Aerobic fitness of young adults born with low birth weight

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Abstract—

A birth weight that is too small could signal the occurrence of growth disorders or even growth deficiency, as well as a variety of disorders of bodily functions, including impaired glucose tolerance, insulin resistance and hypertension. However, so far the relation between birth weight and aerobic capacity has not been studied.

Objective: To compare the aerobic capacity of physically active young adults with different birth weights.

Methods: 159 people born at full term of a single pregnancy (F: 45%, n = 71; M: n = 88), first-year students studying Physical Education. In all cases the subjects' body composition was estimated, height and weight (BW) was measured, and the maximal oxygen uptake during exercises performed on an ergometer bicycle was established.

Results: the smallest birth body weight (BBW) was 2200 g; 3% of students (n = 5) were born with a BBW of less than 2500 g, and only 2% were born with BBW deficiency (<2 SDS). Physical development of the respondents was similar regardless of their gender and their BBW values, except for women born with small BBW (<1 SDS), whose BW was significantly lower than those born with a higher BBW. A trend of higher incidence of particularly good aerobic capacity in women with small BBW was observed.

Conclusions:

1.BBW is not a differentiating factor in young adults as regards their maximal oxygen uptake, but in females there is a tendency for the maximum oxygen uptake to diminish in those born with large BBW (> 2 s);

2. We suggest that when enrolling women for sports disciplines requiring their best aerobic capacity, birth weight should be taken into consideration, and based on the observations from the study it is furthermore suggested that a search for talent should be conducted among girls with BBW between 2300 and 3800 g.

Keywords— small for gestational age; birth weight; aerobic fitness.

I. INTRODUCTION

In some people born with a body size that is too small in relation to their gestational age (*Small for Gestational Age*, SGA) growth disturbances have been described, and in subsequent periods of life such people face an increased risk of chronic metabolic disorders leading to cardiovascular diseases, type 2 diabetes and hormonal disorders within the reproductive system [1, 2, 3, 4, 5, 6, 7]. It has been shown that adults born with body size deficiency are not only shorter, but also often are at a social disadvantage to those born with larger body weight and length [8, 9, 10, 11]. Therefore, can the information on small birth body size be considered to be a negative factor for people planning to become professional athletes? It has been concluded that answering such a question requires studying whether birth weight is correlated to maximum oxygen uptake capacity (VO_2 max). It should be emphasized that the importance of this issue has been growing with the increasing incidence of metabolic disorders in adolescents even before puberty [3, 12, 13, 14].

Birth body size, especially the length and weight, has long been used to assess the maturity of new-borns (as full-term versus pre-term).Since at least the second half of the 19th century, the assessment of new-born maturity was made on the basis of a new-born's birth body length (BBL) [15]. A change in this approach occurred in the 1930s, when a Finnish paediatrician ArvoYlppö suggested that birth body weight (BBW) should be primarily used for this purpose. Already in 1935, Ylppö's suggestions were included in the recommendations of the American Academy of Paediatrics, and in 1961 the experts of the World Health Organization recommended that a baby born of a pregnancy lasting at least 37 weeks should be considered to be full-term, as long as their weight is not less than 2500 grams (g) and babies born weighing less than 2500 g should be considered premature (i.e., pre-term). In this way, the criterion of BBW was introduced into clinical practice[16]. It is still widely used and considered as a simple and convenient screening tool - babies weighing more than 2500 g are considered

healthy and as long as there are no obvious abnormalities in their build and/or the functions of particular organs. Althoughit was soon discovered that such a criterion is too imprecise (and this took place 45 years ago), many medical centres are still using it today. Meanwhile, since the year 1970, scientific journals began to publish papers on the development of full-term new-borns born in a good condition, but bearing distinct features of hypotrophy that is with body size smaller than that of the general population. The classical meaning of the term neonatal hypotrophy was broadened to include intrauterine hypotrophy (IUGR, *Intrauterine Growth Retardation* or *Restriction*), and the broad concept of "a baby too small in relation to the duration of the pregnancy" (*Small for Gestational Age*, SGA) was introduced, so that nowadays less importance is placed on the reason for the slowdown in the growth of the foetus (which often difficult to identify clearly), and more on the necessity to observe the child's development in the following years of life [17, 18, 19, 20]. It turned out that in all populations, a percentage of full-term new-borns is characterized by small body size, and in some of them it is a factor for an increased risk of growth disorders, impaired glucose tolerance, insulin resistance, abnormal lipid profile, obesity, hypertension or type 2 diabetes in subsequent periods of life. In 1989, British researchers presented a paper explaining the relation between intrauterine foetal growth retardation (IUGR/SGA) and the aforementioned disorders. They called their concept the theory of *thrifty phenotype*, and in the literature the name *Barker hypothesis* was adopted, coined from the name of one of the authors [1, 2]. In simple terms, the Barker hypothesis, have now been superseded by "Predictive Adaptive Responses" and "Developmental Origins of Health and Disease", assumes that given the inadequate supply of energy to the foetus a change or shift of the method of regulating foetal metabolism may occur. Foetal development is not interrupted, but runs at a slower pace, and in some cases disorders detrimental to the growth and health condition of the subject may be observed after birth [1, 2, 4, 21]. In consequence of the foetal metabolic shift and the slower growth rate of the foetus, new-born body size is smaller than normal, and as already stated, in some cases growth disorders in childhood may appear, which may finally result in short stature [3, 21]. We believe that it is remarkable that despite extensive knowledge of the links between the course of foetal development and the rate of development and health in the subsequent stages of ontogeny, no papers analysing the potential relationship between birth body size and aerobic fitness have been published [22]. The ability to take up oxygen in an amount to necessary to perform various physical exercises makes it possible not only to do sports, but above all, to work and perform all the necessary daily activities.

Aim of the paper: To compare the aerobic fitness of physically active young adults with different birth body weights.

II. METHODS

2.1 Participants

The study included 159 individuals born at full term from a single pregnancy - female (F 45%, n = 71) and male students (M, n = 88) of the first year of the Department of Physical Education at the University of Physical Education in Warsaw. All respondents practiced physical activity on a regular basis - 73% of respondents exercised during trainings organized by the school or professional sports club, and the remaining respondents participated in individually-organized training sessions.

2.2 Design

The protocol of the study was approved by the local ethics committee. The main criterion for being included in the study was being a student of first year at the faculty of Physical Education, and exclusion criteria were: 1. chronic diseases; 2. inflammation requiring pharmacological treatment for four weeks prior to the tests; 3. sustaining injury to the motor system that requires surgical and/or orthopaedic treatment with the recommendation of limiting physical activity for longer than a week, within three months preceding the tests. All students participated in this study voluntarily, and those conducting the study did not teach students any classes during their first academic year, which was considered the lack of conflict of interests. Prior to testing, subjects were informed of the following requirements: 1. The need to participate in the tests after having slept the previous night; 2. eating a light meal containing no coffee or strong tea within one hour before the test; 3. refraining from drinking alcohol and smoking cigarettes for 24 hours before the test. Respondents were instructed not to do any intense physical activity during the day before the tests. Women during menstruation were excluded from the tests.

2.3 Birth body size assessment

The information on birth body size, duration and whether it was single or twin pregnancy, as well as its course were obtained from medical records, usually the subjects' health booklets. Based on the average birth weight (BBW, g) of all respondents of the given gender and the value of one standard deviation (SD) from the mean, they were grouped in three classes: those with BBW in the range of -1.0 SDS to +1.0 SDS, those with BBW less than -1.0 SDS (BBW<-1 SDS) and those with BBW larger

than 1.0 SDS (BBW > 1 SDS).

2.4 Assessment of the current size and composition of the body

For all respondents, anthropometric measurements were taken in the morning - the current body weight and height and the circumference of the waist and hips were measured. Based on the results of anthropometric measurements, their body mass indexes (*Body Mass Index* BMI, kg/m^2) and the *Waist Hip Ratio* (WHR) were calculated. Body composition was assessed with the method of bioelectrical impedance. The amount of total body fat (*Fat Mass* FM, kg and per cent), lean body mass (*Free Fat Mass*, FFM, kg and per cent) and water (H_2O, TBW, *Total Body Water)* was determined.

2.5 Aerobic fitness assessment

Aerobic fitness was estimated basing on the maximum oxygen uptake (VO_2 max), assessed directly. All measurements were recorded on a "breath to breath" basis in the resting phase, and during the exercise and post-exercise periods of restitution. The study used the following scheme: the exercise which was the subject of the test was preceded by a 5-minute warm-up on the ergometer bicycler with a load of 1 Watt per kilogram of body weight (W/kg) and then (starting from the 5^{th} minute of observation at the beginning of the test), every two minutes the load was increased by 0.5 W/kg of the subject's body weight. The subjects performed the exercise at the speed of 50 revolutions of the ergometer flywheel per minute. After finding that the RQ exceeded 1.0, the workload was not increased, but the subject was recommended to increase the speed of the flywheel rotation to 60-80 revolutions per minute. The following were adopted as the criteria for ending the test: the refusal of the respondent to continue or the reduction of oxygen consumption in the subsequent result on the display screen of the ergospirometer with increasing minute ventilation values.

2.6 Statistical Analysis

For each of the indicators, average values were calculated (±SD) and, subsequently with the aid of the *t-test* for independent trials, the differences between mean values in the separate groups of men's and women's BBW were examined. The significance of differences in the numbers of the study groups was determined by means of the Chi-square test. For all analyses the level of significance of $p<0.05$ was assumed.

III. RESULTS

The average age of male and female respondents was respectively 19.7 ± 0.67 years in the range between 18.3 to 22.7 years and 19.7 ±0.73 years in the range between 18.02 to 22.5 years. The average female birth weight was 3327.9 ± 448.9 g in the range from 2250 to 4420 g, and the average male birth weight was 3523.0 ± 506.9 g in the range from 2200 to 4850 g. In our sample, only 3% of students (n = 5) were born with a birth weight of less than 2500 g. The average value of the maximum oxygen uptake, expressed in millilitres (mL) per minute per kilogram of body weight was, for all women and all men, 41.7 ± 5.1 in the range of 24.9 to 53.3 and 53.2 ± 5.3 in the range of 38.8 to 64.5 respectively, and after normalization it was 0.82 ± 0.73 SDS in the range from -1.61 to 2.51 and 1.42 ± 0.74 SDS in the range from -0.58 to 2.99 SDS [21].Average normalized value of VO_2 max in men proved significantly higher than in women ($p<0.001$).

Tables 1 and 2 show the mean values of birth weight and body length and selected indicators of body composition and maximum oxygen uptake values in men and women surveyed, divided into classes depending on the value of birth weight.

TABLE 1

WOMEN (N=71): SOMATIC FEATURES (MEAN ± SD) ARE PRESENTED DEPENDING ON THE NORMALIZED BIRTH WEIGHT (BBW, SDS) OF THE SUBJECTS

Abbreviations: BBW, SDS - standardized birth weight; "<1.0" - BBW less than the value of one standard deviation from the mean value (SDS) of BBW in the research group; "from -1.0 to 1.0" - BBW in the range of -1.0 to 1.0 of standard deviation from the mean BBW in the research group; "> 1.0" - BBW larger than the value of one standard deviation from the mean BBW in the research group; BMI - body mass index; WHR - Waist-to-Hip Ratio; Fat mass - fat content in body composition; Water mass - water content in body composition; * / ** - Body weight, normalized body weight and fat mass in body composition of women with BBW <-1.0 SDS significantly lower than in other fractions (BBW class "-1.0 to 1.0" SDS and "> 1.0 "SDS), $p<0.05$ (*) / $p<0.01$ (**);$^{\#}$- Average normalized VO_2 max in the group of women with low BBW higher than in the group with high BBW, a statistically significant difference at the level of the trend.

BBW, SDS / VARIABLES	< -1.0 n=12; 16.7%	from -1.0 to 1.0 n=50; 70.8%	> 1.0 n=9; 12,.%
BBW,[g]	2635.8±183.97	3371.9±274.27	4001.1±177.65
Age, [years]	19.74±1.02	19.75±0.69	19.51±0.49
Body weight, [kg]	55.85±5.23**	61.74±7.22	62.48±4.49
Body weight, [SDS]	-0.32±0.86**	0.62±1.19	0.77±0.74
Body height, [cm]	166.09±5.54	169.98±6.5	170.27±4.51
Body height, [SDS]	0.1±0.91	0.74±1.07	0.79±0.74
BMI, [kg/m^2]	20.25±1.68	21.3±2.19	21.63±2.42
Waist size, [cm]	67.11±3.78	69.31±5.52	69.71±4.93
Hip circumference, [cm]	88.21±6.27	90.63±8.12	91.98±5.69
WHR	0.76±0.06	0.77±0.07	0.76±0.08
Fat mass, [%]	22.62±5.77	25.64±5.45	24.27 ±8.16
Fat mass, [kg]	11.34±2.73*	14.56±4.19	15.37±4.71
Water mass, [kg]	32.6±2.41	34.5±3.27	36±5.25
Water mass, [%]	60.48±4.12	60.58±6.7	65.15±4.7
VO_2max,[mL/kg/min.]	43.8±4.8	41.3±4.8	40.9±6.0
VO_2max,[SDS]	1.13±0.7$^{\#}$	0.8±0.71	0.53±0.83

TABLE 2

MEN (N=88): SOMATIC FEATURES (MEAN ± SD) PRESENTED DEPENDING ON THE NORMALIZED BIRTH WEIGHT (BBW, SDS) TESTED

BBW, SDS / VARIABLES	**< -1.0** n=11; 12.5%	**from -1.0 to 1.0** n=64; 72.7%	**> 1.0** n=13; 14.8%
BBW,[g]	2729±254.3	3491±280.15	4355±254.84
Age, [years]	19.81±0.67	19.76±0.78	19.95±0.73
Body weight, [kg]	78.2±7.01	75.51±8.29	78.47±6.95
Body weight, [SDS]	0.93±0.7	0.66±0.83	0.96±0.7
Body height, [cm]	183.43±6.63	181.09±6.49	183.81±5.1
Body height, [SDS]	0.79±1.04	0.42±1.02	0.85±0.8
BMI, [kg/m^2]	23.23±1.44	23.04±2.45	23.21±1.55
Waist size, [cm]	78.78±4.64	78.52±5.53	80.44±3.51
Hip circumference, [cm]	96±7.33	93.09±5.89	95.83±4.95
WHR	0.82±0.07	0.84±0.05	0.84±0.03
Fat mass, [kg]	9.48±3.84	9.47±4.14	9.15±3.3
Fat mass, [%]	11.76±4.16	12.64±4.87	11.96±3.3
Water mass, [kg]	50.31±4.1	48.41±4.42	50.75±4.51
Water mass, [%]	64.43±2.97	64.3±3.21	64.72±2.31
VO_{2max},[mL/kg/min.]	53.2±5.8	53.4±5.4	52.7±4.5
VO_{2max},[SDS]	1.21±0.87	1.49±0.73	1.26±0.62

IV. DISCUSSION

The aim of the study was to find the relation between birth weight and physical capacity, and to investigate what proportion of people born with small body size choose studies in the field of physical education. If the choice of field of study is regarded as a sign of choosing a future career in a particular area of the market, studying physical education may be seen as aiming for professions such as a P.E. teacher, sports instructor, coach, organizer of sports events or sports animator. Due to the demands that both students and graduates working in professions connected with their field of study have to face, the authors of the study have decided to examine whether small birth body size is reflected in the physical fitness of young adults studying physical education. Another argument which encouraged the team to pursue this research question was the fact that small birth body size shows that the body has fewer than the average number of cells, and may increase the risk of growth disorders and/or metabolic disorders, including impaired glucose tolerance, insulin resistance in the subsequent stages of life [24, 25, 26].

In literature it is generally estimated that in European populations approximately 5% of individuals are born with birth weight deficiency (BBW <-2 SDS for population norms) and in other regions of the world this percentage is even 2-3 times higher [27, 28, 29]. In the study group only 2% (n =3; 2 M and 1 F) of all students had a deficiency of body weight. It should be emphasized that none of the subjects was born with birth weight of less than -2.5 SDS BBW, that is, their weight was above the threshold of 2000 g. Meanwhile, among babies born in 1991 and 1992, the years when the respondents were born, new-borns with birth weight of less than 2000 g accounted for 3% of the population. In other words, 16,000 babies in 1991 and nearly 15,000 babies in 1992 in Poland were born with BBW between 2000 and 600 g[30].

To compare the differences between the BBW of respondents and the general population, researchers referred to the classification used in Polish demographic annals, where particular classes of BBW are established with every 500 g. It turned out that all subjects born with the lowest weight would fall into the range of 2001 g to 2500 g, according to the above classification. Their percentage - nearly 4% - is no different from the percentage of new-borns with BBW in the range of 2001 g to 2500 g in the years of 1991 and 1992, amounting to 4.8% and 4.6% [30]. As mentioned above, most of the study subjects were born in the years 1991 and 1992. It was concluded that the evidence was in favour of asserting that physical education as a field of study was not chosen by those born with a profound body weight deficiency (BBW <2000 g or BBW <-2.5 SDS), and the number of physical education students born with less severe weight deficiency is not different from the general population. Consequently, it can be assumed that among physical education teachers, as well as other professional groups related to sports and leisure there are very few people born with a profound BBW deficiency. The authors of this study found no publications describing populations similar to our group in the literature of the subject. In the work of Strauss, who for 26 years followed a cohort of British children (over 14,000) born in 1970, there are indeed some indications as to the education and careers of those born with a body weight deficiency, but it is not possible to determine what courses of study they chose [8]. When assessing the status of the British cohort (53% of the initial group took part in the evaluation 26 years later), Strauss found no vital differences between those born with a weight deficiency and normal body size. Those diagnosed with hypotrophy (SGA) earned less than those born with larger with body size, they were also significantly shorter (-0.55 versus 0.08 SDS). Interesting observations on the development of people born deficient in body size are also presented in Stein's paper from 2013 and the paper of Hollo from a few years earlier [31, 32]. Still, there remains the question concerning the choice of the field of study by people born with hypotrophy and whether these choices may be different than of those born with higher birth body size [8, 11].

In view of the fact that the representation of people born with birth weight deficiency in the studied population is modest, it was decided to investigate whether a smaller reduction in BBW may affect the physical development and aerobic capacity of young adults. The value of one standard deviation from the mean BBW in the study subjects, calculated separately for all women and all men, was used in order to divide subjects into classes. Three categories of studied men and women were thus created: the most numerous class of narrow population standard (from -1 to 1 SDS BBW) and the class of 'lighter' and 'heavier' new-borns in terms of the BBW. It turned out that the BBW of 'lighter' male new-borns was on average by almost 800 g less (range, differences of 523 g to 1323 g) than the mean BBW for all men and in women it was nearly 700 g less (between 478 g and 1078 g) than the mean BBW for all female babies. It was therefore assumed that regardless of gender, such as a significant reduction in the mean BBW can be regarded as a confirmation that the number of cells in the body of those individuals was so much lower than average that it may have caused differences in terms of their somatic development against those born with higher body weight. In the last 20 years, abundant evidence has been demonstrated which proves the hypothesis that the reduction in birth body size in comparison with population norms means the body is equipped in a lower

than average number of cells in certain organs that it may lead to the establishment of a specific metabolic system (Developmental Origins of Health and Disease, DOHD) [1, 2, 24, 25]. Our study focused only on those born at full term from single pregnancies, but it should be emphasized that both in literature and in clinical practice a difference is marked between body size deficiency resulting solely from the fact of premature birth and intrauterine growth retardation in new-borns born at full term (of gestation longer than 37 weeks). In the first case, the dimensions of the body may be appropriate with respect to the duration of the pregnancy, whereas in the second they are reduced due to a factor having a negative impact on foetal nutrition. In such unfavourable conditions for the development of the foetus, a process of adaptation begins, which is designed to ensure the availability of nutrients for the growth of the most important organs whose functioning is indispensable for survival - especially the central nervous system and cardiovascular system. These systems are favoured in terms of distribution of energy. The above process has been described as the theory of *"thrifty phenotype"*(DOHD)[1, 2]. It is worth mentioning that since the validity of DOHD was proved, literature emphasizes the need of recognition of routine diagnosing of reduction in birth body size in relation to the duration of the pregnancy, which should be treated as a factor connected with an increased risk of future cardiovascular and renal diseases, impaired glucose tolerance and insulin resistance (the so called non-communicable disease). Despite numerous publications confirming the validity of DOHD, studies concerning exercise tolerance in people of varied BBW remain rare. In one of such studies Baraldi et al. presented a performance evaluation in children aged from 7 to 12. They found no difference in exercise tolerance in exercises performed on a treadmill for children born with significantly reduced BBW (*Very Low Birth Weight*, VLBW) and normal weight (*Appropriate for Gestational Age*, AGA) [22].

4.1 Body composition of respondents

What was surprising was the lack of significant differences between the body size in subjects with varying BBW - and the difference between the lightest and the heaviest new-borns amounted to more than 2 kg in women and 2.5 kg in men. The exception concerned women born with low birth weight (from the 'light' new-born class), which as adults proved to be significantly lighter (0.01) than women weighing more at birth. Women with small BBW also had on average less (0.05) fat in the body composition than those weighing more at birth. However, when the content of body fat was expressed in per cent, it was discovered that BBW is no longer a factor making them stand out among those with a higher BBW. It was discovered that the amount of fat and lean body mass expressed in kilograms significantly positively correlated with BBW in women (0.001 for FM, kg; 0.01 for FFM). This observation is important in light of the results of the research by Jogkeker's et al. (2007), who found that smaller birth body size may predispose the individual to the development of insulin resistance, and larger size - to the increased risk of cardiovascular diseases [31]. It should be emphasized, however, that the concept of the early development of insulin resistance in the SGA is based on the assumption that the metabolic shift in foetal development resulted in a deterioration of the muscular system development, which has not yet been sufficiently demonstrated.

Among the respondents there were no people with short stature. The lowest male body height was -1.7 SDS (BBW 3200 g and 56 cm BBL), and for women only -1.4 SDS for the population of Warsaw. Therefore, short-statured people of body height of less than -2 SDS, who account for about 3% of each population, were not represented among the respondents.It was discovered that regardless of gender in the class of people with low BBW, the lowest body height was -1.1 SDS, that is only slightly below the lower limit of the normal body height in the population (narrow population norm - between -1 to 1 SDS). It was surprising that the body height for more than half of the number of men classified as having low BBW exceeded 1.5 SDS for the population of Warsaw, with the tallest male subject (1.97 SDS) also being the tallest person (taking into account both average body height both for men and women) among all subjects (n = 159). It has been assumed, therefore, that those in the class of small BBW were people who in childhood quickly made up for the deficiencies of the foetal period and displayed no growth abnormalities typical of some SGAs [21]. It should be stressed that the reported observations are not consistent with the results of the final evaluation of body height among born with body size deficiency, since for more than 40 years many authors have been describing characteristic growth disturbances in a percentage of SGAs and, consequently, smaller final body height than among the AGA [21, 34, 35, 36]. It may be recalled that almost 20 years ago, in 1993, Paz first described the results of measurements of body height of a cohort consisting of nearly 2000 young men [37]. It turned out that those who were born with smaller body size were at the age of 17 significantly shorter than those born with normal body size, and the risk of achieving the final body size below the 10th percentile of the population standard was 4 times higher in the group with deficiencies of birth body size. The incidence and seriousness of growth disorders resulted in the recognition of short stature in SGA children as routine indication for treatment with recombinant human growth hormone [21, 39]. It should be noted that none of the students that were interviewed declared that in childhood they were observed and treated for growth

disorders. And therefore the study group included only those whose growth after birth, regardless of their BBW, proceeded normally and the amount of body fat was also normal because of regular physical activity.

4.2 Aerobic fitness

The results of the analysis of maximal oxygen uptake were surprising. Although statistically significant differences between different classes of BBW have not been demonstrated, women born with low birth weight had slightly higher aerobic fitness than those with higher BBW. The difference was significant at the level of trends for standardized values of VO_2 max. It was found, however, that the most efficient woman in terms of aerobic fitness (VO_2max 2.5 SDS; 53.3 mL/kg/ min.) was born with small body size - weighing 2750 g and 48 cm long. In the group of women with small BBW, 3 other students were characterized by a distinctively higher ability to uptake oxygen - between 1.8 and 1.85 SDS. A similar phenomenon was observed also in men - in the group with low BBW, two from among 11 subjects were characterized by excellent aerobic fitness of 2.4 and 2.8 SDS. However, it was discovered that the percentage of people with the best ability for maximal oxygen uptake in the cohort - men with VO_2 max> 2 SDS and women with > 1.5 SDS - is similar in BBW each class. No difference between the percentage of men and women with high aerobic fitness was demonstrated in individual BBW classes. Therefore, it has not been proved that those born with body size smaller than average in the population are characterized with inferior muscular development and worse capacity for skeletal muscle oxygen uptake. Regardless of gender, all individuals included in the low BBW class from the study group (<1 SDS) and at the same time all with BBW deficiency (<2 SDS) have proven to be fully efficient in oxygen uptake. The ability for maximal oxygen uptake in the female subject with smallest BBW (BBW 2250 g, BBL 49 cm) was estimated to be 0.1 SDS (36.5 mL/kg/min.), and in the male subject with smallest BBW (BBW of 2200 g, BBL 47 cm) to be 0.27 SDS (45 mL/kg/min). Another man, also born with a significant body size deficiency (BBW 2400 g, BBL 49 cm) demonstrated excellent aerobic fitness, determined to be 62.9 mL of oxygen per kilogram of body weight per minute (2.1 SDS).

The occurrence of sexual dimorphism in the relation between BBW and the ability for maximal oxygen uptake has been observed, as only in women a statistically significant (0.01) negative correlation of both indicators has been reported. In women with BBW higher than average, there is a more significant risk that their aerobic fitness will be less favourable for physical activity. It is therefore postulated that in the selection process for women's sports, birth body size should be considered and outstanding athletes should be sought particularly among girls born with low and average birth weight for the population. In the case of the female study group the scope of such "favourable" BBW was between 2250 g to 3750 g (≈2300 – 3800 g).

So far, BBW deficiency was considered synonymous with poor muscular development in SGA children, which in subsequent years of life is reported to be a stimulus for the early development of insulin resistance [14, 33, 34]. The assessment of muscle development in hypotrophic new-borns and infants was previously performed very rarely and indirectly, as it seems, basing on the estimated amount lean body mass in the body composition [39]. Lean body mass is also made up of internal organs, and as it has been demonstrated, at least some of the organs are made of smaller than average number of cells, and have a smaller than average weight [23]. It seems that when formulating the view concerning foetal hypotrophy of muscles in SGA children, the importance of the muscular system to achieve life objectives was not sufficiently catered for, and this regards people to the same extent as any other animal having muscles. In fact, well developed skeletal muscles and good oxygen supply provide access to food, allow adaptation to changing environmental conditions and allow reproduction, and therefore the musculoskeletal system is essential for the survival of each species. Our observations may indicate that unlike previously assumed, the development of the muscular and metabolic pathways responsible for providing oxygen to the muscle fibres is subject to special protection after the introduction of the so-called *thrifty phenotype* - economizing on energy delivered to the body of the foetus. And thus it seems natural that the metabolic program triggered by permanent impairment of foetal nutrition - a kind of contingency plan of the body - favours not only the nervous system and cardiovascular system, but also the muscular system, when it comes to the distribution of energy. Our hypothesis is supported by studies on animals - pigs and sheep showed no reduction in the number of muscle cells despite impaired nutrition of the foetus [40, 41, 42, 43]. The hypothesis that the muscular system is protected in the event of an impairment of the foetal nutrition is also supported by the fact that for thousands of years only the adequate capacity to perform physical activity enabled the survival of the subject, and, above all, the continuity of the species. It is perhaps for this reason that sexual dimorphism favouring women in the protection of selected systems, including perhaps especially the muscular system, may be observed. If so, then the female foetus - reaching smaller weight in times of hunger - may be better suited to survive than the male foetus, which, after the improvement of living conditions, increases the chances of the survival of the species. At the same time it may be postulated

that, in view of these observations, the development of insulin resistance is caused not by the impaired foetal development of the muscular system, but only by insufficient physical activity of the subject in subsequent periods of life, which has repeatedly been demonstrated.

V. CONCLUSION

- Young adults born at full term with a low BBW do not differ in terms of aerobic fitness from their peers born with higher BBW;
- The amount of birth body weight does not differentiate young adults in their maximal oxygen uptake, but in females there is a tendency for the maximum oxygen uptake to worsen in those with high BBW;
- The authors of this study suggest that during enrolment for disciplines requiring first and foremost the best aerobic fitness, the amount of BBW should be taken into account in females, and, basing on the above observations, the authors suggest that the search of talent should be conducted among girls weighing between 2300 g and 3800 g at birth;
- The authors of this study believe that if mode of economic energy consumption was triggered due to permanent foetal nutrition disorders, the development of the structure and metabolic functions of the muscular system is subject to special protection, which allows people born with small body size to perform physical activity to the same extent as those born with normal body size.

REFERENCES

[1] Barker DJP, Osmond C, Winter PDW, Margetts B, Simmonds SJ. Weight in infancy and death from ischaemic heart disease. Lancet 1989; 2(8663):577–580.

[2] Barker DJ, Winter PD, Osmond C, Margetts B, Simmonds SJ (1989). Growth in utero, blood pressure in childhood and adult life, and mortality from cardiovascular disease. BMJ 1989; 298(6673):564-567.

[3] Phenekos C. Influence of foetal body weight on metabolic complications in adult life: review of the evidence. J PediatrEndocrinolMetab2001; 14(supl. 5):1361-1363.

[4] Law CM, Shiell AW, Newsome CA, Syddall HE, Shinebourne EA, Fayers PM.Fetal, infant, and childhood growth and adult blood pressure: a longitudinal study from birth to 22 years of age. Circulation 2002; 105(9):1088–1092.

[5] Wolfenstetter A, Simonetti GD, Pöschl J, Schaefer F, WühlE. Altered Cardiovascular Rhythmicity in Children Born Small for Gestational Age. Hypertension 2012; 60(3):865-870.

[6] Ibanez L, Potau N, Enriquez G, de Zegher F. Reduced uterine and ovarian size in adolescent girls born small for gestational age. Pediatr Res 2000; 47(5):575-577.

[7] Ridgway CL, Ong KK, Tammelin T, Sharp SJ, Ekelund U, Jarvelin MR.Birth size, infant weight gain, and motor development influence adult physical performance.Med Sci Sports Exerc. 2009;41(6):1212-21.

[8] Strauss RS. Adult functional outcome of those born small for gestational age: twenty-six-year follow-up of the 1970 British Birth Cohort.JAMA2000; 283(5):625-632.

[9] Lundgren EM, Tuvemo T. Effects of being born small for gestational age on long-term intellectual performance. Best Pract Res ClinEndocrinolMetab2008; 22(3):477-488.

[10] O'Keeffe MJ, O'Callaghan M, Williams GM, Najman JM, Bor W. Learning, cognitive, and attentional problems in adolescents born small for gestational age. Pediatrics2003; 112(3):301-307.

[11] Lund LK, Vik T, Lydersen S, Løhaugen GC, Skranes J, Brubakk AM, Indredavik MS.Mental health, quality of life and social relations in young adults born with low birth weight. Health Qual Life Outcomes2012;10(146):1-10.

[12] Milovanovic I, Njuieyon F, Deghmoun S, Chevenne D, Levy-Marcha C, Beltrand J. SGA Children with Moderate Catch-Up Growth Are Showing the Impaired Insulin Secretion at the Age of 4. PLoS One2014; 9(6):e100337.

[13] Labayen I, Ortega FB, Sjöström M, Ruiz JR.Early life origins of low-grade inflammation and atherosclerosis risk in children and adolescents.J Pediatr. 2009;155(5):673-677.

[14] Ortega FB, Ruiz JR, Hurtig-Wennlöf A, Meirhaeghe A, González-Gross M, Moreno LA, Molnar D, Kafatos A, Gottrand F, Widhalm K, Labayen I, Sjöström M.Physical activity attenuates the effect of low birth weight on insulin resistance in adolescents: findings from two observational studies.Diabetes. 2011;60(9):2295-9.

[15] Holt LE. Diseases of Infancy and Childhood, in Holt LM, McIntosh (red.) Holt-McIntosh's Textbook of Pediatrics, New York-Presbyterian Morgan Stanley Children's Hospital, 1986.

[16] Ylppö A. New classification and nomenclature for new-born infants including prematures and abortions. ActaPaediatrica1948; 35(suppl 1):160-163.

[17] Maulik D. Fetal growth compromise: definitions, standards, and classification. ClinObstetGynecol 2006; 49(2):214-218.

[18] 18. Chauhan SP, Gupta LM, Hendrix NW, Berghella V.American College of Obstetricians and Gynecologists.Intrauterine growth restriction: comparison of American College of Obstetricians and Gynecologists practice bulletin with other national guidelines.Am J ObstetGynecol2009; 200(4):409.e1-6.

[19] Lausman A, Kingdom J, Maternal Fetal Medicine Committee, Gagnon R, Basso M, Bos H, Crane J, Davies G, Delisle MF, Hudon L, Menticoglou S, Mundle W, Ouellet A, Pressey T, Pylypjuk C, Roggensack A, Sanderson F. Intrauterine growth restriction: screening, diagnosis, and management.J ObstetGynaecol Can2013; 35(8):741-757.

[20] Gardosi J.New definition of small for gestational age based on foetal growth potential.Horm Res 2006;65(suppl 3):15-18.

[21] Lee PA, Chernausek SD, Hokken-Koelega AC, Czernichiw P. (2003). International Small for gestational Age Advisory Board consensus development conference statement: management of short children born small for gestational age. Pediatrics2003; 111(6 Pt 1):1253-1261.

[22] Baraldi E, Zanconato S, Zorzi C, Santuz P, Benini F, Zacchello F. Exercise performance in very low birth weight children at the age of 7-12 years.Eur J Pediatr 1991; 150(10):713-716.

[23] Fletcher GF, Gary J, Balady GJ, Ezra A, Amsterdam EA, Chaitman B, Eckel R, Fleg J, Froelicher VF. Exercise Standards for Testing and Training A Statement for Healthcare Professionals From the American Heart Association. Circulation 2001; 104(14):1694-1740.

[24] Zandi-Nejad K, Luyckx VA, Brenner BM. Adult Hypertension and Kidney Disease: The Role of Fetal Programming. Hypertension 2006; 47(3):502-508.

[25] Luyckx VA, Shukha K, Brenner BM. Low nephron number and its clinical consequences. Rambam Maimonides Med J2011; 2(4):e0061.

[26] Chiavaroli V, Marcovecchio ML, de Giorgis T, Diesse L, Chiarelli F, Mohn A. Progression of cardio-metabolic risk factors in subjects born small and large for gestational age. PLoS One2014; 9(8):e104278.

[27] WHO, UNICEF. Low birth weight: country, regional and global estimates. World Health Organization, Geneva, 2004.

[28] Lee AC, KatzJ, Blencowe H, Cousens S, Kozuki N, Vogel JP, Adair L, Baqui AH, Bhutta ZA, Caulfield LE, Christian P, Clarke SE, Ezzati M, Fawzi W, Gonzalez R, Huybregts L, Kariuki S, Kolsteren P, Lusingu J, Marchant T, Merialdi M, Mongkolchati A, Mullany LC, Ndirangu J, Newell ML, Nien JK, Osrin D, Roberfroid D, Rosen HE, Sania A, Silveira MF, Tielsch J, Vaidya A, Willey BA, Lawn JE, Black RE; CHERG SGA-Preterm Birth Working Group. National and regional estimates of term and preterm babies born small for gestational age in 138 low-income and middle-income countries in 2010.Lancet Glob Health2013; 1(1):e26-36.

[29] Pawlus B, Wisniewski A.Frequence of hypotrophic births in the Warsaw population. PediatrEndocrinol Diabetes Metab2010; 16(3):153-158.

[30] Demographic Yearbook of Poland (1991) and Demographic Yearbook of Poland (1992). Central Statistical Office (CSO), 1992 and 1993, Warsaw.

[31] Stein AD, Barros FC, Bhargava SK, Hao W, Horta BL, Lee N, Kuzawa CW, Martorell R, Ramji S, Stein A, Richter L.Consortium of Health-Orientated Research in Transitioning Societies (COHORTS) investigators.Birth status, child growth, and adult outcomes in low- and middle-income countries.J Pediatr 2013; 163(6):1740-1746.e4.

[32] Hollo O, Rautava P, Korhonen T, Helenius H, Kero P, Sillanpää M. Academic achievement of small-for-gestational-age children at age 10 years.Arch PediatrAdolesc Med 2002; 156(2):179-187.

[33] Joglekar C, Fall CHD, Deshpande VU, Joshi N, Bhalerao A, Solat V, Deokar TM, Chougule SD, Leary SD, Osmond C, Yajnik CS. Newborn size, and childhood growth, and cardiovascular disease risk factors at the age of 6 years; The Pune Maternal Nutrition Study. Int J Obes (Lond) 2007; 31(10):1534–1544.

[34] Ridgway CL, Brage S, Sharp SJ, Corder K, Westgate KL, van Sluijs EM, Goodyer IM, Hallal PC, Anderssen SA, Sardinha LB, Andersen LB, Ekelund U.Does birth weight influence physical activity in youth? A combined analysis of four studies using objectively measured physical activity.PLoS One.2011;6(1):e16125.

[35] Albertsson-Wikland K, Wennergren G, Wennergren M, Vilbergsson G, Rosberg S. Longitudinal follow-up of growth in children born small for gestational age. ActaPaediatr1993;82(5):438-443.

[36] Fitzhardinge PM, Steven EM (1972). The small-for-date infant. I. Later growth patterns.Pediatrics1972; 49(5):671--681.

[37] Paz I, Seidman DS, Danon YL, Laor A, Stevenson DK, Gale R.Are children born small for gestational age at increased risk of short stature? Am J Dis Child1993; 147(3):337-339.

[38] Van Pareren Y, Mulder P, Houdijk M, Jansen M, Reeser M, Hokken-Koelega A. Adult height after long-term continuous growth hormone (GH) treatment in short children born small for gestational age: results of a randomized, double-blind, dose-response GH trial. J ClinEndocrinolMetab2003; 88(8):3584-3590.

[39] Hediger ML, Overpeck MD, Kuczmarski RJ, McGlynn A, Maurer KR, Davis WW.Muscularity and fatness of infants and young children born small- or large-for-gestational-age.Pediatrics1998; 102(5):E60.

[40] Hamada H. Role of physical forces in embryonic development. Semin Cell Dev Biol. 2015; 47-48:88-91.

[41] Greenwood PL, Slepetis RM, Hermanson JW, Bell AW. Intrauterine growth retardation is associated with reduced cell cycle activity, but not myofibre number, in ovine foetal muscle.ReprodFertil Dev1999; 11(4-5):281-291.

[42] McCoard SA, McNabb WC, Peterson SW, McCutcheon SN, Harris PM.Muscle growth, cell number, type and morphometry in single and twin foetal lambs during mid to late gestation.ReprodFertil Dev2000; 12(5-6):319-327.

[43] Bellinger L, Sculley DV, Langley-Evans SC. Exposure to undernutrition in fetal life determines fat distribution, locomotor activity and food intake in ageing rats. Int J Obes (Lond). 2006; 30:729–738.