Development of the Health Index (HI) Statistical Equation as an Alternative Clinical Parameter to the Body Mass Index in the Prediction of Body Fat Percentage

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Citation

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Abstract

Metabolic syndrome is increasing in prevalence in the United States. Body Mass Index is a formula most commonly used to assess body fat percentage. However, the formula contains significant limitations and inefficiencies. As a result, the Health Index equation was developed as an alternative to the BMI. Data from 79 healthy individuals, as defined by the absence of metabolic syndrome risk factors, was collected and a relationship was established between their BMI and body fat percentage. The results showed the BMI produced a poor correlation with the body fat percentage while the Health Index metric produced a stronger correlation to actual body fat percentage.

INTRODUCTION

Metabolic syndrome, a combination of risk factors which increases the risk for cardiovascular disease, diabetes, which all-cause mortality, affects as much as one quarter of the United States population.¬[1-5] The prevalence of metabolic syndrome is increasing in the United States[6] and the cause may be visceral fat mediated insulin resistance, through various cytokines.[7] Central obesity is perhaps the most important risk factor.[8-13] However, other risk factors, such as stress[14-15], sedentary lifestyle[8], aging[8], lipodystrophy[8], and rheumatic diseases have also been proposed.[16]

In most cases of metabolic syndrome, the Body Mass Index (BMI), a statistical measure used to estimate healthy body weight based on a person's height, is the tool used to distinguish between underweight, overweight, and obese patients.[19-22] However, it has significant limitations. First of all, BMI is stature dependent. Therefore, individuals with shorter legs have higher BMIs.[23] Further, the BMI differs between cultures. For instance, in Japan, the BMI's upper limit of normal is 8% which is lower than standards used in the United States.[24-25]

Perhaps most importantly, the BMI cannot distinguish between mass due to muscle and mass due to fat, thus making it "as much a measure of lean body mass as it is a measure of fatness or obesity."[23] Therefore, when a patient loses muscle (and gains proportionately in fat) it actually decreases (because muscle is denser than fat) and when a patient gains muscle and loses fat, it increases (for the same reason). As a result, BMI is an inconsistent predictor of physical health and obesity-related health risk. Other measures, such as waist-circumference are much better predictors.[26-32] In fact, studies have shown that even at low BMIs, high body fat percentage is an important predictor of cardiovascular risk.[33]

Since visceral fat is an important etiologic cause of metabolic syndrome complications, the BMI must be adjusted or replaced by an equation which is based on body fat percentage, since this may lead to better prediction of clinical end points (such as diabetes, coronary heart disease, and stroke).[34-38]

METHODS

Health data was collected from public sources containing the following variables: height, weight, body fat percentage, diabetes mellitus, myocardial infarction and stroke. A total of 79 individuals (32 males and 47 females) with a "perfect" state of health in their prime were selected. A "perfectly healthy" individual, for the purposes of our analysis, was defined as a 25-35 year old male or female, with no known risk factors for metabolic syndrome, body fat percentage of around 12% for males and around 20% for females, and no history of diabetes, myocardial infarction, or stroke.

With this data, we ran multiple regressions in order to establish a standard relationship between the BMI and body fat percentage. We then modified the BMI depending on the variables described above in order to improve the predictive value of the BMI with regards to estimated body fat percentage. The equations developed are shown in Table 1.

It must be noted that we made several assumptions. Our first assumption is that patients with risk factors have 7% more body fat per risk factor than those who don't have that risk factor. This assumption is based on research showing that patients with a risk factor, such as diabetes, have a BMI predicted fat percentage which is ~5% higher than those who do not have the risk factor.[39,40] In our population, individuals with a risk factor had 12% higher BMI predicted body fat percentage. For simplicity, we used 7%, though it is a somewhat arbitrary figure.

Moreover, patients who smoke (or have smoked for a significant period of time, as defined by more than 5 pack years), get an increase of their Health Index by 2.5. This is based on data that shows that smoking increases BP by 5%[41], cholesterol by 33%[42], risk of diabetes by 29-61% (depending on amount of cigarettes consumed per day)[43], risk of PVD (peripheral vascular disease) by 184%[44], risk of stroke by 414%[45], and risk of CAD by 500%.[46] In comparison, rates for coronary disease in the non-smoking population are approximately 2%.[46] Given this data, smoking increases the absolute risk of soft end points by approximately 5 to 15 percent. Since the average Health Index is 27.76, the increase in Health Index from smoking should be 1.4 to 4 points. For simplicity, we used 2.5.

RESULTS

In healthy individuals, the BMI should be 18.5–24.9. However, in this healthy population of 79 individuals, the BMI's standard deviation was 4.9 with a mean of 21.5, tending to classify healthy females as underweight, and healthy males as overweight (see Table 2, Figure 1). When compared to the BMI, the HI produces a more consistent assessment (95% CI = 18.13-19.22, $p < 0.001$). Moreover, the HI Predicted Body Fat Percentage is better correlated to body fat percentage than the BMI (0.86 v. 0.13) in this population (see Table 3, Figure 2). As a result, the HI better approximates the true body fat percentage. In our population, the HI is, on average, within +/- 2% of actual body fat percentage, while the BMI is within +/-5%, ($p < 0.001$).

Figure 1

Table 1

HEALTH INDEX EQUATIONS

General End Point Predictor

$$\text{HI (male)} = \text{BMI}\,(0.95) + 0.079\,(\text{age}) - 1.29 + 2.5\,(\text{smoking})$$

$$\text{HI (male athlete)} = \text{BMI}\,(0.78) + 0.079\,(\text{age}) - 1.29 + 2.5\,(\text{smoking})$$

$$\text{HI (female)} = \text{BMI}\,(1.11) + 0.079\,(\text{age}) - 1.93 - 1 + 2.5\,(\text{smoking})$$

$$\text{HI (female − athlete, estimate)} = \text{BMI}\,(1.03) + 0.079\,(\text{age}) - 1.93 - 1 + 2.5\,(\text{smoking})$$

Body Fat % Estimation

$$\text{HI Predicted Body Fat \% (male, athlete)} = \text{HI} \cdot \left(0.006 + \frac{6.65\,(\text{Risk Factors})}{10{,}000}\right)$$

$$\text{HI Predicted Body Fat \% (male)} = \text{HI} \cdot \left(0.008 + \frac{6.65\,(\text{Risk Factors})}{10{,}000}\right)$$

$$\text{HI Predicted Body Fat \% (female, athlete)} = \text{HI} \cdot \left(0.009 + \frac{6.65\,(\text{Risk Factors})}{10{,}000}\right)$$

$$\text{HI Predicted Body Fat \% (female)} = \text{HI} \cdot \left(0.01 + \frac{6.65\,(\text{Risk Factors})}{10{,}000}\right)$$

Derivations

$$\textit{Health Index Constants} = \left(\frac{\sum \frac{BMI_i}{20}}{n}\right) + \frac{\sum\left(\frac{\sum \frac{BMI_i}{20}}{n} - 20\right)}{n}$$

$$\textit{HI Predicted Body Fat Constant} = \frac{\sum \frac{\textit{Actual Body Fat \%}}{HI_i}}{n}$$

*Athlete defined as an individual performing anabolic exercise 2+ times a week or catabolic exercise 3+ times per week.
**Risk Factors include: HTN, Hyperlipidemia, DM, PVD, AAA, CAD, Age > 45 (m), and Age > 55(f). Note: HDL > 60 negates one risk factor. Tobacco use also deducts one risk factor because it decreases (rather than increases) body fat percentage.
***Risk Factor Adj = # of Risk factors. Females are deducted one risk factor because of their typically higher HDL levels.

Figure 2

Table 2

	Body Mass Index	Health Index
Sample size	79	79
Arithmetic mean	21.4994	18.6751
95% CI for the mean	20.4049 to 22.5938	18.1307 to 19.2194
Variance	23.8762	5.9062
Standard deviation	**4.8863**	**2.4303**
Standard error of the mean	0.5498	0.2734
F-test for equal variances		P < 0.001
Difference		-2.8243
Standard Error		0.6140
95% CI of difference		-4.0371 to -1.6115
Test statistic t		-4.600
Degrees of Freedom (DF)		156
Two-tailed probability		P < 0.0001

Figure 3

Figure 1

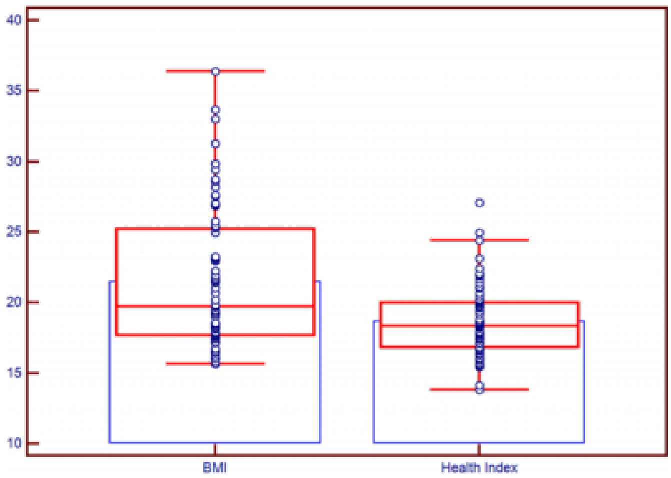


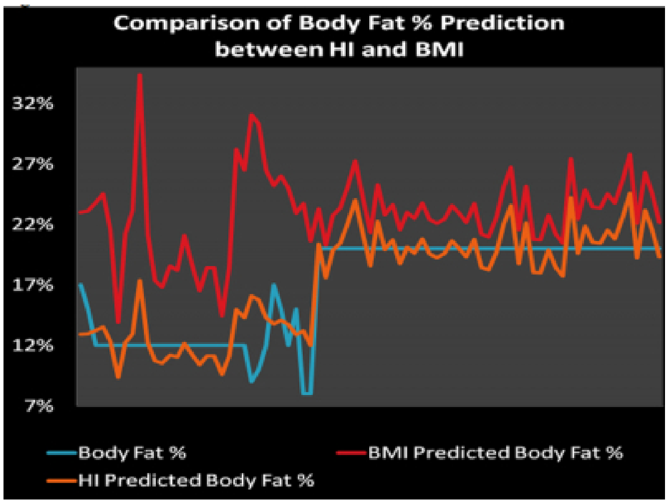
Figure 4

Table 3

Statistic	HI Predicted Body Fat %	Actual Body Fat Percentage	BMI Predicted Body Fat %
Mean	17%	17%	22%
Biased Variance	0.00183	0.00162	0.00115
Biased Standard Deviation	0.04279	0.0403	0.03392
Covariance	0.001505		0.000184
Correlation	0.861725		0.133042
Determination	0.74257		0.0177
T-Test	14.9034		1.7791
p-value (1 sided)	P < 0.001		P = 0.1212
Degrees of Freedom	77		77
Number of Observations	79		79

Figure 5

Figure 2



DISCUSSION

The results show that the HI is a more accurate predictor of body fat percentage in our study population than the BMI. In healthy individuals, the predictive model of the HI is strongly correlated to the actual body fat percentage (R= 0.86, $p < 0.001$), while the BMI predictive model is weakly correlated and not statistically significant (R = 0.13, p = 0.12).

The objective of this research was to create a statistical model to be tested in a prospective research project, where the HI can be used as a clinical predictor versus the BMI. Once this equation is modified based on a larger, more representative population, the accuracy and precision of the statistical model should improve. The intent of this research was to serve as a pilot study that provides the basis for a more comprehensive analysis, which is currently underway at Cleveland Clinic Florida.

It should be noted that the "Health Index" is a general equation predicting onset and complications of Metabolic Syndrome. It should not be used to predict general mortality, as it does not account for mortality associated with cachexia, cancer, and other conditions. Therefore, it should only be used to predict mortality from heart attack or stroke.

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