Charts Based on Body Mass Index and Waist-to-Height Ratio to Assess the Health Risks of Obesity: A Review

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Abstract: This review focuses on the rationale behind the charts that have been used as public health tools to assess the health risks of obesity, with special emphasis on where the boundary values are placed. A chart based on body mass index (BMI) was introduced in the 1980s to replace Tables of best weights for heights and this BMI chart (based on adult weight for height) is still very much in use today. Although the importance of the distribution of body fat, as opposed to the total amount of body fat, in determining health risks of obesity was first suggested in the 1940s, it was not until the mid 1990s that a chart based on Shape was suggested. The Ashwell[®] Shape Chart was based on the use of waist-to-height ratio (WHtR) as a proxy for abdominal obesity. The chart contains three boundary values for WHtR: 0.4, 0.5 and 0.6; originally set on pragmatic decisions. Substantial evidence from a recent systematic review now supports the global boundary value WHtR of 0.5 for Consider Action. WHtR of 0.6 has been proposed for Take Action. An exciting prospect is that the same Shape Chart might be used to assess risk for adults and children in several ethnic groups. Use of the Shape Chart could also improve the efficiency for screening for cardiometabolic risk and could provide substantial cost savings in terms of obesity treatment. The public health message could not be simpler: "Keep your waist circumference to less than half your height".

Keywords: Shape chart, body mass index, waist-to-height ratio, anthropometry, body weights and measures.

TABLES AND CHARTS WHICH ASSESSED RISK BASED ON WEIGHT

The public health approach to communicating the risks of obesity was, for a long time, firmly rooted in the use of appropriate body weights for height. Tables of appropriate weight for height for men and women, originally derived from Insurance Company data [1], were used until the mid 1980s. The Metropolitan Life Insurance Company's sexspecific tables were the standard; they used minimum and maximum weights associated with the lowest mortality among men and women between 25 and 59 years old, hence they were not suitable for children. The table creators attempted to use "frame size" as a way to compensate for the differences between people with different skeletal muscle mass. But in practice, the definition of frame size was too difficult for people to use, so virtually nobody used it as intended. Instead, people subjectively chose their own categories. Those tables survived well into the 1970s and 80s when the Quetelet index (QI), later to be called the 'Body Mass Index' (BMI), provided the option of displaying optimal weights for men and women on the same chart. OI is a formula which is used to estimate a healthy body weight based on a person's height. It is defined as the individual's body weight divided by the square of his or her height; the unit of measure is invariably expressed as kg/m^2 .

While the Quetelet formula dates back to the 19th century [2], the term 'body mass index' for the same ratio and its popularity date back to a 1972 paper by Ancel Keys who found the BMI to be the best proxy for body fat percentage among ratios of weight and height [3]. BMI was explicitly cited by Keys as being appropriate for population studies, and inappropriate for individual diagnosis. Nevertheless, due to its simplicity, it came to be widely used for individual diagnosis. George Bray began to advocate for the use of BMI about 1973 at the time of the Fogarty Center Conference in Washington when he wrote about methods for assessing obesity [4]. Later, Bray prepared a nomogram for BMI with recommended levels based on the upper and lower limits of BMI for men and women (medium frame) in the 1959 Metropolitan Life Insurance Tables [5]. These BMI levels were close to 19-24 kg/m² for women and 20-25 kg/m^2 for men.

The first BMI chart, which displayed BMI as a function of weight (horizontal axis) and height (vertical axis) using contour lines for different values of BMI or colours for different BMI categories, first appeared in 1981 in John Garrow's book "Treat obesity seriously" [6]. Garrow used the term Quetelet index, rather then BMI, and made it clear that the grades of obesity had arbitrary boundaries at 25, 30 and 40 kg/m², since different treatments are needed for different severities. Minimal risk was denoted between the boundary values of BMI between 20 to 25 kg/m² since mortality was lowest here in the U-shaped relationship. Risk therefore increased from BMI 25 onwards and since the increased risk was linear, BMI=30 was designated to be the next boundary value for risk, probably because it was five

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units above BMI=25 kg/m². The first representative survey of obesity in the UK, also published in 1981, took 30 kg/m² as the threshold of "obesity" [7]. Further justification for Garrow's boundary values of 20 and 25 kg/m² for minimum risk came from recalculations on morbidity and mortality data from insurance company data [8] and the BMI chart gradually became accepted in public health practice in the late 1980s and the 1990s.

At the beginning of the 1990's the UK's Health Education Authority (HEA) considered whether there should be a definite cut-off at BMI 20 between 'OK' and 'underweight. There were concerns that this did not really reflect the natural variability in healthy body weight, and that some people who had a BMI of, say, 19 kg/m² were healthy. As a consequence, HEA 'graded' the 'OK' band: BMI 20-25 was shown as a darker yellow band and 18.5-20 was shown as a lighter yellow band [9]. HEA also added a cautionary note: 'if you are at the lower end of the OK band, make sure you maintain weight and don't be tempted to aim for the underweight category'.

In 1995 and 1997, The World Health Organization (WHO) [10, 11] began using the BMI as a standard to determine not only overweight, but also added cut-offs for categories of underweight, preobese, and three classes of obese. They used a BMI of 18.5 to 25 kg/m² to indicate optimal weight; a BMI lower than 18.5 kg/m² suggested the person was underweight (this cut-off had been used for this purpose previously in reports on under nutrition) while a BMI above 25 kg/m² indicated the person was overweight or pre-obese; and a BMI above 30 kg/m² suggested the person was obese (over 40, morbidly obese). Thereafter, virtually all BMI charts tended to use these cut-off values.

JUSTIFICATION FOR METABOLIC RISK ASSESSED BY SHAPE INSTEAD OF WEIGHT

The importance of the distribution of body fat, as opposed to the total amount of body fat, in determining health risks of obesity was first suggested more than 50 years ago [12, 13] but it was only in the late 1980s and early 1990s that the importance of abdominal obesity in determining risk in cross-sectional and from prospective epidemiological surveys became convincing. Originally the evidence was gathered from the relationship between a variety of anthropometric indices and indices of morbidity and mortality, but gradually the use of the waist-to-hip ratio (WHpR) became the most popular 'shape' index [14-21]. Further attempts to use other anthropometric indices as proxies for abdominal obesity produced suggestions such as the 'conicity index' [22] and the saggital diameter [23].

Bjorntorp [24] proposed in 1990 that the definition for obesity should be changed and suggested that only abdominal obesity is distinguished as obesity, not only because it would help the study of obesity to be taken more seriously if it excluded cosmetic problems, but also because a definition for abdominal obesity might generate the risk factors for cardiovascular disease (CVD) and diabetes and therefore constitute an important primary pathogenetic factor for these diseases. However, proxy measures for abdominal obesity were never really fully accepted in a public health context and, at most, guideline values for WHPR appeared alongside BMI risk categories and nomograms for the calculation of WHpR appeared alongside nomograms for the calculation of BMI [25]. Standard values that allow direct inter-individual or interpopulation comparisons were never 'officially set' for WHpR although it became popular to split populations at WHpR of 0.8 for women and WHpR=0.95 for men [11].

WHpR fails in one major respect as a public health measure in that, although it is a convenient risk assessment tool, it is not suitable as a risk management tool. WHpR is a ratio of two circumference measurements and the very likely covariance of waist circumference (WC) with the hip circumference means that WHpR does not necessarily change with either weight increase or weight decrease [26, 27]. For similar reasons, the waist to thigh ratio which was proposed by several groups [28, 29] was also unsuitable for use as a risk management tool since it is also the ratio of two circumference measurements.

SHAPE CHART BASED ON WAIST-TO-HEIGHT RATIO

The principle of a consumer-friendly Shape Chart, to replace a Weight Chart, was proposed as early as 1995 [30]. The suggestion was made after national survey data showed the subgroup of the English population who had high BMI and high WHpR had the most classical risk factors for CVD [31]. The prototype chart suggested that a 'shape number' based on WHpR might be plotted against BMI so that different bands of 'WHpR and BMI' could be distinguished. As it happened, this prototype was never developed because a much simpler basis for a shape chart (waist circumference on the *x* axis and height on the *y* axis) suggested itself very soon afterwards [32] (see Fig. 1).

In 1995, Lean et al. [33, 34] proposed that the waist circumference alone could be used as a measure for indicating need for weight management and to define suitable values for risk groups. They suggested Action Level One for a waist circumference ≥ 94 cm for men and ≥ 80 cm for women and Action Level Two for a waist circumference of ≥ 102 cm for men and \geq 88cm for women. At about the same time, three other groups were using a cross-sectional analysis to relate anthropometric indices to metabolic risk factors and concluded that WHtR was superior to waist circumference (WC). Hsieh and Yoshinaga [35, 36] studied over 3000 men and 1000 women and related anthropometric variables to levels of coronary heart disease (CHD) risk factors and a 'risk factor morbidity index' based on simple summation of five cardiometabolic risk factors. Multiple regression analysis showed that WHtR was a better predictor of multiple CHD risk factors than WHpR or WC alone. Also in Japan, Lee and colleagues [37] showed that WHtR (actually waist : stature ratio) was the anthropometric index with the highest correlation with coronary risk factors in nearly 1000 men. In UK, Ashwell et al. [38] used data for 1411 men and 1481 women (aged between 30 and 74 years) from the 1992 Health Survey for England [39]. For each person, anthropometric measurements and ratios were compared with the logarithm of the 'CHD risk' for that individual, calculated from sex, age, blood pressure, cholesterol, smoking and diabetic status [40]. Stepwise regression showed that WHtR was the two-factor parameter which accounted for the



Fig. (1). The Ashwell[®] Shape Chart based on waist-to-height ratio. (*Copyright is held by Margaret Ashwell*).

The Ashwell[®] Shape Chart is suitable for adults (men and women) and children over 5y. It has waist circumference measurement (cm) on x axis and height (cm) on the y axis. The boundary values for waist-to-height ratio are set at WHtR 0.4 (brown to green), 0.5 (green to yellow) and 0.6 (yellow to red). The Green area indicates OK; Yellow area indicates Consider Action for adults and Take Action for children; Red area indicates Take Action. Brown area indicates Take Care – you will not need to decrease your waist circumference and might even be underweight.

greatest variation in 'CHD risk' for both sexes. Prospective data from UK Health and Lifestyle Survey [41] also helped to provide important reinforcement to the suggestions about WHtR made on the basis of cross-sectional data. Interestingly, WHtR had been shown a few years before to be as good as BMI in predicting CHD and stroke morbidity in the Framingham prospective study [42]. Those authors admitted they calculated WHtR as a 'second best' because they did not have hip circumference measurements to calculate WHpR.

The realisation that WHtR was as good, if not a better, predictor of health outcomes as WC and WHpR, provided the motivation to produce a simple 'Shape Chart' of waist circumference (along the x axis) against height (on the y axis) [32, 43]. A pragmatic public health approach was used in suggesting WHtR boundary values in the chart. Boundary value was also preferred as a term rather than cut-off values

to reflect this approach. The value 0.5 was chosen as one boundary value, partly because this had already been used by others [36, 37] in their cross-sectional population studies and partly because WHtR of 0.5 translates into the easily understood message of 'keep your waist circumference measurement to less than half your height'. The lower value of WHtR 0.4 was chosen pragmatically. The upper value of WHtR < 0.6 was chosen partly for simplicity, in the same way that BMI=30 kg/m² was chosen as the next boundary value above BMI of 25 [6]. However, coincidentally WHtR > 0.6put 17% UK men and 13% UK women in the highest metabolic risk category whereas the traditional BMI Action Level (BMI \geq 30 kg/m²) identified 13% men and 17% women. The Ashwell[®] Shape Chart therefore allowed scientifically-based, but easily understood, risk assessment and helped to emphasise the relative importance of risk management for men who tend to suffer greater metabolic risks of obesity than women [32].

CORROBORATION OF WAIST-TO-HEIGHT RATIO AS THE BASIS OF ASHWELL[®] SHAPE CHART AND OF WAIST-TO-HEIGHT RATIO=0.5 AS A BOUNDARY VALUE

The Ashwell[®] Shape Chart continued to be available in the public domain and appeared in publications advocating the use of WHtR [44]. Several studies were published which used WHtR 20.5 to analyse risk in populations. The suggestion to adopt an index of central obesity (namely waistto-height ratio) was made by Parikh and colleagues in 2007 because it could obviate the need for numerous gender and race specific WC cut-offs in adults and, maybe, in children [45, 46]. An important meta-analysis of ten studies was published in 2008 which concluded that statistical evidence supported the superiority of measures of central obesity, especially WHtR, over BMI, for detecting CVD risk in both men and women [47]. By the beginning of 2009, there were enough peer reviewed publications in the scientific literature to allow us to undertake a systematic review of WHtR, WC and BMI in relation to metabolic health risk [48]. This systematic review collated seventy-eight studies exploring WHtR and WC or BMI as predictors of diabetes and CVD published in English between 1950 and 2008. Twenty-two prospective analyses showed that WHtR and WC were significant predictors of these cardiometabolic outcomes more often than BMI, with similar odds ratios: sometimes being significant predictors after adjustment for BMI. Observations from cross-sectional analyses, forty-four in adults, thirteen in children, supported these predictions. Receiver operating characteristic curve (ROC) analysis revealed mean area under ROC curve values of 0.704, 0.693 and 0.671 for WHtR, WC and BMI, respectively. Mean boundary values (weighted) for WHtR, covering all cardiometabolic outcomes, from studies in 14 different countries and including Caucasian, Asian and Central American subjects, were 0.50 for men and 0.50 for women. The area under ROC curve analyses indicate that WHtR may be a more useful global clinical screening tool than WC, with a weighted mean boundary value of 0.5, supporting the simple public health message "keep your waist circumference to less than half your height". A recent meta-analysis of ROC data from papers published up to mid 2010 has concluded that WHtR was better at discriminating adverse outcomes (diabetes, CVD) than BMI or WC [49].

COMPARISONS OF BOUNDARY VALUES BASED ON BMI, WAIST CIRCUMFERENCE AND WAIST-TO-HEIGHT RATIO: PREVALENCE OF OBESITY IN UK ADULT POPULATION. IMPLICATIONS FOR SCREENING AND COST OF TREATMENT

It is possible to compare boundary values, based on different anthropometric indices, for assessing the prevalence of different grades of obesity using data from the nationally representative surveys such as the National Diet and Nutrition Survey, collected in Britain in 2000-2001 [50]. Table 1 shows how the boundary values would split the population of 806 men and 970 women. It is reassuring to see that WHtR \geq 0.6 would identify fewer men and women at risk than BMI \geq 30 kg/m² and considerably fewer people than Waist Action Level 2. This has implications for cost-

effective savings in the public health budget. Using figures for the cost of treating obesity in England [51], it would have cost one billion pounds to have treated 22% of the population (assessed as obese by BMI) compared with a cost of 0.75 billion (16.5% of the population at risk by WHtR). Projections from the Foresight report of expected obesity levels into 2025 [52] shows these costs (assumed constant per obese person) would rise to 5.3 billion pounds (41.5% population obesity by BMI) compared with 4 billion pounds (31% at risk by WHtR).

Description	Definition	% Men	% Women
Overweight	BMI≥25	67	53
Obese	BMI≥30	24	20
Central fat distribution	\geq waist action level 1*	53	54
Central obesity	\geq waist action level 2*	30	28
Central fat distribution	WHtR≥0.5	76	50
Central obesity	WHtR≥0.6	20	13

Table 1.Adults in British National Diet and Nutrition Survey
Classified by Boundary Values of Body Mass Index,
Waist Circumference and Waist-to-Height Ratio

However, this table with prevalence data does not tell the whole story. Further analysis of the data from the UK survey [50] showed that screening health risk by BMI alone would 'miss' 35% of men and 14% of women who are within the normal BMI range (18.5 to 25 kg/m^2) but have central fat distribution, defined by WHtR greater than 0.5. In the total population this equates to 11% of all men and 6% of all women who would be inadequately screened by BMI alone [53].

EXTENSION OF ASHWELL[®] SHAPE CHART TO CHILDREN

In the twentieth century, childhood obesity was always assessed against age-specific BMI centiles. This approach was slightly simplified in year 2000 with the introduction of centile curves which had been drawn so that at age 18 years, they passed through the widely used BMI cut off points of 25 and 30 kg/m² for adult overweight and obesity [54]. An exciting thought for the future is that assessment of childhood obesity could become even simpler. WHtR may allow the same boundary value for children and adults. There is now growing evidence that WHtR can be used to predict risk in children [55-61]. Since the height and WC of children normally increases continually as they age, the same boundary value (WHtR=0.5) could be used to indicate increased risk across all age groups [62-64].

The latest version of the Ashwell ® Shape Chart (Fig. 1) has been modified to include heights and waist circumferences appropriate to children aged five years and upwards.

Data from [50]. *NICE guidelines [65]: Waist Action Level 1, waist circumference \geq 80cm for women or waist circumference \geq 94cm for men; Waist Action Level 2, waist circumference \geq 88cm for women or waist circumference \geq 102cm for men. BMI: body mass index, WHtR: waist-to-height ratio.

The Chart still has boundary values set at WHtR 0.4 (brown to green), 0.5 (green to yellow) and 0.6 (yellow to red). However, the words used to describe action steps for WHtR greater than 0.5 and less than 0.6 have now been modified to indicate that this value should indicate 'Take Care' or 'Consider Action' for adults, whereas for children it indicates 'Take Action'. The implicated difference in health risk was based on the proportion of UK children and adults who fall above the boundary values of 0.5 and 0.6 [64]. Further research is needed to confirm the suitability of these boundary values for children. Although there is now good global evidence for using WHtR 0.5 as the first boundary value for risk (see above and [48]), the boundary values at 0.4 and 0.6 were set on pragmatic reasoning and it is essential to have data from many other population groups to corroborate these decisions.

DISCUSSION

Considering the increasing interest (medical, commercial and self help) in preventing and treating obesity over the past four decades, it is surprising that only two Charts have been used for public health purposes. One reason could be the enormous global popularity of the BMI, and its chart, after its introduction in the early 1980s. Once established, BMI became the norm and many obesity treatments had to show evidence that they could make worthwhile reductions to BMI to be allowed on the market.

Although there has been gradual scientific recognition of the importance of abdominal obesity, this has been slow to make a public health impact. The 2006 NICE guidance [65] stated that BMI should be used as a measure of overweight in adults, but needed to be interpreted with caution because it is not a direct measure of adiposity. NICE added that "Waist circumference may be used, in addition to BMI, in people with a BMI less than 35 kg/m²".

Maybe the advice to use waist circumference as a proxy for abdominal obesity has hindered the adoption of the shape message into a public health context? Waist circumference boundary values do not convert into an easy chart format, and they are not the same for men and women. Further, those developed for Caucasians cannot be used globally; they can differ between genders, ethnics and even countries [66]. There have been WHO expert consultations to discuss cutoff values for waist circumference. But the simple step of including height as well as waist circumference which avoids some of the problems for other ethnic groups who, for example in the case of Asians, tend to be shorter [45], as well as more centrally obese, has usually been overlooked.

There is no doubt that the simplicity of the BMI chart has been a factor in drawing attention to the importance of obesity as a public health problem. Its use in screening has made it easy for health professionals and individuals to be alerted to the need for checking the presence of underlying cardiometabolic risk factors. The adoption of a Shape Chart in public health practice would have all the advantages of a simple Chart and also detect people at metabolic risk who would not be identified as at risk on the BMI chart [53]. There are also substantial cost saving implications for the public health budget as indicated in this paper. I urge health curve

practitioners to use the Chart in their own population groups and to report comments to the author.

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CONFLICT OF INTEREST

The author devised and copyrighted the Ashwell ® Shape Chart, based on WHtR, which is distributed to health professionals on a non profit making basis.

ABBREVIATIONS

BMI	=	Body mass index
CHD	=	Coronary heart disease
CVD	=	Cardiovascular disease
HEA	=	UK Health Education Authority
QI	=	Quetelet index
ROC	=	Receiver operating characteristic
WC	=	Waist circumference
WHO	=	World Health Organization
WHpR	=	Waist-to-hip ratio

WHtR = Waist-to-height ratio

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