CHAPTER

2

The New Anthropometrics and Abdominal Obesity: A Body Shape Index, Hip Index, and Anthropometric Risk Index

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OUTLINE

INTRODUCTION

Quantities derived from basic body measures (anthropometrics), most commonly body mass index (BMI) and secondarily waist circumference (WC), have been extensively applied in population-level risk assessment for several decades.[1] Despite the introduction of many new biochemical and genomic tests, the convenience and low cost of height (H), weight (W), and WC measurements mean that they continue to play the central role in the epidemiologic and clinical assessment of obesity.

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In this chapter, we will first briefly review the role and limitations of basic anthropometrics in diagnosing abdominal obesity and associated health risks. We will then introduce the new anthropometrics—a body shape index (ABSI), hip index (HI), and anthropometric risk indicator (ARI)—with emphasis on evidence for their potential benefits for improving risk assessment. Finally, we will outline some future research directions and potential clinical applications.

BASIC ANTHROPOMETRICS AND ABDOMINAL OBESITY

BMI was derived more than a century ago by Quetelet to express W independently of H as $\mathrm{BMI} = W{\cdot}H^{-2}$, and is perhaps the most influential contribution of the historical discipline of allometry, with its focus on power-law scaling of biological quantities.[2] Concern regarding the appropriateness of health assessment based on BMI guidelines has arisen with recognition of the "obesity paradox," perhaps better designated the "BMI paradox"[3]: a large cardiovascular and general medical and surgical literature finds the risk for adverse outcomes is actually lower when BMI is modestly elevated (Overweight to Obesity I using World Health Organization [WHO] BMI range definitions[4]) compared to people with WHO Normal BMI. Such "paradoxical" findings highlight the well-understood limitations of BMI. BMI does not distinguish between muscle and fat accumulation,[5–8] and there is evidence that whereas higher fat mass is associated with greater risk of premature death, higher muscle mass reduces risk.[9] As well, BMI does not distinguish between fat locations, when central or abdominal fat deposition is thought to be particularly perilous.[10–13]

The relationship of abdominal obesity to cardiovascular risk is well established. More specifically, the metabolic risk has been shown to correlate with the extent of visceral obesity, while subcutaneous fat is actually a source of protective adipokines. However, partitioning of abdominal fat depots requires imaging technology not available to clinicians. The measurement of WC has become the predominant indicator of abdominal obesity and associated visceral obesity and is incorporated into obesity assessment by WHO and other organizations. In fact, WC is strongly predictive of cardiovascular risk. However, there is a very high correlation between BMI and WC, with r around 0.7–0.9.[3,14,15] This reflects the fact that WC is sensitive to body size (height and weight) as well as to fat percentage and distribution.[16] According to a consensus statement on the clinical usefulness of WC,[17] "Further studies are needed to establish WC cut points that can assess cardiometabolic risk, not adequately captured by BMI and routine clinical assessments."

Efforts to better isolate abnormal abdominal shape apart from BMI have included WC-to-hip circumference (HC) ratio and WC-to-H ratio. These demonstrate somewhat lower but still clinically significant correlations with BMI of at least 0.4.[18] Using these indices in conjunction with BMI to better assess risk is therefore complicated by their correlations with BMI.

Besides WC, multiple circumferences have been examined as predictors of total adiposity and abdominal fat.[19,20] The association of simple anthropometrics with visceral fat by magnetic resonance imaging has been reported as significant as but less strong than for sagittal diameter.[21] With computed tomography (CT) imaging of abdominal visceral fat, WC was the best predictor overall.[22] WC/HC was favored in an earlier study, but in more recent studies was found to actually not be useful for visceral fat estimation compared to WC.[23–25] A recent study using dual-energy X-ray absorptiometry found that among simple anthropometrics WC/H was most correlated with visceral adipose tissue (VAT).[26]

The literature addressing simple anthropometrics and risk for specific outcomes is vast and beyond the scope of this chapter. Several reviews and meta-analyses address cardiovascular risk.[27–29] One meta-analysis focusing on risk for type 2 diabetes showed that WC and WC/HC have the same predictive power as BMI,[30] while another meta-analysis with different methodology found that WC slightly outperformed BMI and WC/HC.[31] Genomic analysis has identified a number of loci associated with simple anthropometrics such as WC/HC and BMI.[32–34]

THE NEW ANTHROPOMETRICS

ABSI

Several years ago, to address the above concerns, we introduced a new "allometric" approach, with ABSI based on a power-law relationship between WC and BMI. This allometric approach offers one means of separating the impact on health of body shape (degree of central bulge, presumably correlating with abdominal fat deposits) from that of body size (as measured by height, weight, and BMI). ABSI was derived empirically from the National Health and Nutrition Examination Survey (NHANES) 1999–2004, a population sample of the United States, and defined as $\mathrm{ABSI} \equiv \mathrm{WC} \cdot H^{5/6} \cdot W^{-2/3}$.[18] The resulting ABSI was, as intended, almost independent of BMI both for NHANES and, with minor adjustments, for studies from a number of other geographic regions.[15, 35]

Much recent clinical application of simple biometrics has been based on the WHO classification, which combines BMI categories with WC cutoffs in an attempt to highlight the added risk of abdominal and visceral adiposity (corresponding to high WC). However, we demonstrated the limitations of WC for risk stratification from national cohort data: WC cutoffs were exceeded, for example, 93% of the time for Obesity I (BMI 30–34.9) and 100% for Extreme Obesity (BMI >40) individuals, so that the WC cutoff had little discriminatory power in these categories. On the other hand, ABSI was above average approximately 50% of the time across the entire range of BMI.[1]

We analyzed mortality follow-up data from NHANES and from a British study. In both, ABSI showed a direct association with mortality, with near log-linear risk increase, especially over the higher range of ABSI.[15, 18, 36] ABSI predicted mortality better than BMI, WC, or waist/height and waist/hip ratios.[15] In a population study in the Netherlands, ABSI showed a stronger association with total, cardiovascular, and cancer mortality compared to BMI, WC, and other anthropometric indices.[37] In a multicountry European study, ABSI was found to be linearly associated with total and cardiovascular mortality, whereas BMI and WC showed J-shaped associations with total mortality (elevated risk both at high and low values).[38] ABSI has also been found to predict mortality hazard in large cohorts from Japan,[39] Australia,[40] Greenland, Denmark, northern Canada,[41] and elsewhere. A meta-analysis found that ABSI outperforms BMI and WC as an indicator of mortality hazard, but is less associated than BMI and WC with hypertension, type 2 diabetes, and cardiovascular disease.[42]

We have previously listed and commented on some of the studies that have evaluated the correlation of ABSI with various health-related measures and outcomes.[1, 43] Relative risk estimates (RR) for ABSI have generally been similar in magnitude to those that can be made using BMI and other simple biometrics. Often in these studies, when significant, RR is modest, often around 1.1–1.3 per standard deviation change in each indicator, and the RRs for different indicators are statistically similar to each other.[38, 44, 45] However, few of the studies published to date exploited the statistical independence of BMI and ABSI to obtain combined RR values and confidence intervals, which may potentially be more informative than for the individual anthropometrics. This is the rationale for combining the risks due to BMI, ABSI, and potentially other independent factors in the form of ARI, discussed below.

An imaging study in overweight and obese individuals showed that individuals with higher ABSI had lower fat-free mass than individuals with lower ABSI and the same BMI, suggesting ABSI could help define the risk of sarcopenia.[46] Another study found that compared to BMI alone, the joint use of BMI and ABSI yielded significantly improved associations for most components of metabolic syndrome (high triglycerides, low high-density lipoproteins, high fasting glucose but not high blood pressure) and for VAT as measured by ultrasound[47]. In a study of patients with type 2 diabetes, ABSI correlated with visceral fat area and with arterial stiffening, thus appearing to reflect visceral adiposity independently of BMI.[48] In a different cohort with type 2 diabetes, ABSI correlated with the ratio of fat mass to fat-free mass, measured by bioelectrical impedance analysis and regarded as an index of sarcopenic obesity.[48a] Women in Naples, Italy, with high ABSI were found to have smaller diameter of low-density lipoprotein particles, which the authors concluded was "in line with the hypothesis that ABSI could be a marker of visceral abdominal [obesity] associated to adverse metabolic changes."[49]

A limited amount of research has so far addressed the association of ABSI with genetic and lifestyle factors. Patterns in ABSI and other health-related phenotypes have been examined across Scotland, finding that regional variation in ABSI remained, presumably due to unmodeled environmental differences, after adjustment for genomic relationship and lifestyle and socioeconomic factors.[50] In Indonesia, food insecurity was correlated with higher ABSI, which mediated increased risk of hypertension.[51]

We presented experience with combination use of the anthropometrics BMI and ABSI, with potential advantages over either alone.[52] The cases discussed illustrate situations where the currently recommended calculation and discussion of BMI alone as the premier clinical obesity indicator may result in an incomplete picture of a presenting patient's risk profile.

HI

Like WC, HC has been fairly widely used as a risk indicator, but is highly correlated with BMI. Thus, HI was developed as a transformation of HC to make it uncorrelated with BMI by using its power-law relationship with H and W: $HI \equiv **HC \cdot \left(\frac{H}{\langle H \rangle}\right)^{0.310} \cdot \left(\frac{W}{\langle W \rangle}\right)^{-0.482}$, where $\langle H \rangle = 166$ cm and $\langle W \rangle = 73$ kg are typical values included as scaling factors.[53] The resulting HI was found to be almost uncorrelated with H, W, BMI, and also WC (even though WC does not appear in the definition of HI). In two samples of the adult US population, HI was found to be a significant mortality predictor, though weaker than BMI or ABSI: both low and very high HI values, relative to the mean, were associated with greater mortality hazard.[53] HI thus allows to better quantify the marginal usefulness of HC measurement, in addition to height and weight.

So far, there have been few studies of the association of HI with outcomes other than mortality. A small study from China found that HI was not a significant risk factor for developing diabetes.[54] In an outpatient clinic cohort of overweight and obese children and adolescents, HI was linearly correlated with few cardiometabolic risk factors, whereas BMI and ABSI were correlated with many more.[55]

ARI

The four indices H, BMI, ABSI, and HI reexpress the information in the four measurements H, W, WC, and HC so that, unlike the original measurements, the correlation between each pair of indices is close to zero. Because of this statistical independence, we might hope that the risks attributed to the indices would multiply to give a combined anthropometric risk. This is the concept behind ARI, which was derived for mortality hazard based on the two US studies.[53] First, the values of the indices are transformed to z scores, giving the number of standard deviations each index is above or below its age- and sex-specific mean. Nonlinear modeling for mortality hazard associated with each anthropometric index yielded functions for the natural logarithm of the estimated hazard for different values of the z score of that particular index. ARI was taken to be the sum of these function values for each individual's combination of anthropometric index z scores, denoting the natural logarithm of the combined estimated hazard from the four independent indices H, BMI, ABSI, and HI. Assuming that these four hazards are independent, ARI should then be the natural logarithm of the mortality hazard based on all four measurements H, W, WC, and HC. Positive values of ARI denote above-average combined risk and negative values denote lower risk. ARI calculated based only on data from one study was applied to the other cohort and found to be well transferable for estimating hazard.[53] An online calculator implementing the derived formula for ARI is freely available at https://nirkrakauer.net/sw/ari-calculator.html. This calculator accepts as inputs age, sex, and anthropometric measurements, and returns index values and z scores, ARI, and the combined anthropometric relative mortality hazard (the exponential of ARI).

ARI could be computed using the same principle for other linearly independent combinations of predictors, and for outcomes other than mortality. For example, we multiplied the BMI and ABSI attributable risks to obtain an ARI measure for bariatric surgery patients, finding that the anthropometric risk estimated with ARI decreased following surgery due to reductions in ABSI as well as BMI.[56]

DISCUSSION

In an era of increasing sophistication and cost of medical care, anthropometrics continue to have a role both for epidemiologists and medical practitioners, as they can offer prognostic utility comparable to that of more expensive and invasive laboratory tests.[57] The combination of BMI with ABSI and HI may offer additional advantage over the now-routine use of BMI (or any other single anthropometric index) for assessing abdominal obesity and associated cardiometabolic abnormalities.

The additional measurements of WC and HC beyond routine weight and height are feasible in the medical office setting, with minimal personnel training and equipment required. Dieticians and exercise physiologists could also readily use this modality. There are several possible clinical benefits of the ARI risk calculator: (1) On a population level, as ABSI quantifies body shape (particularly abdominal adiposity) in a manner that is independent of BMI (i.e., does not correlate with BMI), combining the two provides better estimates of the RR of cardiometabolic disease and mortality. (2) Tracking changes in the RR over time from the ARI calculator should help provide a way to evaluate the effectiveness of clinical interventions. The finding that changes in mortality risk over time track changes in ABSI[15] supports this clinical application. (3) The ARI risk calculator may be used to guide clinical decision-making and to assess comparative effectiveness. For example, ARI could be an additional predictor of the likelihood of health benefits from bariatric surgery.[56, 58] As another example, in the setting of medical weight loss, high ABSI may indicate a higher likelihood of response to metabolic vs appetite suppressive agents. Appropriate studies could verify the value of combined assessment of anthropometrics for particular medical conditions and in specific clinical settings, including hospital and managed care systems.

There are a number of additional directions being explored to make the risk calculations more useful, based on analysis of larger cohort studies with appropriate follow-up data. These including correlating with risk of metabolic syndrome[58a] and with conditions such as coronary artery disease, cancer, and stroke as well as with mortality; better accounting for differences in risk profile across ethnicities and nations; adding information from other body measures and from other clinical measures and laboratory tests to potentially improve risk assessment further; and better understanding the effect of lifestyle factors such as diet and exercise and pharmaceutical therapies on ABSI, HI, and ARI.

CONCLUSION

Anthropometrics play a critical role in the operational definition and assessment of abdominal obesity. The new anthropometric constructs of ABSI, HI, and ARI are intended to allow more information to be extracted from basic measurements, potentially aiding clinical decision making and the targeting of treatment options.

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