Modern approaches to assessing physical development of children and adolescents

Abstract. Background. At present in Ukraine negative tendencies in terms of the physical development of the younger generation population have been revealed with the overweight issue getting increasingly urgent that is a predictor of obesity development in adulthood, an increase in levels of chronic somatic prevalence and mortality. The purpose of the research is to assess the level of the physical development of schoolchildren and to determine the most informative approach to determining risk groups in terms of nutritional status impairment. Materials and methods. We have conducted a cross-sectional examination of 277 schoolchildren aged 10–14 years (125 boys and 152 girls) based on the corresponding anthropometric parameters, Quetelet weight-to-height index, Vervek-Vorontsov index, the results of caliperometry and bio-impedancemetry with their further assessment according to the international and national standards. The data are statistically processed in the licensed package IBM SPSS Statistics v. 22, using the t-test and generalized linear models. Results. The analysis of sex and age peculiarities of the physical development has demonstrated a probable decrease in body mass index at the age of 11 and its increase at the age of 12 in both sex groups, the risk of obesity development in boys of 10 and 12 years, and harmonious development in girls observed. Based on the Vervek-Vorontsov index, elongation growth processes are noticed in eleven-year-old girls, and growth retardation processes are observed in ten-year-old schoolchildren of both sexes. A highly disharmonious physical development by the national regression scales is found at the age of 12, and harmonious development is revealed in ten-year-old boys and thirteen-year-old girls. The amount of adipose tissue content does not differ significantly across different age groups, and muscle content is considerably higher in boys of 14. Such data, in comparison with the body mass index, allow us to make an assumption that higher Quetelet indices are determined due to the developed muscle system and are not the proof of obesity development in boys. It is also confirmed by the results of caliperometry. According to the results of the anthropocentric research, two generalized integrative linear models have been developed to determine adipose and muscle tissue content. The comparison of the models obtained with the results of bio-impedancemetry has shown a high precision of the models developed, which has been proved by the results of the t-test. Conclusions. The study has proved the high informative value of the methods which have been used to assess the physical development and the relevance of their application as a component of the algorithm of the comprehensive assessment of schoolchildren’s physical development, which is potential for further monitoring and analyzing morphofunctional changes.

Keywords: children and adolescents; physical development; body mass index; caliperometry; bio-impedancemetry

Introduction

Physical development is an integrative indicator of the health condition of children and adolescents that is influenced by a cluster of social, economic, demographic, climatic, geographical, and ecological factors, the level of urbanization, the corresponding lifestyle, nutrition peculiarities, scopes of physical and psychological loading, educational technologies [1–7]. At present in Ukraine negative tendencies in terms of the physical development of the younger generation population have been revealed: it is pointed out that currently there are much fewer harmoniously developed children, the overweight issue is getting increasingly urgent, overweight is considered a key predictor of obesity development in adulthood; there is an increase in levels of chronic somatic prevalence and mortality observed [8–10]. Special attention...
should be paid to the age of adolescence as a critical period in terms of obesity development. Body composition during puberty is an indicator of metabolic changes that take place and it contains key information concerning the present and future health conditions. During puberty, the basic components of all body composition (total body fat, fat-free mass, muscle mass) are increasing and closely correlate with the categories of sex and sexual development intensity [11, 12].

The methods of assessing physical development of the population are characterized by a fundamental scientific substantiation and are widely spread in practical and scientific research activities of health-care institutions. International and national standards that are valid in different countries are for assessing physical development under the somatometric and somatoscopic criteria and they mainly include percentile curves of growth, body mass, chest circumference, skinfolds, and various indices (body mass index (BMI), waist-to-height ratios, Vervek-Vorontsov, Pinier, Erismann indices) [9, 13, 14].

One of the specifying indicators of physical development of adolescents is a somatotype, determined by the relative content of fat, muscle, water, mineral, and other components of the corresponding body mass. The fat component is an indicator of a certain nutritional status and it can change dynamically under the influence of different factors, and the muscle component serves as an indicator of the structural and functional condition of the human body, being determined by the corresponding physical activity mode and somatic health conditions [15–17].

Assessing skinfold thickness allows determining the content of subcutaneous fat more accurately in comparison with BMI. The diagnostic potential of caliperometry for assessing children’s nutritional status is confirmed by multicentral research conducted by the World Health Organization [14, 18–22]. It is a bio-impedance analysis that lets experts assess body composition differentially and objectively, and its indicators are specific as for the sex, age, and certain anthropometric data [11, 12, 23, 24].

The monitoring of body composition during puberty allows predicting further changes of its characteristics in adulthood and any probability of developing a multifactor pathology: cardiovascular diseases, diabetes, obesity, and osteoporosis [26].

In this connection, the aim of the research is to assess the level of the physical development of secondary school age pupils by different methods and to determine the most informative approach to determining risk groups in terms of nutritional status impairment.

Materials and methods

We have conducted a cross-sectional examination of secondary school age pupils based on the anthropometric parameters within the framework of realizing the scientific research work “Determining the peculiarities of the somatotype of secondary school age children under the conditions of an industrial city” (state registration No 0120U102732). The research has been focused on the parameters of height, weight, chest circumference, as well as the corresponding indices: the Quetelet weight-to-height index (BMI) and Vervek-Vorontsov index (dividing the body length (cm) by the sum of the exhalation chest circumference (cm) and doubled body mass (kg)). Tissue body composition has been studied using the two method lines at the same time: bio-impedancemetry using the body composition monitor “Omron-BF511” and caliperometry with an emphasis on determining skinfold thickness at five points: the subscapular area (D1), the triceps area (D5), the stomach area (D3), the calf area (D8), and the chest area (D2, only in boys) using mechanical caliper according to standard methods. The participants of the research are 277 schoolchildren (125 boys and 152 girls) aged 10–14 years; the informed consent was taken from their parents following the requirements of the Declaration of Helsinki and the rights of bioethics.

The physical development parameters are assessed using the international body mass index, and the national Ukrainian standards according to the ordinance of the Ministry of Health of Ukraine “Adopting the criteria of assessing physical development of schoolchildren”, “Adopting protocols of providing children with medical assistance “Pediatric endocrinology”, “Screening-assessment of physical development of children aged 6–17 years according to the Vervek index”.

The data are statistically processed in the licensed package IBM SPSS Statistics v. 22 (license FacultyPackL/N: L-GLBC-99H6WQ) using the *t*-test and generalized linear mixed models [27]. All variants of including and excluding variables from the number of the fixed and occasionally random model effects are considered consistently and systematically. The criteria of selecting a qualitative statistically substantiated model are informational (Akaike and Bayes), and the statistical significance of the model on the whole and the variation models was *p* < 0.05.

Results

The results of the analysis of the anthropometric research data obtained as for the parameters of height and body mass in comparison with the national standards demonstrated a dynamic increase in height and body mass in conformity with physiological processes. At the same time, the comparison of the average parameters of these anthropometric criteria with the national standards has proved that classifying children into tall, above-average, average, and short ones in different age and sex groups is characterized by certain deviations. To illustrate, it is registered that at the age of 11, there is the maximum percentage of schoolchildren who are short (13.3 % among boys and 8.6 % among girls) with the average height within the present age group 146.18 ± 1.13 and 147.72 ± 1.08 cm, respectively. The tall adolescents have been most frequently registered among ten-year-old girls (18.8 % with an average height 142.29 ± 0.69 cm) and fourteen-year-old boys (19.6 % with an average height 169.87 ± 1.34 cm).

The parameters of the body mass are characterized by more distinct differences in various sex groups by the quality feature: whereas among girls, there are over 50 % with normal weight at their 10–13, and obvious features of weight deficit develop at the age of 14 (21.4 % of schoolgirls); among the boys of 10, 12, and 14 years, there is over one-third of schoolboys suffering from obesity and over 10 % suffering from overweight. Among the girls, such nutritional status disorders are revealed at the age of ten (21.3 %).
The analysis of sex-age peculiarities by BMI (Fig. 1) has shown a probable index decrease at the age of 11 and an increase at the age of 12 years in both sex groups (p < 0.05), and its qualitative characteristic proves a risk of obesity in boys of 10 and 12 (85th–95th percentile). In the other age groups of boys, BMI is within the 75th–85th percentile. Whereas the girls are characterized by harmonious development, and their BMI is within the 25th–75th centile corridors, except for ten-year-old girls (75th–85th centile).

The results of calculating the Vervek index with its further assessment in terms of the national scales demonstrated that at the age of 10 years regardless of the sex criterion there is an average harmonious physical development with growth process retardation features revealed (0.88–1.13 standard units). Such features have been observed in boys at the age of 13–14. For 11-year-old girls, the average development pattern with the prevalence of elongation processes (0.95–1.16 standard units) is common, and the age of 12–14 years is characterized by a considerable discrepancy in terms of the qualitative assessment of physical development in each age group: from the prevalence of growth process retardation up to the prevalence of elongation processes.

The examination data showed the highest percentage of schoolchildren characterized by harmonious physical development patterns among ten-year-old boys and thirteen-year-old girls, and extremely disharmonious physical development patterns have been discovered in 12-year-old schoolchildren of both sex groups (Fig. 2).

The results of bio-impedancemetry demonstrated that the percentage of adipose tissue has not changed considerably depending on the age but the content of muscle tissue has been proved to be higher at the age of 14 (37.2 ± 0.1 %), which is to a significant degree in comparison with schoolchildren of 10 and 11 years (32.9 ± 0.6 and 35.1 ± 0.3 %, respectively; p < 0.05). Such data compared to BMI allow us to assume that higher BMI is due to a more developed muscle system, not proving the formation of obesity in boys. A similar conclusion can also be confirmed based on the caliperometry results. For example, with age, the triceps skinfold thickness (D5) decreased from 15.7 ± 1.0 mm at

*Figure 1. BMI parameters in schoolchildren*

Note: Error bar with standard errors.

*Figure 2. Results of the assessment of physical development on the regression scales*
the age of 10 years up to 12.9 ± 1.2 mm at the age of 14 (p < 0.05) and as for the chest area (D2) — from 16.8 ± 1.6 up to 10.7 ± 1.9 % in boys of the same age (p < 0.05).

Turning to the method of generalized linear models, we have checked all possible hypotheses and combinations of variables up to the point of finding the best (in terms of prediction precision) statistically valuable model (Fig. 3) and its all independent variables represented by the fixed effects with an elaborated formula to assess the adipose tissue content:

\[
\text{Adipose tissue content} = 0.630 \times D_5 + 0.001 \times D_1 \times D_3 \times D_8 + 8.326,
\]

where \( D_1 \) — subscapular skinfold thickness, \( D_3 \) — stomach skinfold thickness, \( D_5 \) — skinfold thickness above the triceps area, \( D_8 \) — calf skinfold thickness.

Similar calculations are conducted to obtain a generalized integrative linear model for determining the muscle tissue content:

\[
0.275 \times D_l + 0.003 \times S + 0.171 \times H - 0.213 \times W + 0.039 \times \text{Cov}(D_r) + 11.69,
\]

where \( D_l \) — left hand dynamometry parameter, \( S \) — spirometry results, \( H \) — height, \( W \) — weight, \( \text{Cov}(D_r) \) — right hand dynamometry parameter covariation.

The usage of these models lets us avoid applying any body composition analyzer. At the same time, the graphic representation demonstrates a high precision of the models developed (Fig. 3).

The results of \( t \)-test demonstrated the identity of both obtained models to the results of the field research (Table 1).

**Discussion**

Currently, assessing the nutritional status in terms of BMI is spread globally. There are centile tables and \( z \)-scores of the World Health Organization that are included, among others, in the protocols of providing children with medical care within the framework of “Pediatric endocrinology” in Ukraine. However, this index is an approximate parameter as it doesn’t allow determining the components triggering the body composition change [15, 25]. BMI, which can be considered an analogue of the harmonicity of physical development, unlike the Ukrainian standard, doesn’t take into account all the anthropometric parameters but it can be used as an approximate one, being at the same time both a convenient and time-saving way of assessing. Japanese researchers also establish the lack of a universal international method of determining obesity in children and, unlike other countries where they use the BMI or \( z \)-score (standard deviation) age percentiles, percentage of overweight is recommended. It enables researchers to give a more precise assessment of risk groups in terms of obesity development or presence and excludes height errors that are characteristic for BMI: interpreting overweight when the height is significant and insufficient body mass when the height is insignificant [27].

At the same time, in China, according to the research, involving 5,000 children aged 7–18, there have been their own BMI percentiles developed, but they still require specifying the correspondence between various studies in longitudinal research [28].

**Table 1. \( t \)-test results**

| Body composition component | Mean (Assessment) | Mean (Model) | Standard deviation (Assessment) | Standard deviation (Model) | Standard error of mean (Assessment) | Standard error of mean (Model) |
|----------------------------|------------------|--------------|--------------------------------|----------------------------|-----------------------------------|-------------------------------|
| Adipose tissue content     | 19.51            | 19.51        | 6.65                           | 5.08                       | 0.83                              | 0.64                          |
| Muscle tissue content      | 34.96            | 34.96        | 3.14                           | 1.98                       | 0.39                              | 0.25                          |

**Figure 3. Generalized integrative linear model of the components of body composition**
Attempts at introducing their own national standards of assessing physical development are represented in world scientific publications and state a wide range of criteria. For instance, the informative value of assessing the waist circumference for screening examinations of children at high metabolic risk has been substantiated and the approximate percentile curves have been developed, following the results of the Singapore anthropologist [22]. K. Kromeyer-Hauschild and the corresponding co-authors have designed centile tables for the triceps and the subscapular skinfold of schoolchildren of the junior and secondary school age in Germany [29]. There are centile curves of the skinfold thickness calculated, according to the above five parameters, for Canadian children aged from six to nineteen [14], in Japan, they have introduced the over-weight percentage [27].

It is the traditional method of caliperometry and modern methods of bio-impedancemetry that are proved to be the most precise criteria for the level of the development of the muscle system and the degree of adipose tissue deposition. Therefore, in our research, we have established a decrease in biceps and chest skinfold thickness, which can be regarded as an increase in the percentage of muscle tissue under conditions of keeping the general body mass and an increase in fat content. The same conclusion is made by S. Kuhle [14] who discovers a gradual age-dependent increase of the percentile of the thickness of the above five skinfolds with the corresponding peak during puberty in boys. The caliperometry results demonstrated a subcaneous fat increase in children of the junior and secondary school age, particularly with insufficient and standard weight parameters [29]. Unlike S. Kuhle, according to the results of the research of Leipzig children and teenage boys, the peak is registered at the beginning of puberty with a further decrease of skinfold thickness, compared to girls, in whom such changes take place according to the age range (from 3 to 16) [21].

However, in routine examinations, the body composition analysis can’t be a universal method of assessing physical development as it requires special training of the operator and is limited due to the participants’ age and weight.

The integrative methods of assessing the percentage of muscle and adipose tissue content based on the anthropometric data (height, weight, hand dynamometry, and spirometry) and caliperometry enable us to get relatively accurate data without using any special equipment. Assessment and development models are a widely spread practice in anthropological research. In this connection, A.J. Simpkin and the co-authors (2017) laid a special emphasis on the issues of modelling the parameter of growth at peak height velocity, obtaining two model types as a result [30]. Thus, calculating percentile curves and a cluster of complementary indices is one of the progressive mainstreams in medicine and anthropology.

Conclusions

1. The results of the research conducted allow determining the gender peculiarities of physical development based on the parameters of height, weight, adipose, and muscle components in children of 10–14 years in early puberty.

2. The examined scope of modern methods of assessing physical development of children and adolescents, including anthropometric parameters of height, body weight, chest circumference, and a cluster of complementary indices (Quetelet weight-to-height index, Vervek-Vorontsov index), evaluating the percentage of muscle and adipose tissue content (bio-impedancemetry and caliperometry) has been proved to be highly informative for conducting population research and applied comprehensively, the methods considered let experts reveal health disorders objectively and in time.

3. Using regression scales, percentile curves and the whole cluster of complementary indices can be considered as an algorithm of comprehensive assessing physical development of children, which makes our perspective for further monitoring and analyzing relevant dynamics.

Conflict of interests. The authors declare the absence of any conflicts of interests and their own financial interest that might be construed to influence the results or interpretation of their manuscript.

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Современные подходы к оценке физического развития детей и подростков

Резюме.
Актуальность. На данный момент в Украине спостережаются негативные тенденции у физического развития детей и подростков, снижение уровня физического развития учащихся и подростков, что является перспективным для дальнейшего мониторинга и анализа систем. В частности, прослеживаются негативные тенденции в физическом развитии детской популяции, что ведет к увеличению процента детей и подростков, страдающих ожирением.

Цель исследования: оценить уровень физического развития учащихся и подростков.

Материалы и методы. Проведено поперечное обследование 277 школьников 10–14 лет (125 мальчиков и 152 девочки) с использованием антропометрических показателей, индекса Кетле (ИМТ) и Вервека, методов калиперометрии и биоимпендансометрии, сравнение их с результатами биоимпендансометрии продемонстрировало высокую точность побуждаемых моделей, что позволило подтвердить результаты t-теста. Выводы. Доказана высокая информативность методик, использованных для оценки физического развития, и целесообразность их применения в составе алгоритма комплексной оценки физического развития детского контингента, что является перспективным для дальнейшего мониторинга и анализа.

Ключевые слова: дети и подростки; физическое развитие; индекс массы тела; калиперометрия; биоимпендансометрия

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Клінічна педіатрія / Clinical Pediatrics

Сучасні підходи до оцінки фізичного розвитку дітей та підлітків

Резюме. Актуальность. На данный момент в Украине спостерігаються негативні тенденції у фізичному розвитку дитячої популяції з іншого навантаження надлишкової ваги, яка виступає предиктором розвитку ожиріння в дорослому віці, підвищення рівня хроничної соєматичної захворюваності та смертності. Мета дослідження: оцінити рівень фізичного розвитку учнів та визначити найбільш інформативну мето- дуку з позиції виявлення групи ризику щодо порушення хар- чового статусу. Матеріали та методи. Проведено поперечне обстеження 277 школярів 10–14 років (125 хлопців та 152 ді- вчички) із використанням антропометричних показників, ін- дексу Кетле (ІМТ) та Вервека, методів калиперометрії та біо- імпендансометрії з подальшою їх оцінкою за національними стандартами. Статистичну обробку даних проведено в ліцензованому пакеті IBM SPSS Statistics v. 22 з використанням t-тесту і об'єднуючих лінійних моделей. Результати. Аналіз статево-вікових особливостей фізичного розвитку показав вірогідне зменшення ІМТ в 11 роках та його зростання в 12 роках в обох статевих групах, ризик розвитку ожиріння у хлопців 10 та 12 років і гармонійний розвиток ді- вчат. За індексом Вервека процеси витягування реєструвались в 11-річних дівчат, відсутність процесів росту — у 10-річних дівчат і зростаючі процеси росту — у 11-річних хлопців обо- х статей. Різко дисгармонійний фізичний розвиток за національними шкалами регресії визначався в 12-річному віці, а гармонійний — у 10-річних хлопців та 13-річних ді- вчат. Вміст жирової тканини суттєво не відрізнявся в різних вікових групах, а м’язової — був істотно більшим у хлопців 14 років. Такі дані при порівнянні з ІМТ дозволяють зробити припущення, що більш високий індекс Кетле визначався за рахунок розвиненої м’язової системи, а не свідчив про формування ожиріння у хлопців. За результатами антропометричних досліджень отримані дві генералізовані змішані лінійні моделі для визначення вмісту жирової та м’язової тканин. Зіставлення їх із результатами біоимпендансометрії продемонстровало високу точність побудованих моделей, що було підтверджено результатами t-тесту. Висновки. Доведено високу інформативність методик, використаних для оцінки фізичного розвитку, і доцільність їх застосування в складі алгоритму комплексної оцінки фізичного розвитку дитичного контингенту, що є перспективним для подальшого моніторингу й аналізу мор- фофункціональних змін. Ключові слова: діти та підлітки; фізичний розвиток; індекс маси тіла; калиперометрія; біоимпендансометрія