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Optimizing Metabolic Syndrome Screening: A New Region-Specific Body Shape Index

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ABSTRACT

To propose a new anthropometric index (AI) for identifying groups at risk of metabolic syndrome (MetS). Overall, 4360 male workers in hazardous occupations were examined. To determine region-specific ABSI scaling exponents, a least-squares linear regression model was constructed for a subset of 4014 participants. AI independence was assessed by correlation analysis. To estimate combined impact on MetS-risk and control for age, AIs were transformed into z-scores. The prognostic values of AI and their combinations with regional $ABSI_U$ were estimated with ROC curves. Model sensitivity (Se) and specificity (Sp) were determined using a confusion matrix. Region-specific $ABSI_U$, z-scores and their combinations were calculated for the main dataset of 346 subjects. Correlation analysis revealed a weak association between $ABSI_U$ and height (r = 0.044), weight (r = -0.083), HC (r =0.073), BMI (r = -0.116) and BRI (r = 0.365). BRI was best at predicting MetS-risk among individual AIs (AUC = 0.768, Se = 0.896, Sp = 0.579); the best combination was - $ABSI_U$ + BMI (AUC = 0.777, Se = 0.792, Sp = 0.683). Our z-score, based on $ABSI_U$ and BMI, demonstrates a higher prognostic ability to identify groups at risk of MetS against known AIs, opening new prospects for early diagnosis and screening of MetS.

Keywords: Anthropometric index; Body shape index; Metabolic syndrome; ROC analyses; Multiple linear regression.

Introduction

The World Health Organization estimates that overweight and obesity are among the leading global mortality risk factors responsible for 4.8% or 5 million deaths annually worldwide [1], which adds to the economic burden on societies and healthcare systems [2-3]. Overweight and obesity are accompanied by the development of metabolic syndrome (MetS) [4-5].

The metabolic syndrome is defined as a group or cluster of intertwined metabolic disorders, such as insulin resistance, type 2 diabetes, dyslipidemia, hypertension, hyperglycemia and cardiovascular diseases [6]. With the global rise in obesity, MetS has become one of the major public health problems worldwide [7-8]. The estimated prevalence of this symptom complex is about a quarter of the world's population [9]. According to recent studies, the prevalence of MetS in Europe is 24.5% [10], while in some Asian countries this figure varies from 12.9 to 33.2% [11-13]. In other words, currently more than 2 billion people worldwide suffer from MetS, and the incidence of this pathology will be steadily increasing. It is therefore extremely important to diagnose MetS as early on as possible and in as many people as possible, which requires affordable and accessible screening tools.

A number of studies have sought to find an optimal anthropometric index (AI) associated with potential cardiometabolic risk [14-16]. In this vein, the need for a more accurate representation of fat tissue distribution has led to the development of a number of indices that are now recommended for assessing cardiometabolic risk [17]. In addition to the popular WC/HC and WC/Height ratios, these indicators include the less commonly used BRI, ABSI, and LAP [18–21]. Furthermore, the literature discusses the scaling of physiological variables, such as cardiometabolic risk indices, allowing for differences in body size [22], and many sources recognize the value of using allometry in modeling the relationships between such physiological variables and body size [23-25].

This study is devoted to the construction of a new anthropometric index and assessment of its prognostic ability to identify groups at risk of cardiometabolic disorders (metabolic syndrome) relative to the prognostic ability of other AIs.

Methods

Study population and design

We conducted this study using two datasets of male workers engaged in hazardous occupations at five metallurgical enterprises in the Ural region, Russia, who underwent routine medical examination at the Yekaterinburg Medical Research Center for Prophylaxis and Health Protection of Industrial Workers of Rospotrebnadzor during 2019. The first, and the main of the datasets [21] included 346 male workers, aged 27 to 63 years (mean age 46.5 ± 8.3 years), who were additionally examined for the presence (absence) of MetS. The second cohort, compiled for calculating coefficients, included data on 4014 male workers engaged in metallurgical occupations in the same region, aged 21 to 75 years (mean age 45.0 ± 10.1 years).

The requirement to obtain informed consent was waived because we did not have access to personally identifiable data. This study was approved by the Review Board of the Institute of Industrial Ecology, the Ural Branch of the Russian Academy of Sciences (Protocol No. 3 dated 05.06.2023) and was conducted in accordance with the Declaration of Helsinki (2015-11-016-005).

Data collection and measurement

Basic information on height (m), weight (kg), waist circumference (m) and hip circumference (m) was available in both datasets, while that on the presence (absence) of MetS in the main one [21]. All the necessary measurements were carried out in 2019 by trained personnel of the Medical Research Center for Prophylaxis and Health Protection of Industrial Workers of Rospotrebnadzor using standardized protocols. The anthropometric data were then used to calculate anthropometric indices such as BMI, BRI, and ABSI using formulas 1-3:

$$\mathrm{BMI} = \frac{\mathrm{weight}}{\mathrm{height}^2} \tag{1}$$

$$\mathrm{BRI} = 364.2 - 365.5 \cdot \sqrt{1 - \frac{\mathrm{WC}^2}{\pi^2 \cdot \mathrm{height}^2}} \tag{2}$$

$$\mathrm{ABSI} = \frac{\mathrm{WC}}{\mathrm{weight}^{2/3} \cdot \mathrm{height}^{-5/6}} \tag{3}$$

Measurements of metabolic syndrome

The MetS components were determined according to the current IDF criteria [26]. These criteria specify the presence of central (abdominal) obesity and two or more additional clinical features. Abdominal obesity was defined as WC ≥ 94 cm for males. The additional clinical signs of MetS were elevated triglycerides (TG) ≥ 1.7 mmol/L; HDL concentration for males < 1.03 mmol/L; BP ≥ 130/85 mmHg, or had been diagnosed with arterial hypertension; fasting blood glucose ≥ 5.6 mmol/L, or had been diagnosed with diabetes mellitus. These determinants include a combination of categorical and borderline risk factors that can be easily measured in clinical practice. Standardized measurements were carried out at the clinic of the Medical Research Center for Prophylaxis and Health Protection of Industrial Workers of Rospotrebnadzor.

Statistical analysis

The descriptive statistics of the main characteristics were obtained for both samples.

Data for normally distributed continuous variables are presented as means and standard deviation ($\bar{X} \pm SD$), and categorical factors are reported as percentage.

To determine the region-specific ABSI scaling parameters, a least-squares linear regression model was constructed based on log(WC) as a function of log(Ht) and log(Wt) for the entire

second sample dataset of 4014 male workers engaged in metallurgical production in the Ural region.

The indicators thus obtained were then used to calculate a region-specific index, $ABSI_U$, for each participant in the main sample (n=346).

The independence of the anthropometric parameters studied (height, weight, HC, BMI, ABSI, $ABSI_U$) was assessed using correlation analysis (a relationship with a correlation coefficient of $|r| < 0.5$ was considered to be weak).

To assess the combined impact of the indices on the risk of developing MetS and obesity and control for age differences, the values of the anthropometric indices were transformed into z-scores by subtracting the mean value over the sample of industrial workers and dividing by the standard deviation.

To evaluate the prognostic value of the anthropometric indices and their combinations with $ABSI_U$, we constructed ROC curves and determined AUC values using the statistical software package SPSS 29 (SPSS, Chicago, Illinois, USA). The sensitivity (Se) and specificity (Sp) of the models thus constructed were determined from the resulting confusion matrices.

Statistical data processing was performed using Statistica for Windows v.10 (StatSoft, USA). The statistical significance of the differences was estimated at the significance level $\alpha=0.05$.

Results

A total of 4014 workers (second sample) aged 21 to 75 years (mean age 45.0 ± 10.1 years) were examined. The sample's average WC was 0.93 ± 0.12 m, and HC was 1.01 ± 0.08 m. More than half (64.9%) of this sample were overweight or obese (BMI ≥ 25 kg/m^2). In 1,928 (48.0%) of these male workers employed in hazardous working conditions, WC was 94 cm or more. The average BRI value was 4.05 ± 1.43 relative units. The original body shape index varies from 0.058 to 0.104 $m^{11/6} \cdot kg^{-2/3}$ (average value 0.079 ± 0.005 $m^{11/6} \cdot kg^{-2/3}$).

Determination of scalable metrics for calculating the region-specific body shape index $ABSI_U$

ABSI has limitations of applicability because scaling indicators are estimated differently in different countries. To address these limitations, we calculated new coefficients for the ABSI formula using data on 4014 male workers from the metallurgical industry of the Ural region.

A region-specific body shape index ($ABSI_U$) was developed for the sample under consideration using multiple linear regression. The procedure used to construct the regression model was similar to that used for developing the original ABSI [24].

The regression model presents the following dependence of ln(WC) on ln(Height) and ln(Weight) ($R^2 = 0.719$):

$$\ln(WC) = -2.744 + 0.725 \cdot \ln(Weight) - 0.938 \cdot \ln(Height) \quad (4)$$

From this model, it follows that:

$$WC \sim Weight^{0.725} \cdot Height^{-0.938} \quad (5)$$

$ABSI_U$ is proportional to the ratio of actual WC to WC expected according to the regression allometry:

$$ABSI_U = \frac{WC \cdot Height^{0.938}}{Weight^{0.725}} \quad (6)$$

Correlation analysis

For further analysis, 346 workers (main sample) aged 27 to 63 years (mean age and standard deviation – 46.5 ± 8.3 years) were examined.

The average WC in this sample was 0.99 ± 0.11 m, while HC was 1.02 ± 0.07 m. Overweight or obesity (BMI ≥ 25 kg/m^2) were found in 252 (72.8%) workers. In 240 (69.4%) of these male workers employed in hazardous working conditions, the WC was 94 cm or more.

The average BRI value was 4.68 ± 1.33 relative units. The original body shape index was found to vary from 0.062 to 0.097 $m^{11/6} \cdot kg^{-2/3}$ (average value 0.081 ± 0.005 $m^{11/6} \cdot kg^{-2/3}$).

The prevalence of metabolic syndrome in the main sample of male workers was 36.1%.

Based on the obtained scaling indicators, we calculated $ABSI_U$ for each participant of the main sample. The average regional $ABSI_U$ index constitutes 0.067 ± 0.004 $m^{1.938} \cdot kg^{-0.725}$ (the range of values is 0.051 ÷ 0.080 $m^{1.938} \cdot kg^{-0.725}$).

Table 1 shows coefficients of correlation between $ABSI_U$ and other anthropometric indices considered.

The results of the correlation analysis suggest that, like ABSI, the $ABSI_U$ index developed by us is weakly associated with BRI, BMI, HC, height and weight, which allows us to consider the combined impact of these indices on the risk of developing MetS.

ROC analysis was applied to the main dataset of 346 industrial workers from the Sverdlovsk region to evaluate the prognostic ability of the $ABSI_U$ index and other anthropometric indicators to determine the risk of MetS development.

Transformation of anthropometric indices into z-score

Z-score, an estimator of a specific anthropometric index, was determined for all the anthropometric indices considered using the following formula::

$$\text{z-score} = \frac{\text{index} - \overline{\text{index}}}{\text{index}_{SD}} \quad (7)$$

where index is a worker's specific AI;

$\overline{\text{index}}$ is the average value of AI for the main sample;

index_{SD} is the standard deviation of AI for the main sample.

To estimate the combined impact of the indices considered on the risk of developing MetS in Ural male workers, we transformed the values of the anthropometric indices into z-scores [27].

As expected, correlation analysis of the AI z-scores demonstrated results similar to those obtained previously (Table 1). This fact provides additional confirmation to the possibility of considering the combined impact of $ABSI_U$ and other indices on the risk of developing MetS.

Prognostic ability of the developed anthropometric index to identify metabolic syndrome

To assess the combined impact of $ABSI_U$ and other indicators on the risk of developing MetS, the z-scores were summed together, creating various combinations.

The analysis provided AUC, Se and Sp values for the models considered (Table 2).

The results of the analysis suggest that the best predictor of MetS development in industrial male workers in the Ural region aged 27 to 63 years is BRI (AUC = 0.768, Se = 0.896, Sp = 0.579).

As for the predictive ability of the AI combinations considered, the best results were shown by the model $ABSI_U$ + BMI (AUC = 0.777, Se = 0.792, Sp = 0.683).

Figure 1 shows the ROC curves for the two models that demonstrated the best predictive ability according to the analysis.

Discussion

In recent decades, the prevalence of MetS has been steadily increasing, which raises serious public health concerns and requires a comprehensive approach to its diagnosis and prevention. The findings of our study confirm the importance of developing and implementing new AIs that

would enable cardiometabolic risk to be more accurately determined, especially in the context of specific populations.

The aim of this study was to construct a new anthropometric index to identify groups at risk of developing metabolic syndrome among workers employed in harmful occupations in metallurgical industry.

It has been proven that the prevalence of obesity and MetS is contingent on harmful and dangerous production factors as well as on gender, age, genetic predisposition, ethnic origin, area of residence, education, level of physical activity, sleep disorders and many other parameters and factors [28-31].

The Federal State Statistics Service of Russia reports that out of 3.08 million people employed in the Sverdlovsk region's economy, 0.94 million people work in harmful working conditions [32]. Preventive medical examinations carried out in 2023 revealed that the prevalence of MetS among male workers at the metallurgical enterprises of the Sverdlovsk region in the age group over 47 years reached 46.7%.

According to the State Labor Inspection, out of 122 cases of death at work as a result of illness in the Sverdlovsk Region in 2023, 92.5% of deaths were related to diseases of the circulatory system (117 cases, including 108 males). Moreover, the number of cases of death at work as a result of illness consistently exceeds the number of deaths as a result of occupational accidents [33].

The specific cohort of industrial workers (only males, since according to Russian labor legislation, women are not to be employed in hazardous occupations) thus represents a particularly vulnerable group and is at high risk of developing MetS.

Computed tomography (CT), magnetic resonance imaging, dual energy x-ray absorptiometry and PET-CT are the preferred diagnostic procedures for MetS detection, but they are not always available or feasible, especially at the medical units of industrial enterprises in small cities. Moreover, the use of high-precision instrumental studies does not preclude the need to develop reliable working tools for MetS screening throughout the country at minimal cost that could be conducted by nursing staff. A promising alternative, in our opinion, is offered by new (relative to classical BMI and WC) anthropometric indices, such as LAP, BRI and ABSI, which can provide a more accurate understanding of the distribution of adipose tissue and its impact on metabolic disorders.

Several studies suggest that the Lipid Accumulation Product (LAP) shows better results in identifying groups at risk of developing MetS compared to other AIs [21, 34]. However, the LAP index formula includes serum triglyceride levels as a parameter, which obviously limits its use as a low-cost non-invasive tool.

A meta-analysis [34] that examined the prediction ability of AI in MetS diagnosis found that BMI performed better than BRI in half of the cases (where MetS was determined using the IDF criteria). In our study, we found that BRI was sufficiently reliable in identifying people with MetS, but the specificity of the BRI models was lower, which may imply the occurrence of false positives.

Previous studies [35-37] have shown that ABSI has a number of serious limitations of use, primarily related to differences in scaling indicators depending on country and gender.

The model that we built based on logarithmic transformations of waist circumference (WC), height and weight demonstrates a good degree of explanation ($R^2 = 0.719$). This indicates that the selected variables describe the variation in WC values quite well [24].

To our knowledge, our study is the first to calculate new scaling parameters for the region-specific $ABSI_U$ formula using an additional database of male workers from metallurgical enterprises in the Ural region.

The weak association found between $ABSI_U$ and other anthropometric indices may indicate that each of these indices provides unique information about MetS risk. This is important for a comprehensive approach to assessment [36, 38].

The use of ROC analysis to assess the prediction ability of $ABSI_U$ and other indices in MetS risk assessment is a necessary step to understand how well each of the indices may predict the presence of a metabolic syndrome. We evaluated the predictive ability of the body shape index $ABSI_U$ to determine the risk of developing a metabolic syndrome. Its comparison with the original ABSI shows that the new index retains the properties of the latter. In order to increase the sensitivity of the new tool in MetS detection, we transformed each anthropometric index into a z-score. This procedure allows one to standardize data and simplify comparisons between different participants in a sample, while also being instrumental in further analysis of the combined impact of indices [36-38].

Summing the z-scores of different anthropometric indices to estimate their combined impact on MetS risk may reveal new patterns and improve the predictive ability of the model.

Like in [38], BMI was a basic model in our study as well, to be used for comparison with models in which BMI is replaced with other anthropometric markers.

ROC analysis showed that the new z-score, reflecting the combined impact of $ABSI_U$ and BMI, was the best predictor among the models considered in identifying the MetS risk group. This opens up new prospects for early diagnosis and screening of metabolic syndrome, which is extremely important for the development of preventive strategies and interventions at the public health level.

Besides strengths, our study has a number of limitations. First, the sample is restricted to male workers from Ural metallurgical enterprises, which may limit the generalizability of the results to other populations. Second, the lack of data on some social and behavioral factors, such as physical activity and diet, may affect the interpretation of the results. We assumed that metallurgical workers have approximately the same level of education (secondary + vocational school), income, and similar lifestyle and behavior patterns. However, future studies should focus on broader populations and include additional variables to more fully understand the relationships between anthropometric indices and the risk of metabolic disorders.

Conclusion

Our work highlights the need for further research in the field of anthropometric indices and their role in cardiometabolic risk assessment. The development of accessible and effective screening tools is critical to counteract the global epidemic of obesity and metabolic syndrome.

It should be emphasized that early detection of MetS can significantly reduce the risk of developing comorbidities, such as type 2 diabetes and cardiovascular disease. Integration of new anthropometric indices into the practice of routine health examinations can contribute to more effective monitoring of population health and improving quality of life, as well as intensifying efforts around obesity prevention policies and programs.

Competing interests: The authors declare no competing interests.

Author Contributions:

Conceptualization: E.K., T.M. and S.O.

Formal analysis: E.D., T.M. and S.O.

Writing original draft preparation: E.K., T.M. and S.O.

Project administration: E.K.

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Data Availability: Data available on request from the corresponding author.

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Figures and tables

Table 1. Results of Correlation Analysis of Anthropometric Indicators

Anthropometric index	Weight	HC	BMI	BRI	ABSI	[e]$ABSI_U$
Height	**0.450**	**0.335**	**-0.050**	**-0.196**	**0.046**	**0.044**
Weight		0.828	0.866	0.666	**0.040**	**-0.083**
[a]HC			0.739	0.643	**0.179**	**0.073**
[b]BMI				0.862	**0.022**	**-0.116**
[c]BRI					**0.486**	**0.365**
[d]ABSI						0.990

*The values of the correlation coefficient |r| < 0.5 are shown in bold

[a]HC – Hip Circumference.

[b]BMI – Body Mass Index.

[c]BRI – Body Roundness Index.

[d]ABSI – Anthropometric Body Shape Index.

[e]$ABSI_U$ – Ural Anthropometric Body Shape Index.

Table 2. The Results of ROC-Analysis for Anthropometric Indices and Their Combinations

Predictor	AUC	Sensitive	Specificity
Height, m	0.487	0.456	0.624
Weight, kg	0.691	0.864	0.493
[a]HC, m	0.696	0.696	0.620
[b]BMI, kg/m^2	0.710	0.840	0.516
[c]BRI, rel. u.	0.768	0.896	0.579
[d]ABSI, $m^{11/6} \cdot kg^{-2/3}$	0.695	0.680	0.638
[e]$ABSI_U$, $m^{1.938} \cdot kg^{-0.725}$	0.659	0.680	0.588
$ABSI_U$ + Height	0.604	0.496	0.697
$ABSI_U$ + Weight	0.760	0.920	0.489
$ABSI_U$ + HC	0.741	0.608	0.756
$ABSI_U$ + BMI	0.777	0.792	0.683
$ABSI_U$ + BRI	0.760	0.752	0.688

[a]HC – Hip Circumference.

[b]BMI – Body Mass Index.

[c]BRI – Body Roundness Index.

[d]ABSI – Anthropometric Body Shape Index.

[e]$ABSI_U$ – Ural Anthropometric Body Shape Index.

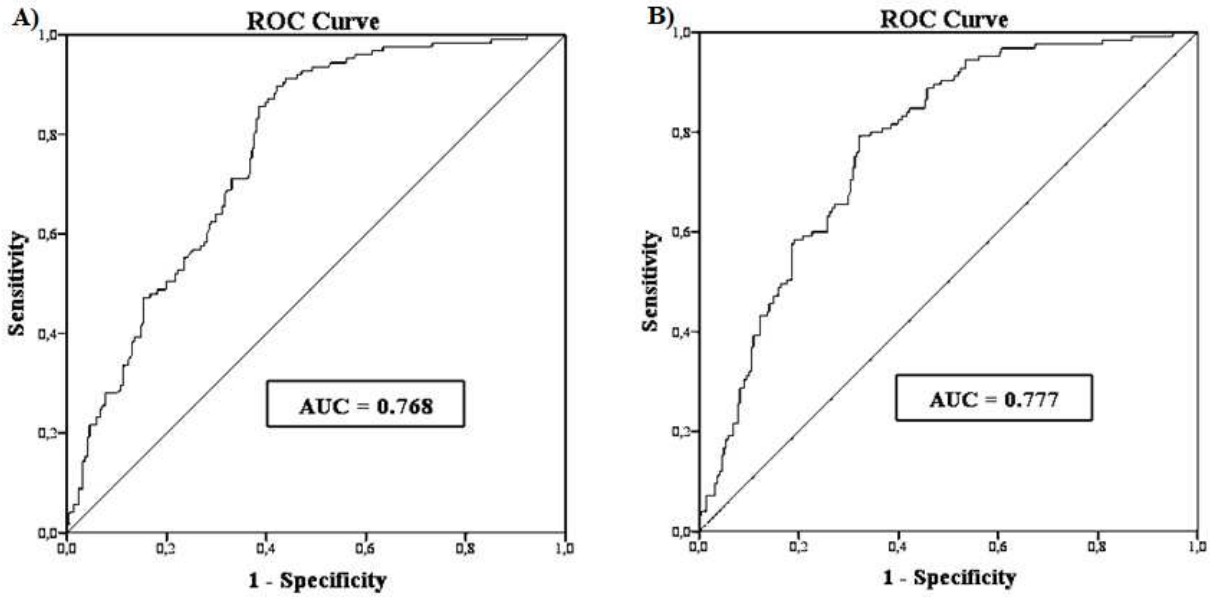


Figure 1. ROC analysis of anthropometric indices: A) BRI; B) ABSIU + BMI