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Cardiometabolic risk assessment in Eastern Slovak young adults using anthropometric indicators

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ABSTRACT: *Introduction:* Selected anthropometric indicators, such as anthropometric measurements, indices, or ratios could be reliable predictors of future cardiometabolic risk in primary prevention, especially in young adults.

Aim: This study aimed to establish cardiometabolic risk status in young Eastern Slovak adults according to anthropometric indicators.

Material and methods: Indicators used in this study, such as heart rate, blood pressure, five anthropometric measurements, as well as a total of 23 anthropometric indices and ratios were selected based on the available literature. These indicators were analyzed in 162 young adult participants of both sexes with a mean age of 20.78±2.22 years. The analyzed indices and ratios were calculated by routine anthropometry and were correlated with blood pressure and heart rate in the whole research group as well as among subgroups divided according to sex, obesity and hypertension status.

Results: Our results showed frequently higher values of input characteristics in males (71.88%), and statistically significant differences between sexes in 81.25% of the characteristics. The values of systolic blood pressure were above the norm in all males, and they also dominated in the obesity group. Correlation analyses conducted on all participants and in subgroups indicated a positive statistical significance in several indicators. The vast majority of the anthropometric indicators were significantly correlated with physiological indicators in almost all subgroups. Only A body shape *index* (ABSI) correlation coefficients did not show a significant correlation with physiological indicators in all analyzed subgroups. The correlations tended to be stronger among subgroup exhibiting potential to obesity. All analyzed indices and ratios were significantly correlated ($p \leq 0.05$), predominantly with blood pressure components rather than heart rate, especially in participants with the potential for disease complications than in participants without them.

Conclusion: The analyzed indicators are noninvasive and useful although they may be at different levels of association and clinical significance for various conditions. Thus some of the indicators may be standardly used in the early diagnostic process for monitoring cardiovascular health and risk stratification of patients.

KEY WORDS: Anthropometry, Cardiometabolic complications, Asymptomatic individual, Primary prevention, Young adulthood.

Original article

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Introduction

The consequences of the COVID-19 pandemic have rapidly translated into the health of the global population, including cardiometabolic health (Pina and Castelletti 2021). The current pandemic situation in the world and Slovakia has forced many to think about what important changes need to be made in the field of civilizational disease prevention. A deterioration in the availability of health care during the pandemic period showed the need for reliable monitoring and assessment of cardiometabolic status, especially in asymptomatic young adults. Young age is a period that allows early detection of future cardiometabolic complications, their prevention, and successful treatment if they are recognized in time (Tanrikulu et al. 2017; Barden et al. 2022). In this context, we can propose alternative approaches for the primary prevention of cardiovascular risk by analyzing anthropometric indicators, such as linear and curvilinear measurements, indices, and ratios. This noninvasive approach may provide valuable information about body size, shape, composition, development, and health, including cardiometabolic and nutritional status, even before any complications appear (Roriz et al. 2016; Piqueras et al. 2021; Minetto et al. 2022). In this context, the aim of our study was to analyze the importance of selected anthropometric indicators to predict cardiometabolic risk status in Eastern Slovak young adults.

Material and Methods

The first step of our research was the selection of indicators that are methodologically undemanding and could be commonly implemented in the first step of primary prevention of cardiometabolic disease conditions. All relevant information was searched in research databases such as NCBI, PubMed, and ScienceDirect® by entering the keywords anthropometry, anthropometry index, indices of adiposity, cardiometabolic risk, and their combinations. Our search strategy allowed us to select anthropometric indicators (i.e., five anthropometric measurements, and 23 indices and ratios) relevant to our study which were then calculated and correlated with physiological indicators (blood pressure and heart rate).

The study was performed among a group of 162 individuals of both sexes in the age range of 18–26 years who were interested in participating in our research activities. The implementation of the research and all procedures performed in the study were in accordance with ethical standards established by the institutional ethics committee (ECUP-022023PO). Participation in the research was anonymous, voluntary, and conditional on the signing of an informed consent form. The condition for participation in the study was the provision of information on sex, age, blood pressure, heart rate, body weight, height, and circumference measurements (waist, hip, and neck circumferences) and stating no acute or chronic disease at the time of obtaining data. To ensure the reliability and consistency of the data and minimize measurement error, we calculated the average value of three measurements of each variable. For statistical analysis, all participants were divided into six different subgroups according to sex, BMI (≥ 25 kg/m^2), and blood pressure values (sBP/dBP $\geq$120/80 mmHg): males and females; obesity$^+$ and obesity$^-$, hypertension$^+$ and hypertension$^-$.

Standard procedures and tools (digital personal scale Omron BF-511 T, Seritex anthropometer GPM MODEL 100, Cescorf flexible steel tape, SencorS-BP 690 digital blood pressure monitor) were used to obtain information about physiological variables such as heart rate (HR; bpm), systolic and diastolic blood pressure (sBP and dBP; mmHg), measurements of body height (Ht; cm), body weight (Wt; kg), waist circumference (WC; cm), hip circumference (HC; cm), and neck circumference (NC; cm). Anthropometric data were collected following the recommendations of the *International Standards for Anthropometric Assessment* from 2011 (Stewart et al. 2011). These data were obtained from all participants and were used to calculate 23 anthropometric indices and ratios as indicators of cardiometabolic risk based on:

1. Body height and weight:
   - *Body mass index* (**BMI**) and optimized alternatives *new BMI* (**nBMI** $= 1.3 \times (Wt_{kg}/Ht^2_{m})$) and *Waist-corrected BMI* (**wBMI** $= WC_{m} \times (Wt_{kg}/Ht^2$ m$)$) and *BMI multiplied by the square root of WC* ($\mathbf{BMI_{\sqrt{WC}}} = (Wt_{kg}/Ht^2$ m$) \times \sqrt{WC_{m}}$),
   - *Triponderal mass index* (**TMI** $= Wt_{kg}/Ht^3$ m),
   - *Weight-adjusted waist index* (**WWI** $= WC_{cm}/\sqrt{Wt_{kg}}$)
2. Waist or hip circumferences:
   - *Abdominal volume index* (**AVI** $= [2\times WC^2_{cm} + 0.7 \times (WC_{cm} - HC_{cm})^2]/1000$),
   - *Body adiposity index* (**BAI** $= [HC_{cm}/Ht^{1.5}_{m}] - 18$),
   - *Body roundness index* (**BRI** $= 365.2 - 365.5 \times \sqrt{\{1 - [(WC_{m}/2\varpi)^2)/(0.5 \times Ht_{m})^2]\}}$),
   - *Conicity index* (**CI** $= WC_{m} / [0.109 \times \sqrt{(Wt_{kg}/Ht_{m})}]$,
   - *Hip index* ($\mathbf{HI_{female}} = HC_{cm} \times Wt^{-0.482}_{kg} \times Ht^{0.310}_{cm}$; $\mathbf{HI_{male}} = HC_{cm} \times Wt^{-2/5}_{kg} \times Ht^{1/5}_{cm}$),
   - *Fat mass* ($\mathbf{FM_{female}} = 11.817 - 0.041 \times Age_{year} - 0.199 \times Ht_{cm} + 0.610 \times Wt_{kg} + 0.044 \times WC_{cm}$; $\mathbf{FM_{male}} = -18.592 - 0.009 \times Age_{year} - 0.080 \times Ht_{cm} + 0.226 \times Wt_{kg} + 0.387 \times WC_{cm}$),
   - *Skeletal muscle mass* ($\mathbf{SM_{female}} = 2.89 + (0.255 \times Wt_{kg}) + (-0.175 \times HC_{cm}) + (-0.0384 \times Age_{years}) + (0.118 \times Ht_{cm})$; $\mathbf{SM_{male}} = 39.5 + (0.665 \times Wt_{kg}) + (-0.185 \times WC_{cm}) + (-0.418 \times HC_{cm} + (-0.0805 \times Age_{years})$,
   - *Relative fat mass* ($\mathbf{RFM_{female}} = 64 - [20 \times (Ht_{cm}/WC_{cm})] + 12$; $\mathbf{RFM_{male}} = 64 - [20 \times (Ht_{cm}/WC_{cm})]]$),
   - *Waist to hip ratio* (**WHR**),
   - *Waist to hip to height ratio* (**WHHR**),
   - *Waist to height ratio* (**WHtR**) and its optimized alternatives *new waist to height ratio* (**WHT.5R** $= WC_{cm}/Ht_{cm}^{0.5}$) and *Waist to the square of the height ratio* ($\mathbf{WHt^2R}$)
3. BMI index:
   - *A body shape index* (**ABSI** $= WC_{cm}/(BMI^{0.66}$ kg/m$^2 \times Ht_{m})^{0.5}$),
   - *Body fat percentage* (**BFP** $= (1.20 \times BMI$ kg/m$^2) + (0.23 \times Age_{years}) - (10.8 \times Sex) - 5.4$, $Sex_{male} = 1$ and $Sex_{female} = 0$),
   - *Body surface area* (Mosteller, **BSA** $= (Ht_{cm} \times Wt_{kg}/3600)^{1/2}$),
   - *The Clinica Universidad de Navarra-body adiposity estimator* (**CUN-BAE** $= -44.988 + (0.503 \times Age_{years}) + (10.689 \times Sex) + (3.172 \times BMI$ kg/m$^2) - (0.026 \times BMI^2$ kg/m$^2) + (0.181 \times BMI$ kg/m$^2 \times sex) - (0.02 \times BMI$ kg/m$^2 \times Age_{years}) - (0.005 \times BMI^2$ kg/m$^2 \times Sex) + (0.00021 \times BMI^2$ kg/m$^2 \times Age_{years})$ $Sex_{male} = 0$ and $Sex_{female} = 1$).

Indices were calculated according to mathematical algorithms recommended in relevant studies (Bergman et al. 2011; Falhammar et al. 2011; Gómez-Ambrosi et al. 2012; Fu et al. 2014; Jelena et al. 2016; Peterson et al. 2017; Antonini-Canterin et al. 2018; Tran et al. 2018; Abolnezhadian et al. 2020; Van Haute et al. 2020; Kang 2021; Wu et al. 2021; Christakoudy et al. 2022; Minetto et al. 2022). Cardiometabolic complications were assessed based on values of standardly analyzed indicators (BMI, WHR, WHtR, WC, HR, and BP) according to generally accepted cut-off values mentioned below in the Table 3 (WHO 2000; WHO 2008; Ashwell et al. 2012; Egan and Stevens-Fabry 2015; Brugada et al. 2020). Data were checked for normality using the Kolmogorov-Smirnov test of normality and statistically evaluated using an online calculator (*https://www.socscistatistics.com*) while MS Office and Excel v.1808 were used to calculate descriptive statistics, t-test for data comparison between sexes, Pearson's correlation for association computation. The interpretation of the correlation coefficient sizes was based on Cohen's criteria (Cohen 1988). An informative value of anthropometric indices and ratios were interpreted according to the strength of correlation with physiological indicators, direction of correlations and statistical significance. All results with a p-value of ≤ 0.05 were considered statistically significant and to have higher informative value.

Results

Descriptive characteristics of research group participants

Our research aimed to analyze cardiometabolic risk status in young adults of both sexes, aged from 18 to 26 years, without confirmed acute or chronic disease, according to selected indices and ratios calculated on routine anthropometry. A group of 162 individuals of both sexes with a mean age of 20.78 ± 2.22 years participated in the study. The mean values of variables characterizing our research group are shown in Table 1 and Table 2. Our results showed that the mean values of 71.88% of the input characteristics, including age, were higher in males compared to females, which was also confirmed by the statistical analyses. The mean values of the indices and ratios ABSI and WHHR were equal in subgroups according to sex (Table 2). Statistically significant differences in mean values of the characteristics between sexes were confirmed in 81.25% of cases, except for dBP and the indices and ratios ABSI, BAI, WHHR, WHt^2R, and FM. Statistically significant intersexual comparisons with a p-value of < 0.001 were confirmed in the 4 out of 6 indices and ratios based on body height and weight, the 9 out of 13 indices and ratios based on waist or hip circumferences, and in all indices and ratios based on BMI calculation except for ABSI. All participants were divided into obesity$^+$ and obesity$^-$ subgroup according to BMI risk values of 25 kg/m^2 and above (41 and 121 individuals, respectively), and according to blood pressure values that indicated hypertension (sBP/dBP ≥120/80 mmHg), into hypertension$^+$ and hypertension$^-$ (97 and 65 individuals, respectively). Males dominated the obesity$^+$ group (73.17% of participants) and, on the other hand, females dominated the hypertension$^+$ group (55.67% of participants).

Table 1. Main characteristics of Eastern Slovakia study participants

	All participants (N = 162)				Male (N = 63)				Female (N = 99)				Statistic		
	$\bar{x}$	SD	MAX	MIN	$\bar{x}$	SD	MAX	MIN	$\bar{x}$	SD	MAX	MIN	T test	95% CI	P value
Age [years]	20.78	2.22	26	18	21.41	2.34	25	18	20.38	2.04	26.00	18.00	-2.957	-1.7179 to -0.3421	**
Ht [cm]	171.72	8.85	201	151	179.58	6.84	201	165	166.72	5.83	183.00	151.00	-12.786	-14.8463 to -10.8737	***
Wt [kg]	69.29	17.11	136	45	82.69	15.59	136	51.1	60.76	11.71	128.90	45.00	-10.194	-26.1785 to -17.6815	***
WC [cm]	78.22	11.99	127	57	87.1	10.11	121	70	72.57	9.39	127.00	57.00	-9.318	-17.6095 to -11.4505	***
HC [cm]	98.85	10.36	145	70	104.84	9.40	135	90	95.03	9.05	145.00	70.00	-6.625	-12.7341 to -6.8859	***
NC [cm]	34.41	3.87	45	28	38.25	2.83	45	33	31.97	2.01	40.00	28.00	-16.499	-7.0317 to -5.5283	***
HR [bpm]	78.15	13.01	120	46	75.57	12.06	120	52	79.80	13.33	109.00	46.00	2.042	0.1392 to 8.3208	*
sBP[mmHg]	121.72	11.65	166	95	126.40	10.04	155	100	118.75	11.62	166.00	95.00	-4.302	-11.1621 to -4.1379	***
dBP [mmHg]	76.09	9.85	109	47	75.70	9.76	109	60	76.34	9.89	104.00	47.00	0.404	-2.4919 to 3.7719	ns

Abbreviations: dBP – diastolic blood pressure; HC – hip circumference; HR – heart rate; Ht – body height; MAX – maximum; MIN – minimum; N – number; NC – neck circumference; ns – not significant; sBP – systolic blood pressure; SD – standard deviation; WC – waist circumference; Wt – body weight; $\bar{x}$ *– mean; 95% CI – 95% confidence interval;* * – $p \leq 0.05$; ** – $p \leq 0.01$; *** – $p \leq 0.001$

Table 2. Calculated indices and ratios of study participants

	All participants (N = 162)				Male (N = 63)				Female (N = 99)				Statistic		
	$\bar{x}$	SD	MAX	MIN	$\bar{x}$	SD	MAX	MIN	$\bar{x}$	SD	MAX	MIN	T test	95% CI	P value
BMI	23.29	4.48	43.27	16.30	25.60	4.44	41.58	18.27	21.83	3.84	43.27	16.30	-5.729	-5.0695 to -2.4705	***
nBMI	23.10	4.30	42.81	16.35	24.85	4.35	41.09	17.70	21.98	3.87	42.81	16.35	-4.383	-4.1631 to -1.5769	***
wBMI	18.71	6.99	54.95	10.01	22.70	6.91	50.32	13.22	16.17	5.75	54.95	10.01	-6.509	-8.5114 to -4.5486	***
BMI√WC	20.81	5.78	48.76	13.14	24.06	5.67	45.74	15.58	18.74	4.82	48.76	13.14	-6.390	-6.9643 to -3.6757	***
TMI	13.56	2.48	25.07	9.70	14.26	2.55	24.02	10.15	13.11	2.33	25.07	9.70	-2.951	-1.9195 to -0.3805	**
WWI	9.44	0.61	11.33	7.85	9.62	0.59	11.33	8.59	9.33	0.59	11.19	7.85	-3.050	-0.4778 to -0.1022	**
AVI	12.85	4.06	32.48	6.62	15.63	3.75	29.30	10.24	11.08	3.16	32.48	6.62	-8.302	-5.6324 to -3.4676	***
BAI	25.96	4.09	45.95	14.44	25.62	3.99	37.33	17.98	26.18	4.14	45.95	14.44	0.851	-0.7394 to 1.8594	ns
BRI	2.63	1.19	8.88	0.87	3.16	1.16	7.87	1.42	2.30	1.07	8.88	0.87	-4.826	-1.2119 to -0.5081	***
CI	1.13	0.08	1.37	0.93	1.18	0.07	1.37	1.07	1.10	0.07	1.35	0.93	-7.091	-0.1023 to -0.0577	***
HI	51.11	2.39	59.03	41.07	50.81	2.20	58.25	43.89	49.05	3.01	60.28	41.41	-4.008	-2.6273 to -0.8927	***
FM	19.54	7.12	62.67	7.45	19.24	7.01	42.37	7.45	19.73	7.18	62.67	10.04	0.427	-1.7745 to 2.7545	ns
SM	25.38	7.14	50.46	16.72	32.83	5.78	50.46	20.59	20.64	2.11	29.83	16.72	-19.11	-13.450 to -10.930	***
RFM	26.66	5.95	48.82	11.66	22.28	4.42	35.39	11.66	29.45	5.05	48.82	17.40	9.238	5.6372 to 8.7028	***
WHR	0.79	0.06	0.99	0.62	0.83	0.06	0.99	0.74	0.76	0.05	0.89	0.62	-8.029	-0.0872 to -0.0528	***
WHHR	0.46	0.04	0.56	0.36	0.46	0.04	0.56	0.38	0.46	0.04	0.55	0.36	0.000	-0.0127 to 0.0127	ns
WHtR	0.46	0.06	0.74	0.34	0.49	0.06	0.70	0.38	0.44	0.06	0.74	0.34	-5.171	-0.0691 to -0.0309	***
WHT.5R	0.60	0.09	0.97	0.44	0.65	0.08	0.92	0.52	0.56	0.07	0.97	0.44	-7.543	-0.1136 to -0.0664	***
WHt^2R	27.10^{-4}	4.10^{-4}	43.10^{-4}	20.10^{-4}	27.10-4	4.10-4	40.10-4	21.10-4	26.10^{-4}	4.10^{-4}	43.10^{-4}	20.10^{-4}	-1.551	-0.0002 to 0.0000	ns
ABSI	0.07	0.004	0.09	0.06	0.07	0.004	0.09	0.07	0.07	0.004	0.08	0.06	0.000	-0.0013 to 0.0013	ns
BFP	23.51	5.73	52.04	11.46	20.40	5.78	39.10	11.46	25.48	4.73	52.04	18.30	6.106	3.4369 to 6.7231	***
BSA	1.81	0.25	2.64	1.39	2.02	0.21	2.64	1.53	1.67	0.16	2.49	1.39	-11.997	-0.4076 to -0.2924	***
CUN-BAE	24.92	6.84	53.48	8.82	21.50	6.80	42.65	8.82	27.10	5.92	53.48	16.30	5.537	3.6026 to 7.5974	***

*Abbreviations: ABSI – A body shape index; AVI – Abdominal volume index; BAI – Body adiposity index; BFP – Body fat percentage; BMI – Body mass index; BMI√WC – BMI multiplied by the square root of waist circumference; BRI – Body roundness index; BSA – Body surface area (Mosteller); CI – Conicity index; CUN-BAE – The Clinica Universidad de Navarra-body adiposity estimator; FM – Fat mass; HI – Hip index; MAX – maximum; MIN – minimum; nBMI – new BMI; ns – not significant; RFM – Relative fat mass; SD – standard deviation; SM – Skeletal muscle mass; TMI –Triponderal mass index; wBMI – waist-corrected BMI; WHHR – Waist to hip to height ratio; WHR – Waist to hip ratio; WHT.5R – New waist to height ratio; WHt^2R – Waist to the square of the height ratio; WHtR – Waist to height ratio; WWI – Weight-adjusted waist index; $\bar{x}$ – mean; 95% CI – 95% confidence interval; * – $p \leq 0.05$; ** – $p \leq 0.01$; *** – $p \leq 0.001$*

The frequency of cardiometabolic complications

The percentage of participants who were evaluated according to recommended classification criteria (WHO 2000; WHO 2008; Ashwell et al. 2012; Egan and Stevens-Fabry 2015; Brugada et al. 2020) of traditional indicators of cardiometabolic risk like BMI, WC, WHR, WHtR, BP, and HR as participants at potentially increased or high risk is presented in Table 3. According to BMI, preobesity and obesity status were predicted in 19.14% and 5.55% of all participants, respectively. Values of BMI predicted more cases of males with the potential for preobesity and obesity. Waist circumference and WHR were relatively high in the group of females (both in 8.08% females). The risk of central obesity, according to the WHtR index, was predicted predominantly in males (28.57% males). The most frequently confirmed complication in our research group was increased blood pressure (57.41% for sBP, 23.46% for dBP, and 24.07% for both sBP and dBP). The sBP values of all males were above the norm (≥ 120 mmHg). An increase in both blood pressure components (sBP and dBP, respectively), was found in 19.75% of all individuals, with a predominance in females (24.24% of females). Hypertension-risk values of both blood pressure components were confirmed in only 3.03% of females and 6.35% of male participants. Information about heart rate predicted supraventricular tachycardia and increased future cardiovascular risk in 6.79% of individuals (2.02% of females and 14.29% of males). The values of all the mentioned indicators of cardiometabolic complications (BMI + WC + WHR + WHtR + sBP + dBP) were increased above the recommended norms only in 1.23% of participants (1 female and 1 male). From a comprehensive point of view, in males, there were confirmed risk values for the analyzed indicators more often than in females.

Table 3. Cardiometabolic complications of study participants

Indicator	Classification	Interval	All (N = 162)	Male (N = 63)	Female (N = 99)
BMI	Preobesity (increased risk)	25.0 – 29.9 kg/m²	19.14%	34.92%	9.09%
	Obesity class I. (moderate risk)	30.0 – 34.9 kg/m²	3.09%	7.93%	0.00%
	Obesity class II. (severe risk)	35.0 – 39.9 kg/m²	1.23%	1.59%	1.01%
	Obesity class III. (very severe risk)	≥40 kg/m²	1.23%	1.59%	1.01%
WC	High risk	♀ ≥80 cm ♂ ≥ 94 cm	6.79%	11.11%	4.04%
	Very high risk	♀ ≥88 cm ♂ ≥102 cm	7.41%	6.35%	8.08%
WHR	Moderate risk	♀ 0.81 – 0.85 ♂ 0.96 – 1.0	7.41%	4.76%	9.09%
	High risk	♀ > 0.85 ♂ > 1	4.94%	0.00%	8.08%
WHtR	Central obesity (increased risk)	≥0.5	16.67%	28.57%	9.09%

Indicator	Classification	Interval	All (N = 162)	Male (N = 63)	Female (N = 99)
sBP	Prehypertension (increased risk)	120 – 139 mmHg	52.47%	92.06%	27.27%
	Hypertension (high risk)	≥140 mmHg	4.94%	7.94%	3.03%
dBP	Prehypertension (increased risk)	80 – 89 mmHg	16.05%	7.94%	21.21%
	Hypertension (high risk)	≥90 mmHg	7.41%	7.94%	7.07%
sBP+dBP	Prehypertension (increased risk) sBP/dBP	120 – 139/80 – 89 mmHg	19.75%	12.70%	24.24%
	Hypertension (high risk)	≥140/≥90 mmHg	4.32%	6.35%	3.03%
HR	SVT (increased risk)	≥100 bpm	6.79%	14.29%	2.02%
BMI+WC+ WHR+WHtR+ sBP+dBP	Increased risk	All values above the norm	1.23%	1.59%	1.01%

Abbreviations: BMI – Body mass index; dBP – diastolic blood pressure; N – number; WHR – Waist to hip ratio; WHtR – Waist to height ratio; HR – heart rate; sBP – systolic blood pressure; SVT – supraventricular tachycardia, WC – waist circumference; ♀ – female; ♂ – male

Heart rate and blood pressure correlations with analyzed indicators

The relationship of anthropometric measures, indices, and ratios versus HR and BP was confirmed by correlation analyses in all participants and in six different subgroups (males and females according to sex; obesity$^+$ and obesity$^-$ according to BMI; hypertension$^+$ and hypertension$^-$ according to blood pressure). The correlation analysis confirmed statistical significance in several indices and ratios, especially with BP (Table 4 and Table 5). From the total number of 567 calculated correlation coefficients, 38.80% cases were found to be significant at $p \le 0.05$. Our results highlight the positive correlation across the vast majority of indicators. A significant inverse correlation was predicted only in the cases of NC and HR in the group of all participants; in the cases of NC, CUN-BAE, BFP, and HR in the obesity$^-$ group of participants; and in the cases of Wt, WC, HC, NC, BSA, SM, and HR in the group of participants from the subgroup hypertension$^+$. According to our data, there was a predominantly weak and moderate correlation. Only 0.53% of coefficients indicated a strong positive correlation relationship ($r \ge 0.5$), namely in the index CUN-BAE and HR and also in the cases of FM, CUN-BAE, and dBP, but only in the obesity$^+$ subgroup. The strongest correlation from our results was observed in the obesity$^+$ subgroup in the cases of FM and dBP ($r = 0.5372$; $p \le 0.001$), CUN-BAE and HR ($r = 0.5109$; $p \le 0.001$) and also CUN-BAE and dBP ($r = 0.5065$; $p \le 0.001$).

The vast majority of the indicators that we analyzed were significantly correlated with dBP in almost all subgroups. Only in the participants without obesity and in the participants with potential for hypertension (hypertension$^+$ subgroup) were the vast majority of indicators significantly correlated with sBP. The heart rate was the least significantly correlated parameter, with statistical significance observed only in 3.88% of all 567 correlation coefficients. A nonsignificant relationship between all the analyzed indicators and HR was observed in both sex-based subgroups and in the hypertension$^-$ subgroup.

Table 4. Correlation analyses in the whole research group and in both sexes

	All (N = 162)			Male (N = 63)			Female (N = 99)		
	HR	sBP	dBP	HR	sBP	dBP	HR	sBP	dBP
Wt	ns	0.3851***	0.2298**	ns	0.2634*	0.2482*	ns	0.2503*	0.3865***
WC	ns	0.3603***	0.2606***	ns	ns	0.3233**	ns	0.2176*	0.3629***
HC	ns	0.3028***	0.1964*	ns	ns	ns	ns	ns	0.2926**
NC	-0.1697*	0.3036***	ns	ns	ns	ns	ns	ns	ns
BMI	ns	0.3406***	0.3102***	ns	0.2638*	0.3054*	ns	0.2325*	0.3925***
nBMI	ns	0.3131***	0.325***	ns	0.2559*	0.3124*	ns	0.2224*	0.3858***
wBMI	ns	0.3487***	0.3037***	ns	0.2934*	0.3505**	ns	0.2109*	0.3659***
BMI√WC	ns	0.3497***	0.3069***	ns	0.2811*	0.3337**	ns	0.2234*	0.3811***
TMI	ns	0.2783***	0.3341***	ns	ns	0.3161*	ns	0.2103*	0.3756***
WWI	ns	ns	0.2036**	ns	ns	0.2883*	ns	ns	ns
AVI	ns	0.3496***	0.2647***	ns	0.2629*	0.3344**	ns	ns	0.3408***
BAI	ns	ns	0.2479**	ns	ns	ns	ns	ns	0.2596**
BRI	ns	0.2934***	0.3112***	ns	ns	0.3656**	ns	ns	0.3322***
CI	ns	0.2435**	0.1787*	ns	ns	0.2674*	ns	ns	0.2005*
HI	ns	ns	ns	ns	ns	ns	ns	ns	0.2063*
FM	ns	0.2264**	0.3637***	ns	0.2635*	0.3151*	ns	0.2441*	0.3924***
SM	ns	0.3837***	ns	ns	0.2622*	ns	ns	0.2561*	0.3555***
RFM	0.1802*	ns	0.2946***	ns	ns	0.3168*	ns	0.2072*	0.3549***
WHR	ns	0.2681***	0.2199**	ns	ns	0.3221*	ns	ns	0.2408*
WHHR	ns	ns	0.2397**	ns	ns	0.3309**	ns	ns	ns
WHtR	ns	0.3068***	0.3115***	ns	ns	0.3539**	ns	ns	0.3444***
WHT.5R	ns	0.3413***	0.2880***	ns	ns	0.3431**	ns	0.2068*	0.3566***
WHt²R	ns	0.1939*	0.3184***	ns	ns	0.3534**	ns	ns	0.3066**
ABSI	ns	ns	ns	ns	ns	ns	ns	ns	ns
BFP	0.155*	ns	0.3127***	ns	ns	0.2944*	ns	0.19992*	0.3634***
BSA	ns	0.3806***	0.1821*	ns	ns	ns	ns	0.2493*	0.3689***
CUN-BAE	ns	ns	0.3175***	ns	ns	0.2606*	ns	0.2260*	0.3860***

Abbreviations: ABSI – A body shape index; AVI – Abdominal volume index; BAI – Body adiposity index; BFP – Body fat percentage; BMI – Body mass index; BMI√WC – BMI multiplied by the square root of waist circumference; BRI – Body roundness index; BSA – Body surface area (Mosteller); CI – Conicity index; CUN-BAE – The Clinica Universidad de Navarra-body adiposity estimator; dBP – diastolic blood pressure; FM – Fat mass; HC – hip circumference; HI – Hip index; HR –heart rate; MAX – maximum; MIN – minimum; nBMI – new BMI; NC – neck circumference; ns – not significant; RFM – Relative fat mass; sBP – systolic blood pressure; SD – standard deviation; SM – Skeletal muscle mass; TMI –Triponderal mass index; wBMI – waist-corrected BMI; WC – waist circumference; WHHR – Waist to hip to height ratio; WHR – Waist to hip ratio; WHT.5R – New waist to height ratio; WHt²R – Waist to the square of the height ratio; WHtR – Waist to height ratio; Wt – body weight; WWI – Weight-adjusted waist index; * *– $p < 0.05$; ** – $p < 0.01$; *** – $p < 0.001$*

Table 5. Correlation analyses in the participants according to obesity and hypertension status

	Obesity^{+} (N = 41)			Obesity^{-} (N = 121)			Hypertension $^{+}$ (N = 97)			Hypertension^{-} (N = 65)		
	HR	sBP	dBP	HR	sBP	dBP	HR	sBP	dBP	HR	sBP	dBP
Wt	ns	0.3542*	0.3379*	ns	0.2200*	ns	-0.2482*	0.3213***	ns	ns	0.4028***	0.3995***
WC	ns	ns	0.3612*	ns	0.2309*	ns	-0.2139*	0.3477***	ns	ns	0.3214**	0.3287**
HC	0.3439*	ns	0.3277*	ns	ns	ns	-0.2341*	0.2396*	ns	ns	0.2869*	0.2822*
NC	ns	ns	ns	-0.2008*	ns	ns	-0.3269**	0.3573***	ns	ns	0.2572*	ns
BMI	0.4232**	ns	0.4798**	ns	ns	ns	ns	0.3395***	ns	ns	0.3098*	0.3679**
nBMI	0.4374**	ns	0.4909**	ns	ns	ns	ns	0.3334***	0.2531*	ns	0.2630*	0.3413**
wBMI	0.3522*	ns	0.4389**	ns	0.1969*	ns	ns	0.3339***	ns	ns	0.3447**	0.3796**
BMI√WC	0.3776*	ns	0.4569**	ns	ns	ns	ns	0.3397***	ns	ns	0.3336**	0.3768**
TMI	0.4418**	ns	0.4914**	ns	ns	ns	ns	0.3215**	0.3096**	ns	ns	0.3048*
WWI	ns	ns	ns	ns	ns	ns	ns	0.2189*	0.2715**	ns	ns	ns
AVI	ns	ns	0.3677*	ns	0.2153*	ns	ns	0.3316***	ns	ns	0.3327**	0.3400**
BAI	0.4495**	ns	0.4184**	ns	ns	ns	ns	ns	0.3380***	ns	ns	ns
BRI	ns	ns	0.4015**	ns	ns	ns	ns	0.3194**	0.2732**	ns	ns	0.2904*
CI	ns	ns	ns	ns	0.1882*	ns	ns	0.2692**	ns	ns	ns	ns
HI	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
FM	0.4948**	ns	0.5372***	ns	ns	ns	ns	ns	0.3245**	ns	ns	0.3655**
SM	ns	ns	ns	ns	0.2939**	ns	-0.3080**	0.3301***	ns	ns	0.4243***	0.3504**
RFM	0.3874*	ns	0.4249**	ns	ns	ns	0.1998*	ns	0.4782***	ns	ns	ns
WHR	ns	ns	ns	ns	0.2380**	ns	ns	0.3419***	ns	ns	ns	ns
WHHR	ns	ns	ns	ns	ns	0.1994*	ns	0.2408*	0.3624***	ns	ns	ns
WHtR	ns	ns	0.4016**	ns	ns	ns	ns	0.3341***	0.2567*	ns	ns	0.2842*
WHT.5R	ns	ns	0.3895*	ns	0.2069*	ns	ns	0.3457***	ns	ns	0.2831*	0.3144*
WHt^2R	ns	ns	0.3920*	ns	ns	ns	ns	0.2840**	0.3837***	ns	ns	ns
ABSI	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
BFP	0.4953***	ns	0.4943**	ns	-0.2412**	ns	ns	ns	0.4221***	ns	ns	ns
BSA	ns	0.3461*	ns	ns	0.2222*	ns	-0.3048**	0.3009**	ns	ns	0.4013***	0.3768**
CUN-BAE	0.5109***	ns	0.5065***	ns	-0.2051*	ns	ns	ns	0.4094***	ns	ns	ns

Abbreviations: ABSI – A body shape index; AVI – Abdominal volume index; BAI – Body adiposity index; BFP – Body fat percentage; BMI – Body mass index; BMI√WC – BMI multiplied by the square root of waist circumference; BRI – Body roundness index; BSA – Body surface area (Mosteller); CI – Conicity index; CUN-BAE – The Clinica Universidad de Navarra-body adiposity estimator; dBP – diastolic blood pressure; FM – Fat mass; HC – hip circumference; HI – Hip index; HR –heart rate; MAX – maximum; MIN – minimum; nBMI – new BMI; N – number; NC – neck circumference; ns – not significant; RFM – Relative fat mass; sBP – systolic blood pressure; SD – standard deviation; SM – Skeletal muscle mass; TMI –Triponderal mass index; wBMI – waist-corrected BMI; WC – waist circumference; WHHR – Waist to hip to height ratio; WHR – Waist to hip ratio; WHT.5R – New waist to height ratio; WHt^2R – Waist to the square of the height ratio; WHtR – Waist to height ratio; Wt – body weight; WWI – Weight-adjusted waist index; * – $p \le 0.05$; ** – $p \le 0.01$; *** – $p \le 0.001$

Key results from correlation analysis after categorization of anthropometric indicators into three groups (indices and ratios based on body height and weight, indices and ratios based on waist or hip circumferences, and indices and ratios based on BMI index calculation) are presented in Table 6. All three groups of indices and ratios that were calculated in our study were predominantly significantly correlated with BP rather than HR, and a greater number of significant correlation coefficients were calculated in the whole research group (55.56%) than in the male and female subgroups (34.57% and 45.68%). The analyzed indicators were significantly correlated with obesity and hypertension status more frequently than in subgroups without these complications.

Table 6. Key results of correlation analysis after division of the analyzed indices and ratios

Status	Indices and ratios based on body height and weight	Indices and ratios based on waist or hip circumferences	Indices and ratios based on BMI calculation
Sex	• a higher correlation with sBP in whole research group than in sex-based subgroups; • a higher correlation with dBP in females compared to males and to the whole research group;	• not significantly correlated with HR in the sex-based subgroups; • less significantly correlated with sBP in the sex-based subgroups;	• more significantly and closely correlated with BP components in females than in males; • not significantly correlated with HR in the sex-based subgroups;
Obesity	• significantly correlated with HR only in the obesity$^+$ subgroup; • the highest correlation coefficients with the HR and dBP in the obesity$^+$ subgroup; • almost completely not significantly correlated in the obesity$^-$ group;	• the highest correlation coefficients in the obesity$^+$ subgroup; • no significant correlation with sBP;	• the highest correlation coefficients with the HR and dBP in the obesity$^+$ subgroup • not significantly correlated with the HR and dBP in the obesity$^-$ group;
Hypertension	• more significantly correlated with sBP in the hypertension$^+$ subgroup;	• more correlated with both components of BP in the hypertension$^+$ subgroup;	• relatively low number of significant correlations; • the highest correlation coefficient in relation to HR;
Informative value	• the WWI index had the lowest informative value; • the highest correlation in the case of TMI and dBP;	• the HI index had the lowest informative value; • the highest correlation in the case of FM and dBP;	• the ABSI index without any calculated significant correlation in any subgroup; • The CUN-BAE the highest correlation with HR and dBP in the hypertension$^+$ subgroup;

Abbreviations: ABSI – A body shape index; BMI – Body mass index; BP – blood pressure; CUN-BAE – The Clinica Universidad de Navarra-body adiposity estimator; dBP – diastolic blood pressure; FM -Fat mass; HI – Hip index; HR – heart rate; sBP – systolic blood pressure; TMI – Triponderal mass index; WWI – Weight-adjusted waist index

Discussion

The purpose of the current study was to analyze anthropometric indicators in the context of cardiometabolic health based on an examination of whether physiologic characteristics, such as heart rate and blood pressure, five anthropometric measurements, and 23 indices and ratios could be useful in the noninvasive prediction of cardiometabolic risk status in the group of 162 Eastern Slovakia participants of both sexes with a mean age of 20.78±2.22 years. Several studies have reported that many anthropometric indicators based on measurements of body weight and height, waist and hip circumferences reflect cardiometabolic status in different age, sex, and ethnic subgroups and may be associated with each other or with other health indicators (Fu et al. 2014; Tran et al. 2018; Padilla et al. 2021; Wu et al. 2021; Casadei and Kiel 2022; Minetto et al. 2022). On the other hand, our results are in line with other studies showing that the frequency of cardiometabolic complications is heterogeneous in various research groups (Mladenova 2019; Nişancı Kılınç et al. 2019; Mangalavalli et al. 2021; Lahole et al. 2022).

From the point of view of all the analyzed indicators of cardiometabolic complications in our study, male participants were evaluated as a potentially higher-risk subgroup, and increased values of sBP were recorded in all males. The results of this study showed that especially values of BMI, WC, WHR, WHtR, sBP, and dBP, of some participants may be at potentially increased or high cardiometabolic risk and should be monitored in the future. Preobesity and obesity status, according to BMI values, were predicted for 19.14% and 5.55% of all participants, respectively. Waist circumference and WHR were increased in 14.20% and 12.35% of all participants, respectively, and an increased risk of central obesity according to the WHtR index was predicted in 16.67% of participants. Prehypertension, according to blood pressure values, was observed in 19.75% of individuals, with a predominance in females, and hypertension was observed in 4.32% of individuals, especially in males. The risk of supraventricular tachycardia was evaluated at 6.79%.

Lahole et al. (2022), in their cross-sectional study of 1,000 students with a mean age of 21.3±2.0 years, calculated increased risk mean values of BMI, WC, and WHR indices. The mean values of sBP and dBP were more favorable than the values in our research group (115.7±12.6 and 73.6±8.9 mmHg vs. 121.72±11.65 and 76.09 ±9.85 mmHg in our research group). A comparison of the mean values of the analyzed indices in both sexes did not result in significant results. The highest percentage of students with obesity status was predicted by WHR (57.30% of students), and the lowest percentage was predicted by NC (8.4% of students). The prevalence of hypertension and obesity was higher in the Lahole et al. (2022) research group compared to the results of our study and varies according to anthropometric indices.

Similarly to the results of our study, the mean values of BMI, neck circumference, and WHtR were higher in males in the Nişancı Kılınç et al. (2019) study of 4873 university students with a mean age of 20.58±1.86 years. Their results indicated that more male students were at increased or high risk of obesity.

In the Mladenova (2019) study the prevalence of anthropometric and cardiovascular risk factors in a group of 386 Bulgarian students with a mean age of 21.20±2.4 years was analyzed. This study showed that mean values of the analyzed characteristics were higher in males, and these differences were statistically significant. Overweight and obesity, according to BMI, were predicted in 26.94% of participants and more frequently in males. Risk values of WHtR were predicted at 20.1% and prehypertension and hypertension were predicted according to blood pressure in 33.2% and 5.6% of cases, respectively (Mladenova 2019).

A study by Mangalavalli et al. (2021) analyzed 150 young students for blood pressure and routine anthropometric measurements, including the calculation of BMI in the context of obesity and prehypertension estimation. According to values of blood pressure, prehypertension was observed in 33.33% of students, predominantly females. Except for traditional indicators of cardiometabolic risk (BMI and waist circumference) determining the level and distribution of obesity, the neck circumference was a promising indicator, predicting obesity in more than half of the research group. Pearson's correlation analysis showed a significant, strong positive correlation between NC and systolic and diastolic blood pressure.

In our study, NC was correlated with heart rate and blood pressure, but not in all analyzed subgroups. According to our results, NC was better correlated with sBP in the subgroup of participants with the potential for hypertension (hypertension^{+}) than in the subgroup with obesity (obesity^{-}).

Anthropometric markers of obesity such, such as weight, height, WC, HC, BMI, WHR, and NC were also analyzed in the Hingorjo et al. (2012) study of 150 participating students aged 18 to 20 years. The mean values of the analyzed indicators were higher in males, except for hip circumference. In this study statistically significant differences between male and female mean values of NC and WHR were calculated at the $p \leq 0.001$ level. In contrast, the authors of the the Hingorjo et al. (2012) study did not report significant results after comparing BMI, WC, and HC mean values. A similar percentage of participants as in our research were categorized as overweight or obese according to BMI values.

The potential of using anthropometric indicators (BMI, WC, WHtR, WHR, new BMI, BAI, CUN-BAE, ABSI) as predictors of cardiometabolic risk was analyzed in a research group consisting of 550 British young individuals aged between 18 and 25 years (Amirabdollahian and Haghighatdoost 2018). The results showed that indicators based on body weight were in stronger association with measurements of body fat than indices related to body shape. According to their results, the authors presented the WHtR index as the best indicator of cardiometabolic risk, which together with WC had a better diagnostic capability for identifying cardiometabolic risk in young adults (Amirabdollahian and Haghighatdoost 2018).

Another study focused on the anthropometric indices HI, ABSI, and WHtR in 3844 Spanish Caucasian individuals reported that ABSI and WHtR but not HI were associated with high cardiovascular risk (Corbatón-Anchuelo et al. 2021).

Our study showed that of the three categories of indices and ratios, the ones that were based on body height and weight were more strongly correlated with blood pressure compared to indices and ratios based on waist and hip circumferences or based on the calculation of BMI. The vast majority of the analyzed indicators were significantly more correlated with blood pressure compared to heart rate in almost all subgroups. The indicators were significantly correlated with obesity and hypertension status more frequently compared to status without these complications. The strongest correlation regarding HR and dBP was observed in the subgroup of participants with obesity. A stronger correlation was observed in the obesity^{+} subgroup regarding FM in relation to dBP and CUN-BAE in relation to both HR and dBP. The ABSI index had the lowest informative value as the correlation values were nonsignificant in all of the analyses. For comparison, amongst all of the indices analyzed in 550 British young individuals, CUN-BAE could be a new indicator of adiposity, and ABSI had the weakest correlation with adiposity (Amirabdollahian and Haghighatdoost 2018). In addition, Dominguez et al. (2021) demonstrated that increased adiposity estimated according to CUN-BAE has a predictive value for incident hypertension. The researchers of this study reported that a 2-unit increase in the CUN-BAE index values increased hypertension risk by 27% and 29%, respectively, according to sex (Dominguez et al. 2021). Another study showed a significant association between WC and sBP in females and WC and dBP in males, but other anthropometric indicators such as BMI and WHtR were nonsignificant in relation to blood pressure (Mladenova 2019). In a study by Chaudhary et al. (2019) BMI, WC, and WHR values increased in a linear relationship with blood pressure. According to the study by Gutema et al. (2020) the indicators BMI, WC, WHR, and WHtR were useful predictors of high blood pressure.

Conclusion

In recent years a lot of indicators reported in research studies have proven to be more useful in the association with cardiometabolic complications. Our study, based on the analysis of indicators, including 23 anthropometric indices and ratios, confirmed that from a total number of 567 calculated correlation coefficients, 38.80% of cases were with $p \leq 0.05$. All analyzed indices and ratios were significantly correlated, predominantly with blood pressure components rather than heart rate, especially among participants with the potential for disease complications. To conclude, the quantitative measurements of the body, calculated indices and ratios are non-invasive and useful indicators, although they may be at different levels of association and clinical significance for various conditions. Thus, some of the indicators may be standardly used in the early diagnostic process for monitoring cardiovascular health and risk stratification of patients.

Conflict of interest statement

Authors declared no conflict of interests.

Authors' contribution

All authors contributed to the planning of the research, discussed the problem, and contributed to the final manuscript. MZ supervised the study and was a major contributor to writing the manuscript, and MZ was also the corresponding author. JG, HV, and MŠ were responsible for data obtaining and anthropological indices and ratio calculations. EP, SK, and MMB were responsible for statistical analyses, language corrections, and data interpretation.

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