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Research article

ANTHROPOMETRIC INDICES AND BIOIMPEDANCE BODY COMPOSITION AS ONTOGENETIC INDICATORS TO DESCRIBE RISK OF OBESITY

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The body mass index does not distinguish body fat mass from fat-free mass and does not capture changes in these parameters. The aim of this study was to establish an association between anthropometric indexes and bioimpedance indicators with age-specific obesity on the example of male population in the Magadan oblast. To achieve it, we examined 586 males who lived in the Magadan oblast by using conventional methods for assessment of physical development. The ROC analysis was performed and the area under the ROC curve (AUC) was measured.

The analysis of the obtained research data established a significant decrease in FFMI values with age (from young males to elderly ones) together with growing FMI, FMI/FFMI ratio, total body fat and the waist-to-hip ratio. To determine an optimal BMI value as an indicator eligible to diagnose obesity, a ROC-curve was built to describe a relationship between BMI and FMI/FFMI value < 0.4 cu. It showed that when BMI ranged between 22 kg/m^2 and 25.0 kg/m^2 in young males, bioimpedance values corresponded to the physiological norm; in the early maturity group, the optimal BMI cut-off point for diagnosing obesity was 26.5 kg/m^2; the optimal BMI range in the 2nd maturity group was 24.0–27.5 kg/m^2. It is noteworthy that the ROC-analysis turned out to have no predictive significance among elderly men; this indicates that BMI is hardly eligible for being used as an indicator of obesity risk in this period of ontogenesis.

Classical BMI ranges cannot be considered a clear indicator to diagnose obesity among males in the Magadan oblast whereas indicators obtained by bioimpedance analysis (FMI/FFMI ratios) can be used as relevant indicators when assessing risks of obesity and sarcopenia in the analyzed population.

Keywords: *BMI, bioimpedance analysis, anthropometric indices, age dynamics, physical development, male population, obesity, ROC-analysis.*

Nowadays, prevalence of obesity has reached an epidemic level and this poses a serious threat for population health in both developed and developing countries [1]. Obesity is considered a principal public health concern and ranked as the fifth foremost reason for death globally; another alerting fact is that obesity and overweight also lead to further health concerns and contribute to numerous chronic diseases, including cancers, diabetes, metabolic syndrome, cardiovascular diseases, hypercholesterolemia, and diseases of the musculoskeletal system [2–4]. Hence, obesity and its consequences affect quality of life, decrease work efficiency and lead to greater expenditure on healthcare [5].

At present, the body mass index (BMI) is widely used in clinical practices, especially for determining whether a patient has overweight or obesity [6, 7]. Although BMI is a rather informative indicator and correlates well with a growth in fat mass, its main drawback is that it does not differentiate precisely between fat and muscle mass and is

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also unable to capture the body composition and exact localizations of fat tissues. Moreover, it is a well-known fact that relative total fat to muscle mass ratios tend to differ significantly in people with the same BMI [8, 9]. This low diagnostic sensitivity of BMI results in impossibility to use it for identifying the body composition and, consequently, detecting people with so called normal weight obesity (hidden obesity). The latter is defined as a high fat percentage in the body under BMI values being within the reference range [10], which, in its turn, can be a risk of diseases associated with 'common' obesity [11, 12].

Previous studies have revealed that various components in the body composition can play quite the opposite roles as risk or protective health factors. Thus, in general, fat mass creates elevated risks of cardiovascular diseases whereas muscle mass, on the contrary, is a protective factor as regards chronic non-communicable diseases [13]. Greater muscle mass may have a protective impact on high TC, high LDL cholesterol, hyperglycemia, and insulin resistance. This finding suggests that the "obesity paradox" may be partly explained by high muscle mass [14]. Chronic diseases associated with cardiometabolic dysfunction (insulin resistance, metabolic syndrome, diabetes mellitus, hypertension, dyslipidemia, and coronary artery disease) have been shown to be quite modifiable by changes in diets and lifestyles. Having an optimal body composition is a major modifiable risk factor; it is primarily achieved by reducing obesity and maintaining a proper ratio between fat mass and muscle mass [15].

Therefore, it is necessary to use alternative methods instead of BMI estimation to diagnose risks of obesity and metabolic disorders. Bioimpedance analysis is one of such methods. It is used in clinical diagnostics to assess the body composition. The method is simple, cheap, non-invasive and effective and allows estimating physical development as well as a wide range of physiological and morphological characteristics of the body [16, 17]. In addition to that, there are some indices such as fat-to-lean mass ratio, waist-to-hip ratio and others, which are recommended for assessing risks of obesity, sarcopenia and sarcopenic or abdominal obesity. Wide use of such methods and indices in clinical practice should result in establishing new criteria for obesity diagnostics, which will also be sex-dependent among adult population. A measured fat percentage in the body should become a conventional indicator in effective diagnostics as well as in obesity screening [18].

Therefore, the aim of this study was to assess how informative the body mass index was when assessing obesity among males in the Magadan oblast in the ontogenetic aspect based on investigating a combination of BMI and such indices as fat-free (FFMI) and fat (FMI) mass indices as well as their relationships with the total fat in the body and the waist-to-hip ratio.

Materials and methods. We analyzed 586 case histories of male patients provided by the Magadan Regional Center for Medical Prophylaxis. All patients lived in the Magadan oblast. Prior to inclusion in the study, each patient provided his informative voluntary consent; all patients' data were depersonalized prior to analysis.

The analyzed sample was divided into four groups in accordance with the age difference as of 1965: the first group was made of young males (158 people); the second one, men in early (first) maturity (154 people); the third one, men in the second maturity (163 people); the fourth group included elderly males (111 people). Then, each group was divided as per conventional BMI estimates where its value < 18.5 kg/m^2 was considered underweight; 18.5–24.9 kg/m^2, normal weight; 25–29.9 kg/m^2, overweight, and BMI values > 30 kg/m^2 meant obesity [19].

The following indices were input into the research database: height (cm), weight (kg), lean mass as per Durnin – Womersley (kg), fat mass as per Durnin – Womersley (kg), fat (%) (identified with ABC-02 MEDASS bioimpedance analyzer of metabolic processes and body composition, Russia), as well as waist-to-hip ratio (W/H, cu). Measurements of fat and fat-free mass were used to calculated fat mass index (FMI = fat mass index, kg/height (m)^2, kg/m^2) and fat-free mass index (FFMI = fat-free (lean) mass index, kg/height(m)^2, kg/m^2). FMI values ≥ 8.3 cu were considered high fat mass and FFMI values ≤ 17.4 cu were considered low lean mass [20].

We calculated the FMI / FFMI ratio as well, which is ranked as metabolic health if its value is < 0.4 cu; obesity, if it is 0.4–0.8 cu; values > 0.8 cu mean sarcopenic obesity [20]. When interpreting the waist-to-hip (W/T) ratio, we considered its value > 0.90 cu as an indicator of abdominal obesity in the examined males.

A fat percentage in the body higher than its reference range was classified as follows according to the WHO recommendations: more than 19 % for young males, more than 21 % for men in the first and second maturity age, and more than 24 % for elderly males [21, 22].

The results were statistically analyzed with Statistica 7.0 applied software. Distribution of the measured variables was checked for normality by using the Shapiro – Wilk test. The results are given as mean and its standard error ($M \pm m$). We applied parametric one-factor disperse analysis (ANOVA) to perform multiple comparisons between normally distributed samples; next, we used a post-hoc Scheffe test to establish any significant difference between specific groups. The ROC analysis was performed and the area under the ROC curve (AUC) was measured. The ROC analysis was used to estimate whether BMI or FMI/FFMI made it possible to identify obesity in various age groups. Predictive capability was quantified through an area under ROC curve (AUC) where higher values indicated greater predictive capability[1]. Critical significance (p) was taken at 0.05; 0.01; 0.001.

Results and discussion. The analyzed indicators, calculated indices and statistical differences inside age groups can be found in Table 1. Table 2 provides significant differences between the analyzed age groups. The provided percentage of people with different BMI values indicates there is an age-specific decline in a number of people with underweight and normal weight (from young males to elderly ones). Hence, in the ontogenetic aspect, we can state that a number of people with overweight and obesity is growing with age among males in the Magadan oblast. It is noteworthy that overweight people prevail over obese ones in the first and second maturity group whereas percentages of overweight and obese men are practically the same among elderly males. Among young males, underweight, normal weight and overweight are typical though obesity is also detected, the percentage being as follows: 9 % / 72 % / 13 % / 6 % respectively; people with normal body weight apparently prevail in this age group. In the first maturity age, the percentages of normal weight and overweight are practically the same (3 % / 42 % / 43 % 12 %); obesity grows in the second maturity age (0 % / 26 % / 38 % / 36 %). The greatest number of males with overweight and obesity was identified in the elderly age group (0 % / 15 % / 45 % / 40 %).

Low FFMI values identified in young underweight males and males in the first maturity group indicate low muscle mass; these groups have no significant differences as per all analyzed indicators. The same situation occurs in the second maturity group and elderly people with normal body weight; it is worth noting that males in the second maturity group tend to have an elevated fat percentage and high FMI/FFMI values in elderly males indicate they have obesity even if their BMI appears to be normal.

We should also note that young males with overweight and obesity tend to have fat percentages above their reference range. Overweight males in the first maturity group have high FMI/FFMI values and fat percentages; obese men tend to have abdominal obesity against elevated FMI, FMI/FFMI values and total fat percentage, which confirms obesity in this age group.

Males in the second maturity group and elderly males, with BMI values indicating both overweight and obesity, tend to have elevated FMI, FMI/FFMI, W/H values and total fat percentage, which means marked obesity in each group. It is noteworthy that we have not identified any statistical differences between these two age groups as per all analyzed indicators under normal weight or obesity.

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[1] Swets J.A. Measuring the accuracy of diagnostic systems. *Science*, 1988, vol. 240, no. 4857, pp. 1285–1293. DOI: 10.1126/science.3287615

Table 1

Analyzed indicators, their calculated indices and differences inside the analyzed groups, ($M \pm m$)

	Underweight (1)	Normal weight (2)	Overweight (3)	Obesity (4)	1–2	2–3	3–4	1–3	2–4	1–4
Young males										
N, people	15 (9 %)	113 (72 %)	21 (13 %)	9 (6 %)						
BMI, kg/m^2	17.7 ± 0.2	21.7 ± 0.2	26.9 ± 0.3	33.4 ± 0.7	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
FFMI, kg/m^2	15.3 ± 0.3	18.9 ± 0.8	20.7 ± 0.3	25.3 ± 0.3	$p < 0.001$	$p < 0.05$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
FMI, kg/m^2	2.4 ± 0.2	3.9 ± 0.2	6.1 ± 0.3	7.3 ± 0.7	$p < 0.001$	$p < 0.001$	$p = 0.13$	$p < 0.001$	$p < 0.001$	$p < 0.001$
FM/FFM, kg/m^2	0.16 ± 0.02	0.21 ± 0.01	0.30 ± 0.02	0.29 ± 0.03	$p < 0.05$	$p < 0.001$	$p = 0.76$	$p < 0.001$	$p < 0.01$	$p < 0.001$
W/H, cu	0.76 ± 0.02	0.79 ± 0.00	0.82 ± 0.01	0.84 ± 0.03	$p = 0.23$	$p < 0.01$	$p = 0.59$	$p < 0.01$	$p < 0.05$	$p < 0.05$
Fat percentage, %	13.5 ± 1.4	17.2 ± 0.6	22.8 ± 0.9	22.1 ± 1.6	$p < 0.05$	$p < 0.001$	$p = 0.73$	$p < 0.01$	$p < 0.01$	$p < 0.001$
First maturity										
	Underweight (1)	Normal weight (2)	Overweight (3)	Obesity (4)	1–2	2–3	3–4	1–3	2–4	1–4
N, people	5 (3 %)	64 (42 %)	66 (43 %)	19 (12 %)						
BMI, kg/m^2	17.6 ± 0.3	22.4 ± 0.2	27.3 ± 0.2	33.0 ± 0.6	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
FFMI, kg/m^2	15.3 ± 0.7	17.6 ± 0.2	19.5 ± 0.2	22.4 ± 0.5	$p < 0.01$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
FMI, kg/m^2	2.2 ± 0.5	4.9 ± 0.2	7.7 ± 0.2	10.7 ± 0.5	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
FM/FFM, kg/m^2	0.15 ± 0.04	0.28 ± 0.01	0.40 ± 0.01	0.48 ± 0.02	$p < 0.01$	$p < 0.001$	$p < 0.01$	$p < 0.001$	$p < 0.001$	$p < 0.001$
W/H, cu	0.80 ± 0.03	0.80 ± 0.01	0.86 ± 0.01	0.92 ± 0.01	$p = 0.93$	$p < 0.001$	$p < 0.001$	$p = 0.09$	$p < 0.001$	$p < 0.001$
Fat percentage, %	12.9 ± 2.9	21.2 ± 0.8	28.0 ± 0.7	32.2 ± 1.1	$p < 0.01$	$p < 0.001$	$p < 0.01$	$p < 0.001$	$p < 0.001$	$p < 0.001$
Second maturity										
	Underweight (1)	Normal weight (2)	Overweight (3)	Obesity (4)	1–2	2–3	3–4	1–3	2–4	1–4
N, people	0 (0 %)	44 (26 %)	60 (38 %)	59 (36 %)						
BMI, kg/m^2	–	22.9 ± 0.2	27.1 ± 0.2	34.4 ± 0.5	–	$p < 0.001$	$p < 0.001$	–	$p < 0.001$	–
FFMI, kg/m^2	–	16.5 ± 0.2	18.3 ± 0.2	20.9 ± 0.4	–	$p < 0.001$	$p < 0.001$	–	$p < 0.001$	–
FMI, kg/m^2	–	6.4 ± 0.3	9.1 ± 0.4	12.7 ± 0.4	–	$p < 0.001$	$p < 0.001$	–	$p < 0.001$	–
FM/FFM, kg/m^2	–	0.39 ± 0.02	0.50 ± 0.02	0.62 ± 0.02	–	$p < 0.001$	$p < 0.001$	–	$p < 0.001$	–
W/H, cu	–	0.85 ± 0.01	0.91 ± 0.01	0.97 ± 0.01	–	$p < 0.001$	$p < 0.001$	–	$p < 0.001$	–
Fat percentage, %	–	27.5 ± 1.0	33.5 ± 1.2	36.5 ± 1.0	–	$p < 0.001$	$p < 0.05$	–	$p < 0.001$	–
Elderly males										
	Underweight (1)	Normal weight (2)	Overweight (3)	Obesity (4)	1–2	2–3	3–4	1–3	2–4	1–4
N, people	0 (0 %)	17 (15 %)	50 (45 %)	44 (40 %)						
BMI, kg/m^2	–	22.7 ± 0.5	27.4 ± 0.2	33.7 ± 0.6	–	$p < 0.001$	$p < 0.001$	–	$p < 0.001$	–
FFMI, kg/m^2	–	16.2 ± 0.3	17.7 ± 0.2	21.2 ± 0.5	–	$p < 0.001$	$p < 0.001$	–	$p < 0.001$	–
FMI, kg/m^2	–	6.6 ± 0.4	9.6 ± 0.2	12.6 ± 0.3	–	$p < 0.001$	$p < 0.001$	–	$p < 0.001$	–
FM/FFM, kg/m^2	–	0.41 ± 0.03	0.55 ± 0.02	0.61 ± 0.02	–	$p < 0.001$	$p < 0.05$	–	$p < 0.001$	–
W/H, cu	–	0.87 ± 0.01	0.93 ± 0.01	0.98 ± 0.01	–	$p < 0.001$	$p < 0.001$	–	$p < 0.001$	–
Fat percentage, %	–	28.7 ± 1.4	35.2 ± 0.7	37.4 ± 0.8	–	$p < 0.001$	$p < 0.05$	–	$p < 0.001$	–

Table 2

Statistical differences between the analyzed groups

	Young males – 1st maturity	1st maturity – 2nd maturity	2nd maturity – elderly males	Young males – elderly males
Underweight				
N, people	$p = 0.69$	–	–	–
BMI, kg/m^2	$p = 1.00$	–	–	–
FFMI, kg/m^2	$p = 0.76$	–	–	–
FMI, kg/m^2	$p = 0.84$	–	–	–
FM/FFM, kg/m^2	$p = 0.32$	–	–	–
W/H, cu	$p = 0.84$	–	–	–

End of the Table 2

	Young males – 1st maturity	1st maturity – 2nd maturity	2nd maturity – elderly males	Young males – elderly males
Normal weight				
N, people	$p < 0.05$	$p = 0.11$	$p = 0.76$	$p < 0.05$
BMI, kg/m^2	$p = 0.09$	$p < 0.001$	$p = 0.43$	$p < 0.01$
FFMI, kg/m^2	$p < 0.001$	$p < 0.001$	$p = 0.62$	$p < 0.001$
FMI, kg/m^2	$p < 0.001$	$p < 0.001$	$p = 0.62$	$p < 0.001$
FM/FFM, kg/m^2	$p < 0.05$	$p < 0.001$	$p = 0.11$	$p < 0.001$
W/H, cu	$p < 0.001$	$p < 0.001$	$p = 0.49$	$p < 0.001$
Overweight				
N, people	$p = 0.23$	$p = 0.49$	$p = 0.32$	$p = 0.16$
BMI, kg/m^2	$p < 0.001$	$p < 0.001$	$p < 0.05$	$p < 0.001$
FFMI, kg/m^2	$p < 0.001$	$p < 0.001$	$p = 0.23$	$p < 0.001$
FMI, kg/m^2	$p < 0.001$	$p < 0.001$	$p < 0.05$	$p < 0.001$
FM/FFM, kg/m^2	$p < 0.05$	$p < 0.001$	$p < 0.05$	$p < 0.001$
W/H, cu	$p < 0.001$	$p < 0.001$	$p = 0.23$	$p < 0.001$
Obesity				
N, people	$p = 0.69$	$p < 0.05$	$p = 0.32$	$p = 0.76$
BMI, kg/m^2	$p < 0.001$	$p < 0.05$	$p = 0.62$	$p < 0.001$
FFMI, kg/m^2	$p < 0.001$	$p < 0.001$	$p = 0.76$	$p < 0.001$
FMI, kg/m^2	$p < 0.001$	$p < 0.001$	$p = 0.62$	$p < 0.001$
FM/FFM, kg/m^2	$p < 0.01$	$p < 0.001$	$p = 0.62$	$p < 0.001$
W/H, cu	$p < 0.001$	$p < 0.01$	$p = 0.49$	$p < 0.001$

Figure 1 provides a graph showing dynamics of percentage distribution for people with normal weight as well as overweight and obesity (people with underweight as per BMI were excluded from the graph due to absence of such sub-group in the second maturity and elderly age groups).

Bearing in mind, that BMI did not identify obesity correctly in our investigations, we built a series of ROC-curves for the examined age-specific groups of males to estimate the optimal BMI cut-off point that meant no obesity in accordance with reference FMI/FFMI values (Figure 2).

The analysis of the obtained research data established a significant decrease in FFMI values with age (from young males to elderly ones) together with growing FMI, FMI/FFMI ratio, total body fat and the waist-to-hip ratio in males with normal body weight, overweight and obesity. This is consistent with findings reported by other authors [23]. Stratification of the examined males as per BMI made it possible to establish a significant ascending trend in the analyzed variables as BMI values grew in each age group. Higher muscle mass values in people with overweight and obesity are in line with findings reported by other authors who believe this fact to be related to anabolic activity due to the body overweight load on the musculoskeletal system [24]. It should be noted that we established age-specific changes in BMI ranges from its minimum to maximum values. Thus, BMI range was 16.15–36.33 kg/m^2 in young males; 16.36–41.4 kg/m^2 in the first maturity group; 19.02–48.52 kg/m^2 in the second maturity group; the bottom value shifted considerably among elderly males where the range started at 25.03 kg/m^2 and its upper value was 49.69 kg/m^2.

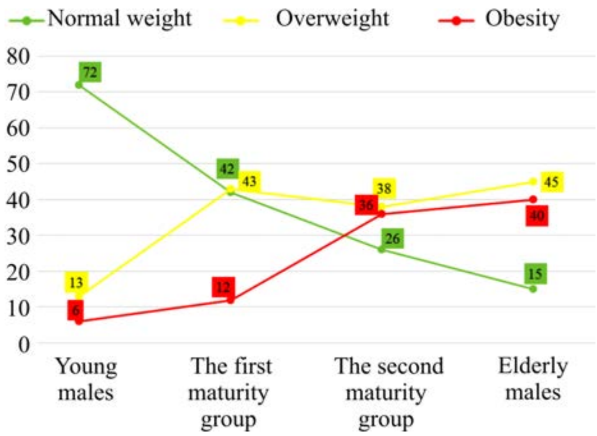

Figure 1. Distribution of the analyzed sample as per frequency of normal weight, overweight and obesity in different age groups

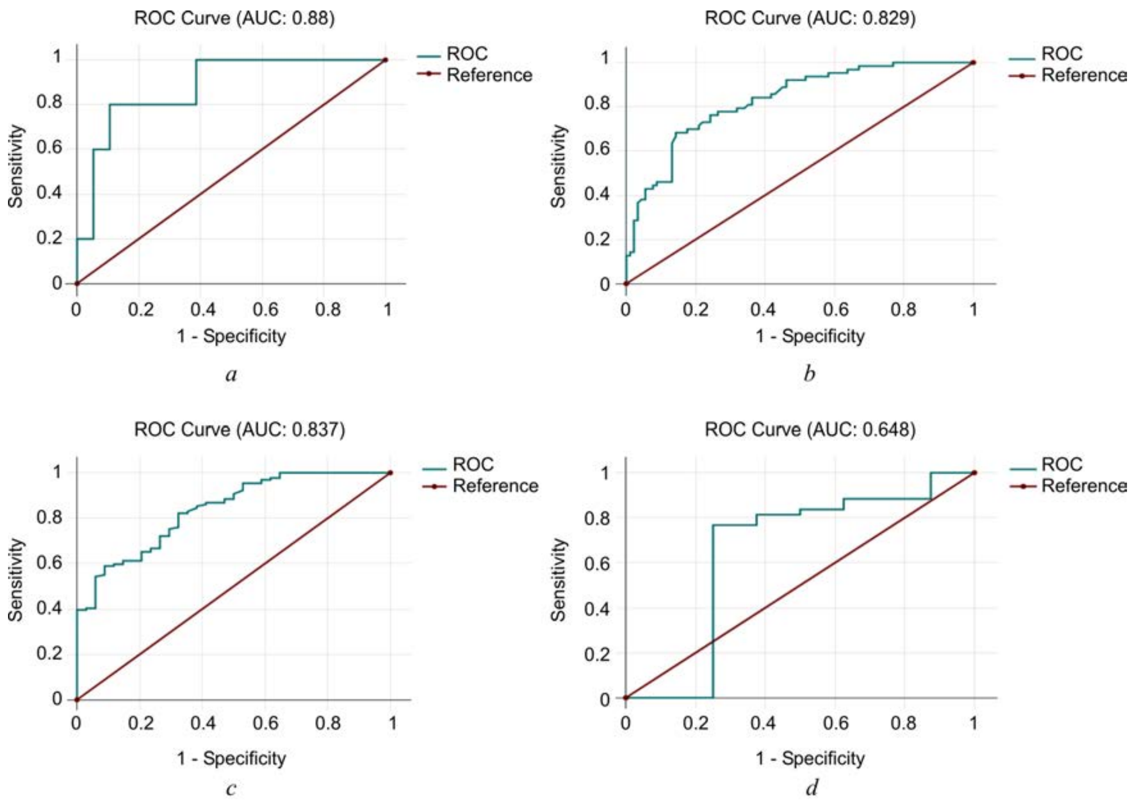

Figure 2. ROC-analysis in young males (a), the first maturity group (b), the second maturity group (c), elderly males (d)

Figure 1 obviously shows that normal body weight prevails among young males (72 %); overweight prevails in the first maturity group (43 %) and its percentage is higher than that of normal weight (42 %) whereas both obesity (36 %) and overweight (38 %) are quite frequent in the second maturity group and their percentages are higher than that of normal weight (26 %). Among elderly males, we established a considerable decrease in normal weight percentage (15 %) with growing overweight (45 %) and obesity (40 %). Data provided in Figure 1 give evidence of rather unfavorable manifestations in males' physical state, which become apparent through two crosspoints of the graph in the age aspect. In the first maturity group (the first crosspoint), they are characterized with the percentage of overweight people being higher than people with normal weight; in the second maturity group (the second crosspoint), obesity is more frequent than normal weight with a simultaneously high percentage of people with overweight.

Analyzing the research data, we should establish the fact that underweight in young males occurs due to low muscle mass. All analyzed indicators in people with normal weight were within the reference range but higher body fat percentages were identified in young males with overweight and obesity against optimal FMI and FFMI values and FMI/FFMI and W/H ratios. This allows us to conclude that BMI can be used to diagnose obesity in this age group.

Lower muscle mass was also detected in underweight males from the first maturity group whereas males with BMI values between 18.5 and 24.9 kg/m^2 (normal weight) were established to have excessive total fat in the body. The same fact was established for males from the second maturity group and elderly males; these changes in these two groups were combined with lower fat-free mass index (muscle component). Therefore, it is rather doubtful that BMI can be used as an indicator of normal body weight in these age groups. Several studies established that both high and low BMI values were associated with risks of chronic non-communicable diseases and all-cause mortality [25]. A risk of incidence as per BMI was shown to create either a U- or J-like curve; that is, low or high BMI increased this risk in comparison with BMI closer to its medium values [26]. Our findings also confirm a U-like curve for BMI among young males and males from the first maturity group where low BMI values meant lower muscle mass and BMI values higher than 30 kg/m^2 indicated excessive body fat.

We should emphasize that we established a combined set of negative signs as regards the physical state in overweight people starting from the second maturity group and older. This manifested itself in obesity (high FMI/FFMI values), excessive total body fat and elevated fat mass index as well as signs of abdominal obesity (the waist-to-hip ratio > 0.90 cu). The identified trends aggravated further in obese people.

Overall, our findings indicate that classical BMI ranges determining obesity / underweight cannot serve an accurate parameter for identifying both obesity and underweight since they do not allow determining muscle mass deficiency or high fat percentage in the body in male population, especially in age-specific aspects. The issue was to identify those BMI values that could serve as markers of optimal FMI/FFMI ratio excluding obesity and sarcopenic trends in the analyzed groups. To do that, the research data were analyzed to determine their predictive significance by building a ROC-curve and calculating AUC value. It should be noted that FMI/FFMI ratio had significant and quite strong correlations with FMI and fat percentage (young males, 0.86 ($p < 0.001$) and 0.98 ($p < 0.001$); the first maturity group, 0.95 ($p < 0.001$) and 0.95 ($p < 0.001$); the second maturity group, 0.86 ($p < 0.001$) and 0.86 ($p < 0.001$); elderly people, 0.79 ($p < 0.001$) and 0.98 ($p < 0.001$) respectively) but not with FFMI. The latter did not have any significant associations with FMI/FFMI ratio in young males ($r = -0.07$, $p = 0.98$), males from the first maturity group ($r = 0.13$, $p = 0.47$), and males from the second maturity group ($r = 0.06$, $p = 0.84$) whereas we detected an inverse correlation between FMI/FFMI and FMI $r = -0.48$ ($p < 0.01$) in elderly males. The latter, in our opinion, reflects sarcopenic trends in this age group.

Figure 2 shows ROC-curves used to identify the marker BMI value under FMI/FFMI ratio > 0.4 cu, which means obesity. In young males, BMI higher than 25 kg/m^2 is shown to have high predictive value as regards obesity detection and this is evidenced by AUC equal to 0.88 ($p < 0.001$). It is worth noting that we detected one more marker in this curve, namely, BMI value of 22.0 kg/m^2. Another interesting fact was that a mean FFMI value equaled 14.8 ± 0.12 kg/m^2 in young males with BMI values below the foregoing threshold. This means lower muscle mass and can reflect some sarcopenic trends in the physical state. It is also worth noting that ROC-analysis data obtained for young males are confirmed by a rather high correlation coefficient between BMI and FMI/FFMI ratio ($r = 0.50$, $p < 0.001$), which was established together with a low percentage of people with FMI/FFMI ratio above the reference range. Frequency of such people equaled only 4 % in the examined group made of young males.

In the first maturity group, BMI cutoff point equal to 26.5 kg/m^2 turned out to have high predictive value as regards obesity detection (AUC = 0.829, $p < 0.001$) with a high correlation coefficient between BMI and FMI/FFMI, which was 0.68 ($p < 0.001$) and a 41 % percentage of people with FMI/FFMI values being higher than the metabolic health threshold.

In the second maturity group, the optimal BMI range between 24.0 and 27.5 kg/m^2 also had high predicative significance determined by AUC value equal to 0.837 ($p < 0.001$) where men with BMI below this bottom threshold had a decline in FFMI down to 16.9 ± 0.07 kg/m^2 (the reference level being 17.4 kg/m^2) whereas men with BMI higher than 27.5 kg/m^2 tended to have a growth in FMI up to 12.2 ± 0.9 kg/m^2 with its reference level being below 8.3 kg/m^2. It is worth noting that men with BMI between 24.0 and 27.5 kg/m^2

tended to have optimal FMI (7.98 ± 0.06 kg/m^2) and FFMI (17.8 ± 0.16 kg/m^2) and these values were totally within the reference range. We should also mention a high correlation coefficient between BMI and FMI/FFMI ratio (r = 0.60, p < 0.001) together with a growing percentage of people with FMI/FFMI reflecting obesity up to 78 % in the second maturity group.

Attention should be paid to the fact that the ROC-analysis turned out to have no predictive value for elderly males (AUC = 0.562). This indicates that BMI is hardly eligible for being used as an indicator of obesity risk in this period of ontogenesis and this is further confirmed by absence of any correlations between BMI and FMI/FFMI (r = 0.008, p = 0.54) and high frequency of men with FMI/FFMI > 0.4 cu, the percentage being 91 %. Our findings are in line with the results obtained by other researchers who revealed that elderly people tended to have a high fat percentage in the body under certain BMI values. That's why the established BMI threshold values can also be less accurate in elderly people (≥ 65 years) [23].

Conclusion. Stratification of the examined males as per BMI established a significant positive dynamics in the analyzed variables as BMI values grew in each analyzed age group together with age-specific decline in FFMI values from young males to elderly ones against growing FMI, FMI/FFMI, total body fat and waist-to-hip ratio in people with normal weight, overweight and obesity identified as per BMI.

Our findings allow us to conclude that classical BMI ranges cannot be considered a clear indicator to diagnose obesity among males in the Magadan oblast whereas indicators obtained by bioimpedance analysis (FMI/FFMI ratios) can be used as relevant indicators when assessing risks of obesity and sarcopenia in the analyzed population. This is confirmed by highly significant correlation coefficients between this indicator and the fat percentage in the body as well as fat mass index in each age group.

Overall, our study findings confirm the opinion that any assessment of physical state aimed to identify obesity should consider anthropometric indices that rely not only on a body weight related to height (BMI) but also on fat-free mass index (FFMI), fat mass index (FMI) as well as their ratio FMI/FFMI. At present bioimpedance analysis is widely available due to its low costs and simplicity; given that, it seems advisable to implement assessment of these indices in screening preventive and clinical practices. This will allow analyzing both absolute (kg) and relative (%) values of muscle and fat mass in the body for effective early diagnostics and prevention of obesity.

Limitations. Our study has certain limitations. The major one is that our participants were exclusively males and this does not allow describing the total population of northern regions. In addition to that, our results apply only to Caucasians as a specific ethnic group. To our best knowledge, this is the first study with its focus on males living in the north-eastern Russia and with its aim being to analyze whether anthropometric indices are eligible for assessing obesity and its types relying on fat mass index and free-fat mass index.

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References

1. Gómez-Campos R., Vidal-Espinoza R., Castelli Correia de Campos L.F., Sulla-Torres J., Cossio-Bolaños W., de Arruda M., Albornoz C.U., Cossio-Bolaños M. Comparison of anthropometric indicators as predictors of the percentage of fat mass in young people and older adults in Chile. *Endocrinol. Diabetes Nutr. (Engl. Ed.)*, 2022, vol. 69, no. 1, pp. 25–33. DOI: 10.1016/j.endien.2022.01.002

2. Safaei M., Sundararajan E.A., Driss M., Boulila W., Shapi'i A. A systematic literature review on obesity: Understanding the causes & consequences of obesity and reviewing various machine learning approaches used to predict obesity. *Comput. Biol. Med.*, 2021, vol. 136, pp. 104754. DOI: 10.1016/j.compbiomed.2021.104754

3. Hu L., Huang X., You C., Li J., Hong K., Li P., Wu Y., Wu Q. [et al.]. Prevalence of overweight, obesity, abdominal obesity and obesity-related risk factors in southern China. *PLoS One*, 2017, vol. 12, no. 9, pp. e0183934. DOI: 10.1371/journal.pone.0183934

4. Young N., Atan I.K., Rojas R.G., Dietz H.P. Obesity: how much does it matter for female pelvic organ prolapse? *Int. Urogynecol. J.*, 2018, vol. 29, no. 8, pp. 1129–1134. DOI: 10.1007/s00192-017-3455-8

5. Chooi Y.C., Ding C., Magkos F. The epidemiology of obesity. *Metabolism*, 2019, vol. 92, pp. 6–10. DOI: 10.1016/j.metabol.2018.09.005

6. Tuovinen E.-L., Saarni S.E., Männistö S., Borodulin K., Patja K., Kinnunen T.H., Kaprio J., Korhonen T. Smoking status and abdominal obesity among normal- and overweight/obese adults: Population-based FINRISK study. *Prev. Med. Rep.*, 2016, vol. 4, pp. 324–330. DOI: 10.1016/j.pmedr.2016.07.003

7. Dedov I.I., Shestakova M.V., Melnichenko G.A., Mazurina N.V., Andreeva E.N., Bondarenko I.Z., Gusova Z.R., Dzgoeva F.K. [et al.]. Interdisciplinary Clinical Practice Guidelines "Management of obesity and its comorbidities". *Ozhirenie i metabolism*, 2021, vol. 18, no. 1, pp. 5–99. DOI: 10.14341/omet12714 (in Russian).

8. Rehunen S.K., Kautiainen H., Korhonen P.E., Eriksson J.G. Lean body mass is not beneficial, but may be detrimental for glucose tolerance – Splitting body mass index according to body composition. *Prim. Care Diabetes*, 2020, vol. 14, no. 6, pp. 747–752. DOI: 10.1016/j.pcd.2020.05.003

9. Pyastolova N.B. Quetelet index as a tool for assessing the physical condition of the body. *Fizicheskaya kul'tura. Sport. Turizm. Dvigatel'naya rekreatsiya*, 2020, vol. 5, no. 4, pp. 43–48. DOI: 10.24411/2500-0365-2020-15406 (in Russian)

10. De Lorenzo A., Martinoli R., Vaia F., Di Renzo L. Normal weight obese (NWO) women: an evaluation of a candidate new syndrome. *Nutr. Metab. Cardiovasc. Dis.*, 2006, vol. 16, no. 8, pp. 513–523. DOI: 10.1016/j.numecd.2005.10.010

11. Romero-Corral A., Somers V.K., Sierra-Johnson J., Korenfeld Y., Boarin S., Korinek J., Jensen M.D., Parati G., Lopez-Jimenez F. Normal weight obesity: a risk factor for cardiometabolic dysregulation and cardiovascular mortality. *Eur. Heart J.*, 2010, vol. 31, no. 6, pp. 737–746. DOI: 10.1093/eurheartj/ehp487

12. Kozlova L.V., Bekezin V.V., Druzhinina T.V., Peresetskaya O.V. Place of bioimpedance analysis in epidemiological assessment of nutritional status of adults and children (review). *Smolenskii meditsinskii al'manakh*, 2017, no. 4, pp. 13–22 (in Russian).

13. Lee D.H., Keum N., Hu F.B., Orav E.J., Rimm E.B., Willett W.C., Giovannucci E.L. Predicted lean body mass, fat mass, and all cause and cause specific mortality in men: prospective US cohort study. *BMJ*, 2018, vol. 362, pp. k2575. DOI: 10.1136/bmj.k2575

14. Xiao P., Cheng H., Yan Y., Liu J., Zhao X., Li H., Mi J. High BMI with adequate lean mass is not associated with cardiometabolic risk factors in children and adolescents. *J. Nutr.*, 2021, vol. 151, no. 5, pp. 1213–1221. DOI: 10.1093/jn/nxaa328

15. Haldar S., Chia S.C., Henry C.J. Body Composition in Asians and Caucasians: comparative analyses and influences on cardiometabolic outcomes. *Adv. Food Nutr. Res.*, 2015, vol. 75, pp. 97–154. DOI: 10.1016/bs.afnr.2015.07.001

16. Perevoshchikova N.K., Seliverstov I.A., Drakina S.A., Chernykh N.S. Bioelectrical impedance analysis in clinical practice. *Mat' i ditya v Kusbasse*, 2021, no. 3 (86), pp. 11–20. DOI: 10.24412/2686-7338-2021-3-11-20 (in Russian).

17. Samoylov A.S., Zholinskiy A.V., Rylova N.V., Velichko M.N., Bolshakov I.V., Bodrov A.V., Simonov R.A., Chizhikov P.D. Modern methods of body composition analysis. *Prakticheskaya meditsina*, 2022, vol. 20, no. 1, pp. 21–26. DOI: 10.32000/2072-1757-2022-1-21-26 (in Russian).

18. Górnicka M., Szewczyk K., Białkowska A., Jancichova K., Habanova M., Górnicki K., Hamulka J. Anthropometric indices as predictive screening tools for obesity in adults; the need to define sex-specific cut-off points for anthropometric indices. *Appl. Sci.*, 2022, vol. 12, no. 12, pp. 6165. DOI: 10.3390/app12126165

19. WHO Expert Consultation. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. *Lancet*, 2004, vol. 363, no. 9403, pp. 157–163. DOI: 10.1016/s0140-6736(03)15268-3

20. Kyle U.G., Pirlich M., Lochs H., Schuetz T., Pichard C. Increased length of hospital stay in underweight and overweight patients at hospital admission: A controlled population study. *Clin. Nutr.*, 2005, vol. 24, no. 1, pp. 133–142. DOI: 10.1016/j.clnu.2004.08.012

21. WHO European Regional Obesity Report 2022. Copenhagen, Denmark, WHO, 2022, 206 p. Available at: https://apps.who.int/iris/handle/10665/353747.pdf (May 05, 2023).

22. Pluta W., Dudzińska W., Lubkowska A. Metabolic Obesity in People with Normal Body Weight (MONW) – Review of Diagnostic Criteria. *Int. J. Environ. Res. Public Health*, 2022, vol. 19, no. 2, pp. 624. DOI: 10.3390/ijerph19020624

23. Nimptsch K., Konigorski S., Pischon T. Diagnosis of obesity and use of obesity biomarkers in science and clinical medicine. *Metabolism*, 2019, vol. 92, pp. 61–70. DOI: 10.1016/j.metabol.2018.12.006

24. Gažarová M., Bihari M., Lorková M., Lenártová P., Habánová M. The Use of Different Anthropometric Indices to Assess the Body Composition of Young Women in Relation to the Incidence of Obesity, Sarcopenia and the Premature Mortality Risk. *Int. J. Environ. Res. Public Health*, 2022, vol. 19, no. 19, pp. 12449. DOI: 10.3390/ijerph191912449

25. Aune D., Sen A., Norat T., Janszky I., Romundstad P., Tonstad S., Vatten L.J. Body Mass Index, Abdominal Fatness, and Heart Failure Incidence and Mortality: a systematic review and dose-response meta-analysis of prospective studies. *Circulation*, 2016, vol. 133, no. 7, pp. 639–649. DOI: 10.1161/CIRCULATIONAHA.115.016801

26. Zhang D., Chen J., Wang J., Gong S., Jin H., Sheng P., Qi X., Lv L. [et al.]. Body mass index and risk of brain tumors: a systematic review and dose-response meta-analysis. *Eur. J. Clin. Nutr.*, 2016, vol. 70, no. 7, pp. 757–765. DOI: 10.1038/ejcn.2016.4

Alyoshina O.O., Averyanova I.V. Anthropometric indices and bioimpedance body composition as ontogenetic indicators to describe risk of obesity. Health Risk Analysis, 2024, no. 1, pp. 111–120. DOI: 10.21668/health.risk/2024.1.11.eng

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