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REVIEW

Untangling Waist Circumference and Hip Circumference from Body Mass Index with a Body Shape Index, Hip Index, and Anthropometric Risk Indicator

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Abstract

Body mass index (BMI) corrects body weight for height and is well established for diagnosing overweight and obesity and correlating with many medical conditions. Waist circumference (WC) is used to diagnose abdominal obesity. However, the correlation of BMI and WC is high, around 0.9, making the use of BMI and WC in concert challenging. A body shape index (ABSI) is a new measure of risk associated with abdominal size. Derived in 2012, ABSI is analogous to BMI in that it normalizes WC for weight and height (and thus to BMI). A similar derivation led to hip index (HI), normalizing hip circumference for BMI. Hazard ratios (HRs) for univariate risk associations of the independent measures height, BMI, ABSI, and HI can be multiplied to give a combined HR, the anthropometric risk indicator (ARI). Compared to any one anthropometric factor, including BMI and WC, ARI more accurately estimates personalized mortality hazard. Published work on ABSI, HI, and ARI supports their association with many aspects of health, including cardiometabolic conditions related to the metabolic syndrome.

Keywords: a body shape index, anthropometric risk indicator, body mass index, hip circumference, hip index, waist circumference

Background

The historic discipline of allometry sought to derive power laws relating measurements such as basic anthropometrics and metabolic rate that would be valid across sources of variation such as age, gender, and ethnicity. Body mass index (BMI) is the ratio of body weight to the square of body height, motivated by the 19th century observation of A. Quetelet[1] that weight scales as the square of height. Since being advocated in 1972 by Ancel Keys and others, calculation of BMI from weight (W) and height (H) measurement has become nearly universal over the age span and across continents and ethnicities.[2] More recently, there has been increasing interest in waist circumference (WC) as a measure of cardiometabolic risk potentially superior to BMI, including making WC thresholds part of definitions of the metabolic syndrome (MS). However, the correlation of BMI with WC within populations is close to 0.9, making it difficult to demonstrate the added value of WC over BMI.[3,4]

Defining a Body Shape Index, Hip Index, and Anthropometric Risk Indicator

In 2012, a body shape index (ABSI) was derived as an allometric power law expression to normalize WC for BMI. Multiple linear regression on a population survey was used to derive a power law that used W and H to optimally estimate WC. The expected value of WC was found to be proportional to $\mathrm{BMI}^{2/3} \times \mathrm{height}^{1/2}$. This power law expression was divided into WC to define ABSI[5]:

$$\mathrm{ABSI} = \mathrm{WC}/(\mathrm{BMI}^{2/3} \times \mathrm{height}^{1/2}).$$

In 2016, hip index (HI), a normalization for hip circumference (HC), was similarly derived, using the expected value of HC for given H and W based on a power law:

$$\mathrm{HI} = \mathrm{HC} \times (\mathrm{H}/\{\mathrm{H}\})^{0.310}/(\mathrm{W}/\{\mathrm{W}\})^{0.482},$$

where $\{\mathrm{H}\} = 166$ cm and $\{\mathrm{W}\} = 73$ kg were population average values.[6]

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Also in 2016, anthropometric risk indicator (or index—ARI) was introduced as the combined hazard ratio (HR) for an outcome such as mortality given an individual's anthropometric profile. The indicator ARI is obtained by multiplying the individual HRs obtained by separately regressing the available statistically independent allometric indices on the outcome[6]:

$$\mathrm{ARI(H,\ BMI,\ ABSI,\ HI)} = \mathrm{HR(H)} \times \mathrm{HR(BMI)} \times \mathrm{HR(ABSI)} \times \mathrm{HR(HI)}.$$

(ARI can also be defined as the logarithm of the above quantity, in which case it is equal to the sum of the HR logarithms.[6]) Since ABSI and BMI show the best associations with outcomes such as mortality, while H shows the weakest associations, for practical purposes, it is sufficient to calculate ARI(BMI,ABSI) or ARI(BMI,ABSI,HI). Figure 1 shows a published example calculation of the ARI(BMI,ABSI) surface. This illustrates that the combined mortality hazard is greatest for people with above-average ABSI combined with either above- or below-average BMI. A calculator is available for computation of the indices ABSI and HI and associated mortality HRs and ARI, with 95% confidence intervals (CIs), at https://nirkrakauer.net/sw/absi-calculator.html, and all the needed numerical values needed to independently implement these calculations have been released as supplementary material to.[6]

With individual anthropometrics such as BMI, WC, WC/HC, ABSI, and HI, HRs for outcomes such as mortality and major cardiovascular (CV) diseases show some variability, but tend to be modest, at around 1.2 per standard deviation (SD). Many studies rank the utility of anthropometrics, for example ABSI versus BMI, to find the most appropriate one for a given population or condition. Based on the statistical independence of ABSI, BMI, and HI, ARI combines the separate risks, thereby creating a more informative risk metric. For example, for mortality in the Atherosclerosis Risk In Communities (ARIC) cohort, the HR for ARI(BMI,ABSI,HI) was 1.43 (95% CI: 1.38–1.49) per SD, significantly higher than for ABSI, which was 1.26 (1.22–1.30) or BMI [1.11 (1.09–1.15)] and also of greater magnitude than the mitigation of risk from higher HI [0.92 (0.89–0.97)].[6]

Applying the New Anthropometric Indices

We suggest transforming BMI, ABSI, and HI into z-scores relative to age- and sex-specific means and SDs for several reasons.[5–7] First, normal values for anthropometric measures vary considerably by age and also by sex, indeed more noticeably for ABSI and HI than for BMI. Second, z-scores (also known as t scores) are widely familiar from bone densitometry. Most importantly, conversion to z-scores [based on U.S. population normals, which we computed from the National Health and Nutrition Examination Survey (NHANES) for ages 3–90] facilitates conversion into HRs that are found to be valid across demographic categories.[6] In addition, the vast majority of the population should have z-scores in the range −2.5 to +2.5, which allows, for example, for five simple categories of much below normal (<−1.5), below normal (−1.5 to −0.5), normal (−0.5 to 0.5), above normal (0.5 to 1.5), and much above normal (>1.5) to simplify clinical interpretation. The methodology for calculating ARI in fact uses z-scores of the individual indices,[6] as illustrated in Fig. 1. Most publications that have compared associations across anthropometric

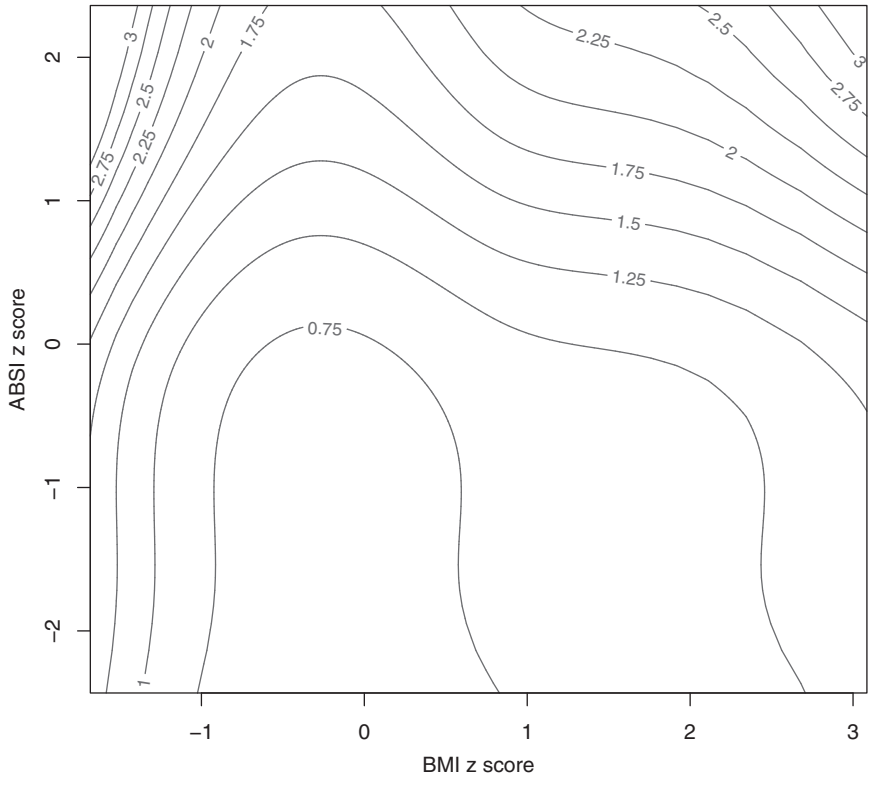

FIG. 1. Contour plot showing relative mortality hazard as a function of age- and sex-corrected z-scores of BMI (horizontal axis) and ABSI (vertical axis). For a given BMI, the mortality hazard increases with rising ABSI. For a given ABSI, the changes in mortality with BMI follow a U-shaped distribution, with higher mortality hazard for both high and low BMI z-scores. ABSI, a body shape index; BMI, body mass index. Figure taken from Krakauer and Krakauer[5] (Creative Commons Attribution License).

measures have, however, used the raw scores, which raise the potential for confounding of the effects of anthropometric factors with those of age and sex.

Mortality Hazard

It is well known that BMI has a U-shaped association with mortality. The lowest mortality observed for NHANES III study participants (examined 1988–1994–mortality through 2011) was for BMI around 24 and in NHANES 1999–2004 (mortality though 2006) for BMI around 28.[5,6] In contrast, ABSI had a positive linear relationship to mortality hazard. We examined the association of baseline anthropometrics with subsequent mortality in NHANES III, the British Health and Lifestyle Survey (HALS), and the ARIC cohort. The mortality curves for these studies are qualitatively similar to from the initial findings with NHANES 1999–2004.[6,7] Studies from Australia, Greenland, Denmark, Iran, Japan and from the U.S. Women's Health Initiative have confirmed the associations of ABSI with mortality.[8–13]

The HI was found to share the U-shaped relationship to mortality of BMI.[6] Association of larger HC with lower mortality had been noted for women, but not for men.[14] A U-shaped association of HC with mortality was reported from Mauritius.[15]

Diabetes

Only one quite small study [$n = 687$, 74 new onset type II diabetes mellitus (DM2)] has been published on HI, reporting on its association with 15-year incidence of DM2. In this study, DM2 development risk for the higher four HI quintiles, relative to the lowest quintile's risk (designated 1.0), showed a suggestively U-shaped association, (0.98, 0.78, 0.61, 0.92), but the trend was not significant.[16] There have also been studies assessing ABSI correlation with incident diabetes and association with future risk.[17,18]

CV Disease

In a study from Turkey, ABSI standing alone predicted 10-year CV disease (CVD) risk better than BMI or other obesity measures, particularly in men, using as standards the Framingham score and the European System for Cardiac Operative Risk Evaluation (SCORE).[19] A similar study from Bangladesh found an HR per SD ABSI of 3.2 (95% CI: 1.6–6.4) in women, and no significant association in men.[20] In the prospective population-based Rotterdam Study, ABSI was also found, but in men only, to be an equivalent CV risk predictor to laboratory testing.[21] In a study from Scotland, ABSI was among the obesity traits showing regional variation ''with lifestyle and socioeconomic variables, such as smoking, diet and deprivation.''[22] A study from the Netherlands[23] found that raw ABSI scores did not associate with CVD incidence, possibly because this study did not correct for sex or age differences in mean ABSI. Derived scaling exponents for WC in an Indonesian population did not differ much from those originally found for ABSI in the U.S. population.[24] Fujita et al. addressed risk for development of diabetes, hypertension, and dyslipidemia in a Japanese population.[25] In both of the studies, ABSI was not associated with hypertension, implying that BMI and ARI would give similar results for risk of hypertension.

Cancer

Interest continues in the predictive power of anthropometrics for cancer development.[26] Associations of ABSI have been found across separate geographies and a number of common malignancies, but none has used the likely more powerful ARI.[27–29]

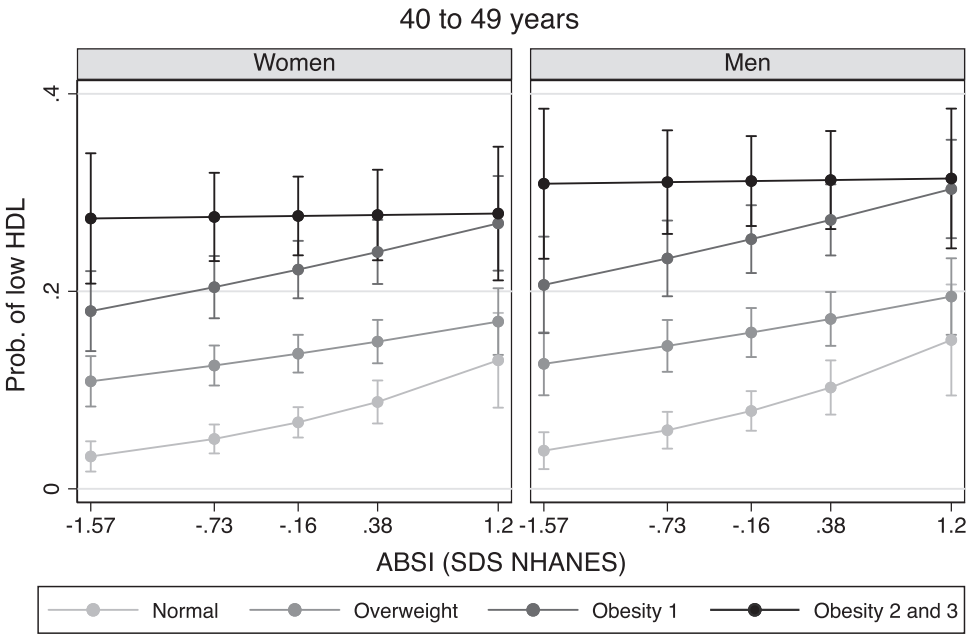

FIG. 2. Illustration of typical relationship between ABSI and likelihood of a MS component (low HDL) at different levels of obesity measured by BMI. The data analyzed were from an Italian clinical sample of adults aged 40–49. Both ABSI and BMI were found to affect the likelihood of having this cardiometabolic risk factor: both men and women had greater likelihood of low HDL at greater obesity (higher BMI), but within each BMI category, risk increased with greater ABSI z-score. Similar assessments were conducted for other age groups and components of MS. HDL, high-density lipoprotein; MS, metabolic syndrome; NHANES, National Health and Nutrition Examination Survey; SDS, standard deviations (z-score). Figure taken from Bertoli et al.[41] (Creative Commons Attribution License).

Associations with Other Health Conditions in Adults

There has been one small study on abdominal surgical outcomes and ABSI.[30] A study from Singapore found that sarcopenia as determined by dual x-ray absorptiometry was associated with elevated ABSI.[31] Regional differences affecting Tunisian woman are reflected in abdominal-only obesity, and hence, presumably, in ABSI [32] Worsening of a noninvasive measure of carotid arterial stiffness was predicted by elevated ABSI.[33] There are reports of association of high ABSI with reduced lean tissue mass[34] and on the laboratory side, transaminase levels[35] and microalbuminuria.[36]

Pediatrics

NHANES data used to derive ABSI included pediatric subjects from age 3 years. In a study of Portuguese adolescents, blood pressure and ABSI were inversely correlated,[37] although the magnitude and dispersion of ABSI values shown suggest that the authors might not have computed ABSI correctly. A clinical cohort study of obese Italian children confirmed ABSI and BMI to be statistically independent.[38] Further study of the same subjects provided evidence that ABSI was of comparable power to BMI as a predictor of risk factors. In that study, ABSI seemed a more suitable CV risk predictor when considering metabolic markers, while BMI was better correlated with the presence of obesity-related threshold-based risk factors.[39] A primary school study from Egypt of intestinal helminthiasis reported lower ABSI for infected children.[40]

ABSI and MS

The relationship of ABSI and BMI with components of MS and visceral abdominal tissue thickness (VAT) was evaluated in over 6000 participants, retrospectively studied at the International Center for the Assessment of Nutritional Status, University of Milan.[41] Significant positive associations were found for ABSI and each of triglycerides, elevated glucose, hypertension, low high-density lipoprotein (HDL) (Fig. 2), as well as VAT. The combination of BMI and ABSI was significantly better at prediction than BMI or ABSI alone for triglycerides, elevated glucose, low HDL, and VAT, but only borderline significant for hypertension. The untangling of WC and HC from BMI has the potential to improve the definition of MS by providing a better anthropometric surrogate for dangerous abdominal adiposity and associated pathologies.

Current Status of the New Anthropometrics

The accumulating evidence suggests that, when properly applied, ABSI and HI can be a valuable complement to BMI. Compared to WC, HC, WC/H or WC/HC, ABSI, and HI were defined to be statistically independent, with very low correlations with BMI confirmed in several large cohorts. In conjunction with BMI, computation of ABSI and HI and the calculation of ARI could boost the utility of simple anthropometrics in clinical practice, healthcare assessment, and analysis of prospective studies and clinical trials. We previously described several case vignettes where combined consideration of BMI and ABSI helped guide clinical care for diabetes, identified otherwise unappreciated risk (where BMI suggested low risk) and might have avoided an unsuccessful bariatric surgery.[42] Consalvo et al., in a recent analysis of a bariatric surgical cohort, found that baseline ABSI and ARI identified patients who showed the most improvement in mortality risk at 3 years after surgery, despite having lower baseline BMI.[43]

With roots in the 19th century, BMI came into widespread use only in the 1970s. The fledgling ABSI shows some promise to follow an accelerated timeline for adoption as a complementary measure to BMI.[4] An array of new sensors, including genome information, combined with big data and advanced computation is bringing medical science from the cohort to the individual level.[44–47] We believe that ABSI, HI, and ARI, as the new generation of indicators based on basic anthropometrics, can help identify subjects most likely to see benefit from treatment and optimize the power of clinical studies, serving as an effective tool of personalized medicine.

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Author Disclosure Statement

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