143	148	153	158	162	167	172	177	181	186	191
4′11″	94	99	104	109	114	119	124	128	133	138	143	148	153	158	163	168	173	178	183	188	193	198
5′	97	102	107	112	118	123	128	133	138	143	148	153	158	163	168	174	179	184	189	194	199	204
5′1″	100	106	111	116	122	127	132	137	143	148	153	158	164	169	174	180	185	190	195	201	206	211
5′2″	104	109	115	120	126	131	136	142	147	153	158	164	169	175	180	186	191	196	202	207	213	218
5′3″	107	113	118	124	130	135	141	146	152	158	163	169	175	180	186	191	197	203	208	214	220	225
5′4″	110	116	122	128	134	140	145	151	157	163	169	174	180	186	192	197	204	209	215	221	227	232
5′5″	114	120	126	132	138	144	150	156	162	169	174	180	186	192	198	204	210	216	222	228	234	240
5′6″	118	124	130	136	142	148	155	161	167	173	179	186	192	198	204	210	216	223	229	235	241	247
5′7″	121	127	134	140	146	153	159	166	172	178	185	191	198	204	211	217	223	230	236	242	249	255
5′8″	125	131	138	144	151	158	164	171	177	184	190	197	203	210	216	223	230	236	243	249	256	262
5′9″	128	135	142	149	155	162	169	176	182	189	196	203	209	216	223	230	236	243	250	257	263	270
5′10″	132	139	146	153	160	167	174	181	188	195	202	209	216	222	229	236	243	250	257	264	271	278
5′11″	136	143	150	157	165	172	179	186	193	200	208	215	222	229	236	243	250	257	265	272	279	286
6′	140	147	154	162	169	117	184	191	199	206	213	221	228	235	242	250	258	265	272	279	287	294
6′1″	144	151	159	166	174	182	189	197	204	212	219	227	235	242	250	257	265	272	280	288	295	302
6′2″	148	155	163	171	179	186	194	202	210	218	225	233	241	249	256	264	272	280	287	295	303	311
6′3″	152	160	168	176	184	192	200	208	216	224	232	240	248	256	264	272	279	287	295	303	311	319
6′4″	156	164	172	180	189	197	205	213	221	230	238	246	254	263	271	279	287	295	304	312	320	328

TABLE 33.2

Percent Body Fat for Men and Women of Different Ethnic Groups and Three Age Ranges According to Body Mass Index*

BMI (kg/m²)	Females (% fat) African American	Females (% fat) Asian	Females (% fat) Caucasian	Males (% fat) African American	Males (% fat) Asian	Males (% fat) Caucasian
Age 20–39						
18.5	20	25	21	8	13	8
25	32	35	33	20	23	21
30	38	40	39	26	28	26
Age 40–59						
18.5	21	25	23	9	13	11
25	34	36	35	22	24	23
30	39	41	41	27	29	29
Age 60–79						
18.5	23	26	25	11	14	13
25	35	36	38	23	24	25
39	41	41	43	29	29	31

* Adapted from Gallagher, D et al. *Am J Clin Nutr* 2000 Sep; 72(3): 694-701.

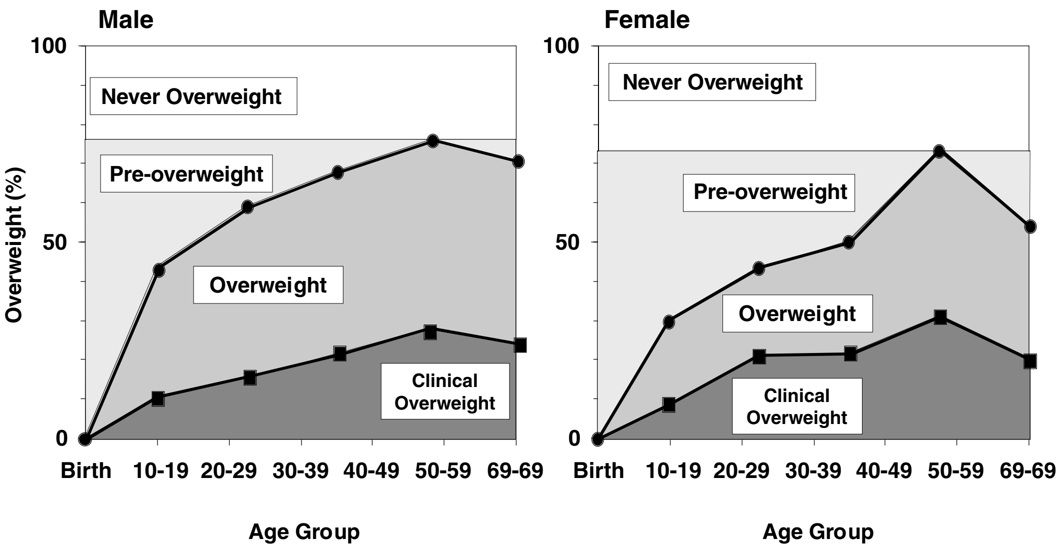

FIGURE 33.1
The natural history of overweight is a gradual transition of the potentially, pre-overweight into overweight, or clinical overweight categories. In addition, there appears to be about 25% of the population who will never become overweight.

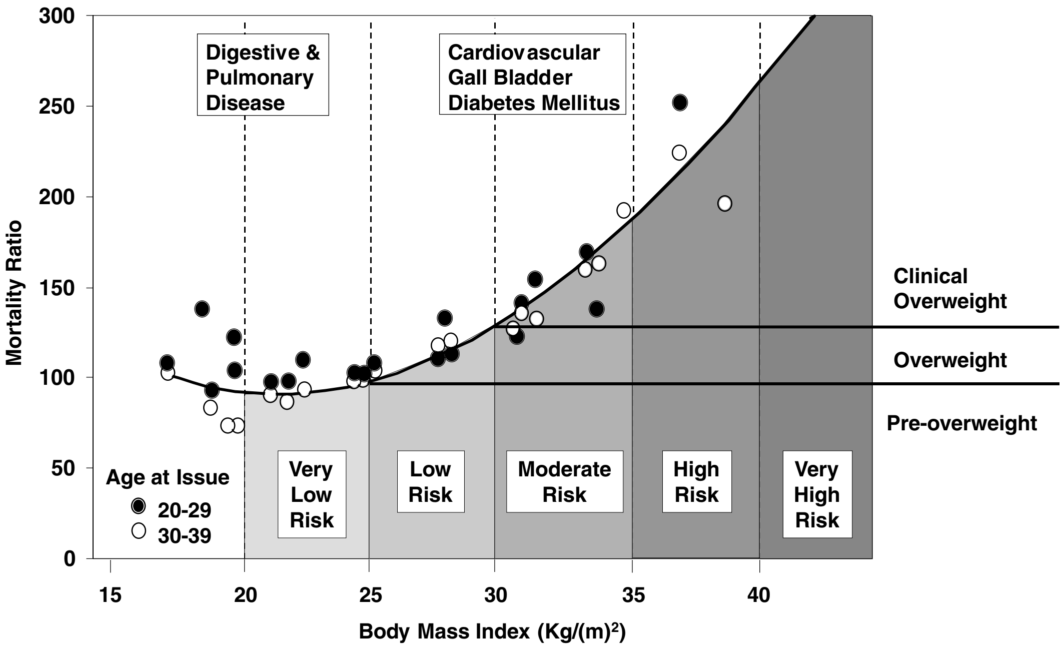

FIGURE 33.2
In epidemiological studies, the risk of many diseases increases as BMI increases. The curvilinear relationship shown here is for overall mortality. The steepness of the curve varies for different diseases.

this disease, individuals with a BMI of 23 to 24 are already at higher risk than those with a BMI of 20.

The curvilinear relationship of BMI has a similar shape to that of diastolic blood pressure and risk of death, or cholesterol concentrations and the risk of death. This is shown for all three in Figure 33.3. The dashed vertical lines in this figure represent the arbitrary cut points that separate low from moderate and high risk.

Starting with an accurately determined BMI, a clinician can sort through an algorithm such as that developed by the National Heart, Lung, and Blood Institute (Figure 33.4). Using this algorithm points the clinician and patient along the path of effectively evaluating the patient's BMI. "Know Your BMI" could serve as an effective public health campaign. If the public began to learn their BMI, it would be incumbent upon health professionals to be able to guide their patients in its use.

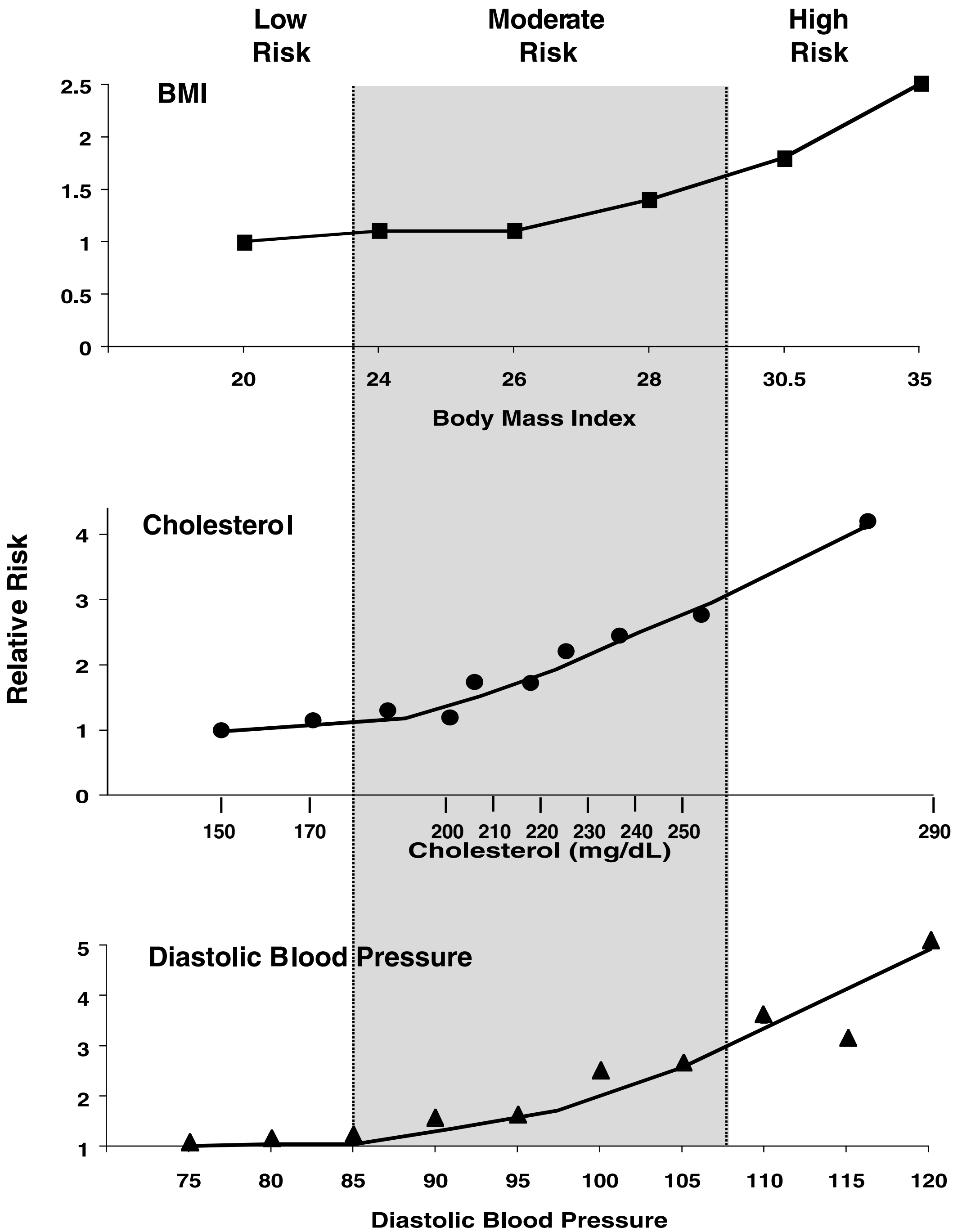

FIGURE 33.3
The curvilinear relationship of BMI has a similar shape to that of diastolic blood pressure and risk of death or cholesterol concentrations and the risk of death. The dashed vertical lines represent the arbitrary cut points that separate low from moderate and high risk.

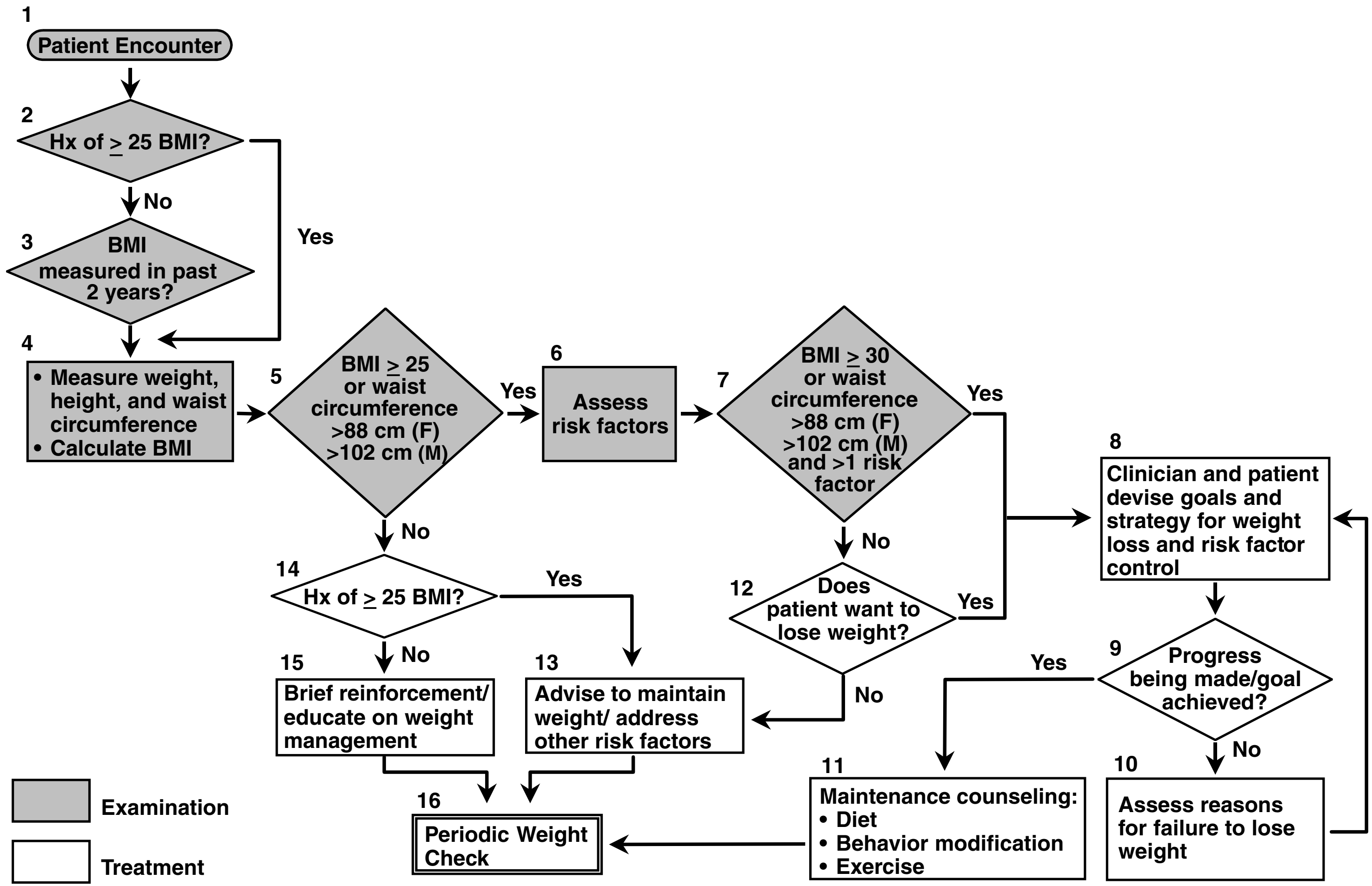

FIGURE 33.4
This algorithm developed by the National Heart, Lung, and Blood Institute can point the clinician and patient along the path of effectively evaluating the patient's BMI.

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