Anthropological Review • Vol. 87(4), 55–67 (2024)

ANTHROPOLOGICAL REVIEW

Available online at: https://doi.org/10.18778/1898-6773.87.4.04

Changes in body composition (muscle mass and adipose tissue) among adolescents aged 11–15 from Kraków during the COVID-19 pandemic

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Abstract: Study aim: To assess changes in body composition, specifically focusing on muscle mass and adipose tissue, among adolescents aged 11–15 in Kraków during the COVID-19 pandemic.

Materials and Methods: Cross-sectional studies were conducted in four selected districts of the city of Kraków in the years 2020 and 2022 (before and after the COVID-19 pandemic). The study group included adolescents aged 11–15 years. The percentage of body fat (%BF) was measured using the bioimpedance method. Additionally, measurements of height, arm circumference, and skinfold thickness of triceps were taken using a skinfold calliper. The collected data were used to calculate the Corrected Arm Muscle Area (CAMA). The normality of the distribution of each feature was assessed using the Shapiro-Wilk test. Statistical analysis was performed to compare differences between groups using two-way ANOVA with Tukey's HSD post-hoc test or the Kruskal-Wallis test.

Results: Among girls, a decrease in muscle mass was observed in most age categories. The opposite trend was observed among boys, as an increase in muscle mass was observed in most of the age groups. Girls were characterized by a decrease in the %BF in all cohorts, while in boys, an increase in the %BF was observed among 11,13 and 15-year-olds. In most age groups, there was an increase in the average muscle mass and increase in the %BF depending on BMI (Body Mass Index) categories in both sexes.

Conclusions: This study found no notable variances in muscle mass and %BF within the examined group amid the COVID-19 pandemic. While certain outcomes indicated regression, possibly linked to reduced physical activity or prolonged sedentary periods, not all research findings exhibited decline. This could be attributed to online physical activity or enhanced dietary habits.

Key words: coronavirus, children, muscle mass, body fat

Received: 23.04.2024; Revised: 3.09.2024; Accepted: 5.12.2024

Introduction

The disease caused by the SARS-CoV-2, has been recognized as one of the most serious pandemics in the world, significantly impacting the lifestyles of billions of children and young people (Karatzi et al. 2021; de Girolamo et al. 2022; Kutac et al. 2022; Musa et al. 2022). To prevent the spread of the coronavirus and the collapse of national healthcare systems, governments on all continents have imposed strict isolation measures on their citizens. The implemented precautionary measures included the closure of schools for a significant portion of 2020 at all levels of education, restrictions on travel and various forms of transportation, the closure of shops, restaurants, and all non-essential businesses where remote work was feasible, and the government mandated stay-at-home orders (Martinez-Ferren 2020; Damanti et al. 2021; Karatzi 2021; Musa et al. 2022). Unfortunately, some of the imposed restrictions, such as social distancing, closure of gyms and sports facilities, as well as limitations on outdoor activities have significantly impacted people's lifestyles, including overall health status, habits related to physical activity, diet, and other health-related behaviors (Lesser, Nienhuis 2020; Tison et al. 2020). Research has shown that during the pandemic unhealthy eating patterns have risen, including changes in the types of food consumed as well as changes in other eating habits that might have caused the loss of control over the caloric content of consumed food (Ammar et al. 2020). It has been suggested that the current lack of physical activity may lead to the formation of entrenched habits that persist after the SARS-CoV-2 crisis (Chen et al. 2020). The factors described above can also contribute to the occurrence of overweight, obesity, and a decline in physical fitness (Kovacs et al. 2021; Kutac et al. 2022). This is supported by the findings of an online survey conducted in Italy, showing that 49.6% of respondents did not change their diet, 46.1% of respondents reported eating more during the lockdown, and 19.5% gained weight. The survey revealed a notable increase in the consumption of "comfort food," particularly ice cream, chocolate, desserts (42.5%), as well as salty snacks (23.5%). Despite reduced access, 21.2% of participants increased their intake of fresh vegetables and fruits (Scarmozzino, Visioli; 2020). In turn, obesity was shown to be a significant public health issue that increases the risk of cardiometabolic problems such as cardiovascular diseases, diabetes, hypertension, and dyslipidemia, and it is correlated with an increased risk of COVID-19 complications (Krams et al. 2020; WOF 2020; Karatzi et al. 2021; Loza et al. 2022). Body composition analysis is one of the methods of assessing health status, nutritional status, and the impact of illness and dietary changes (Toomey et al. 2015; Kutac et al. 2022). Body composition measurement provides insights into the health status and lifestyle habits of young individuals. Body composition is influenced by genetic and exogenous factors, physical activity, nutrition, and overall health (Kutac et al. 2022). Studies among adolescents aged 11–18 have shown that the COVID-19 pandemic has significantly affected body composition. For example, there has been an increase in adipose tissue surface area and visceral adipose tissue, accompanied by a decrease in skeletal muscle mass. In addition, no significant changes in body weight and Body Mass Index (BMI) have been observed (Kutac et al. 2022).

Studies have shown that the pandemic may have contributed to an increase in the rate of weight gain among children and adolescents due to limited access to physical activity and extracurricular activities (Kovacs et al. 2021; Loza et al. 2022). Data collected worldwide have documented a significant decrease in physical activity, coupled with an increase in screen time during the SARS-CoV-2 virus-induced pandemic (Kovacs et al. 2021). Research on Austrian children aged 7–10 further highlights these trends, revealing a decline in cardiovascular-respiratory fitness alongside increases in BMI SDS values. The prevalence of overweight and obesity among these children rose from 15.0% to 21.2% when analysing the results before and after the COVID-19 pandemic (Jarnig et al. 2022). These data are supported by observational studies (n=8395) conducted in 10 European countries, which reported the exceeding of the daily screen time limit (>2 hours/day) among 69.5% of young individuals aged 6–18 during weekdays and 63.8% on weekends (Kovacs et al. 2021). Furthermore, among adolescents in Shanghai, an increase from 21.3% to 65.6% in physically inactive students was recorded (Xiang et al. 2020).

The aim of the study was to assess changes in body composition, specifically the proportion of muscle mass and adipose tissue, among adolescents aged 11–15 from Kraków during the COVID-19 pandemic.

Materials and methods

The adolescents analysed in this study were included in two series of cross-sectional studies conducted in 2020 and 2022, carried out in randomly selected primary schools located in four traditional districts (Śródmieście, Podgórze, Krowodrza, Nowa Huta) of Kraków.

The study group consisted of adolescents aged 11–15, who were divided by age and sex. The calendar age of the participants was calculated as the difference between the date of the study and the date of birth, expressed as a decimal fraction. The calendar age of the participants ranged from 10.50 to 15.49 years and served as the basis for classifying each participant into one of five age groups (e.g., adolescents aged 10.50–11.49 years were classified as 11-year-olds). The sample size included 1069 individuals in 2020 (557 girls, 512 boys) and 593 children in 2022 (288 girls, 305 boys) (Tab. 1).

Table 1. Number of children included the sample

Age category [yrs.]	2020		2022	
	Girls	Boys	Girls	Boys
11	170	115	94	72
12	107	110	78	79
13	87	115	54	77
14	93	79	44	46
15	100	93	18	31
Total	557	512	288	305
	1069		593	

The data from the 2022 survey series was compared with the results from the series in 2020. The study was conducted as recommended by the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008 and was approved by the Bioethics Committee of the Regional Medical Association in Kraków (5/KBL/OIL/2019, 66/KBL/OIL/2022). In addition, the study was conducted with the consent of school principals. The basis for the inclusion of the participant in the study was the written consent of the parent/legal guardian, as well as the oral consent of the subjects themselves before the study begin. Possible exclusion from participation was based on the lack of consent of the parent/legal guardian, participant or information about contraindications to the study.

In both studies, researchers have followed COVID-19 standard operating procedures.

All anthropometric measurements took place in the morning hours. The youth were dressed in gym clothes and were barefoot. The anthropometric data obtained in this study covered the winter-spring period (January–May) in 2022, which were analysed comparatively with the results of the "Child of Krakow 2020" project, conducted in the winter-spring period (January–March) in 2020, just before the year in which the COVID-19 pandemic began. Both studies collected data from the same schools.

Body height was measured using an anthropometer (GPM, Switzerland, with an accuracy of 1mm) according to Martin's technique. To measurement of the percentage of adipose tissue was conducted using the portable segmental body composition analyser (bioimpedance method BIA; Tanita, Japan, with an accuracy of 0.1%). The study was conducted according to a standard protocol for all participants. The measurements were taken in the morning hours, under similar temperature and humidity conditions.

A non-stretch anthropometric (with an accuracy of 5mm) tape was used to measure the circumference of the arm (cm). The arm circumference was measured at the midpoint of the humerus bone. The measurement of the triceps brachii skinfold (in mm) was taken at the midpoint of the arm, on the right side of the body, using a skinfold calliper (a constant pressure of 10g/mm^2 and an accuracy of 0.5mm). Both measurements were used to calculate the corrected arm muscle area (CAMA). Total body muscle mass (kg) was calculated from CAMA using a prediction equation:

Formula for women:

$$CAMA = [(MAC-(\pi \times TSF))^2/4\pi]-6{,}5$$

Formula for men:

$$CAMA = [(MAC-(\pi \times TSF))^2/4\pi]-10$$

TSF denotes triceps skinfold and MAC mid-arm circumference (cm) while the term 6.5 refers to the correction for bone area in females and 10 for men.

$$\text{Muscle mass (kg)} = H \times (0.0264+(0.0029 \times CAMA))$$

H- body height (cm)

Statistical analysis was performed using the Statistica software (version 13.3). To compare the differences between the 2020 and 2022 cohorts, two-way ANOVA and Kruskal-Wallis test were performed. According to the assumptions, the observable effect should reflect both waves of the pandemic.

Results

Girls

A decrease in muscle mass was observed among the examined girls in the majority of age groups, analysing the cohort from 2022 compared to peers examined in 2020 (the difference was statistically significant among 14-year-olds). However, among 11- and 12-year-old girls the opposite trend was observed, as muscle mass increased (Tab. 2).

Table 2. Mean and SD values of muscle mass and body fat in particular age categories and differences between cohorts

Age category [years]	Muscle mass [kg]					BF [%]				
	2020		2022		2022 vs 2020	2020		2022		2022 vs 2020
	$\bar{x}$	SD	$\bar{x}$	SD		$\bar{x}$	SD	$\bar{x}$	SD	
Girls										
11	14.50	3.76	14.72	3.67	0.22	19.96	6.35	19.45	6.26	-0.51
12	16.82	3.78	17.02	4.82	0.20	21.40	6.60	20.91	6.69	-0.49
13	18.11	3.83	17.62	3.51	-0.49	21.79	5.96	21.45	5.94	-0.34
14	21.03	4.40	18.55	4.75	-2.48**	24.11	6.53	21.00	6.52	-3.11**
15	21.60	4.57	20.49	3.83	-1.11	24.27	7.44	23.19	6.07	-1.08
Boys										
11	14.97	3.68	15.93	4.87	0.96	16.88	6.63	18.07	7.03	1.19
12	17.91	5.05	17.37	4.74	-0.54	16.48	6.91	16.36	5.85	-0.12
13	20.09	4.66	19.84	5.28	-0.25	14.90	7.03	14.94	6.49	0.04
14	22.68	6.20	23.74	5.94	1.06	13.27	6.07	12.75	5.07	-0.52
15	27.11	6.57	27.50	6.47	0.39	13.01	6.75	14.24	5.46	1.23

**- statistically significant $p<0.01$

Furthermore, the analysis of the %BF in girls examined in 2022 compared to 2020 showed a general decrease in all age categories. There was a statistically significant difference among 14-year-olds (Tab. 2).

Figure 1 illustrates the average percentage of body fat according to BMI categories. Among girls, an increase in the occurrence of both underweight and overweight was observed. In addition, an increase in the average values for all BMI categories was observed. However, an opposite trend was observed in the case of normal body weight (Fig. 1).

Analogous values were observed when analysing the results of average muscle mass in the context of BMI categories (Fig. 2).

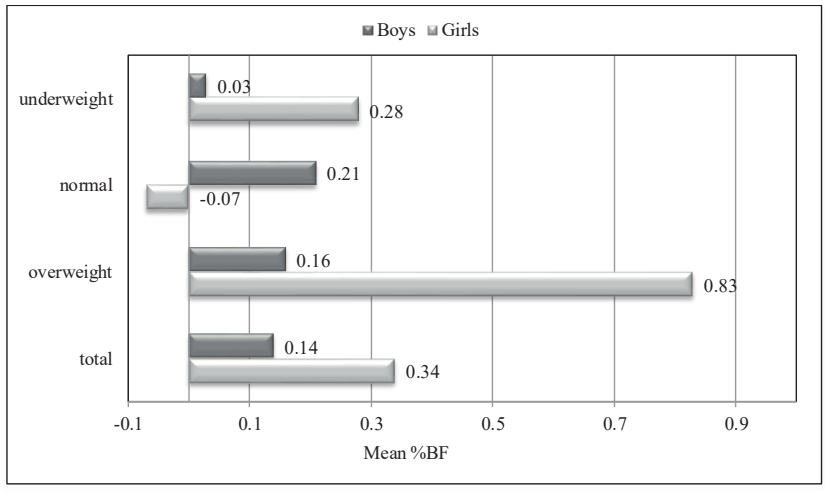

Figure 1. Mean ($\bar{x}$) of % Body Fat for the Total (girls and boys)

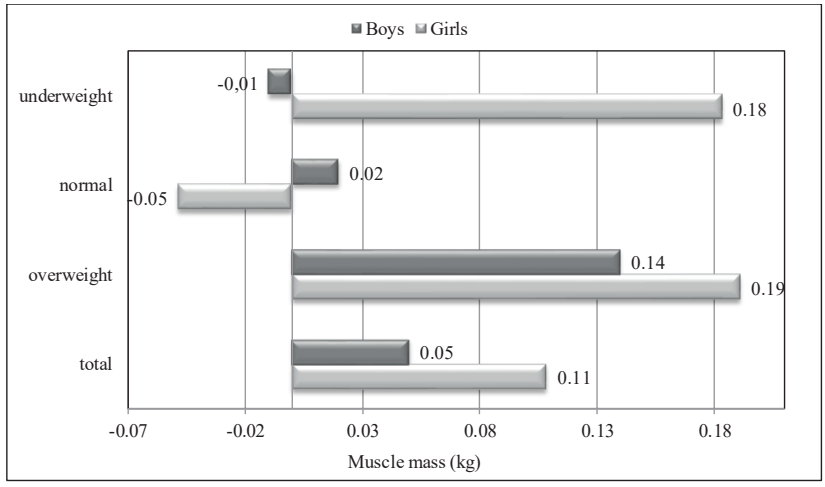

Figure 2. Mean ($\bar{x}$) of muscle mass for the Total (girls and boys)

Boys

In boys aged 11, 13, and 15, an increase in muscle mass was observed, analysing the results from 2022 compared to boys examined in 2020. Among the other groups (12 and 14 years), a decrease in muscle mass was observed but without significant differences (Tab. 2). In addition, an increase in %BF was observed in most age groups, except for 12 and 14-year-old boys who exhibited a decreasing pattern (Tab. 2). There was an increase in all average body fat percentage values in different BMI categories (Fig. 1).

Moreover, Figure 2 depicts the results of the average muscle mass in various BMI

categories. An increase in both normal body weight and overweight was observed. Furthermore, there was an increase in the average values for all BMI categories. Only a different trend was observed in the underweight category (Fig. 2).

Discussion

Body composition

The high prevalence of obesity has reached the dimensions of a pandemic, especially in developed countries in the West. Obesity in children and adolescents poses a significant health threat, and is associated with insulin resistance, risk factors for cardiovascular diseases, type 2 diabetes, cancers, and increased mortality (Trang et al. 2019; Stierman et al. 2021; Brambilla et al. 2022). According to the assessment of the World Health Organization (WHO), obesity, as a non-communicable disease, is a key risk factor for severe illness resulting from the SARS-CoV-2, which was operating as a global pandemic characterized by severe pneumonia and a significant level of mortality and morbidity (Malavazos et al. 2020, WHO 2020). Although government-imposed restrictions, such as social distancing, home isolation, limitations on travel and gatherings were necessary non-pharmaceutical interventions to control the spread of the SARS-CoV-2, they significantly impacted the health and behaviours of society, as well as the daily routines of people worldwide (Wang et al. 2020; Jeong et al. 2023). Remaining inactive has become more accessible than ever before. As a result of these restrictions, there has been a reduction in physical activity, an increase in sedentary time, and changes in dietary habits (Kirwan et al. 2020). According to a study by Rúa-Alonso et al. (2022), the COVID-19 pandemic-induced social restrictions may have had a negative impact on the body composition of children and adolescents, resulting in increased rates of obesity, as well as a reduction in muscle strength. Hence, it is important to monitor body composition among the young population, reflecting their behaviour and potentially impacting their current health status (Hernández-Ortega, Osuna-Padilla 2020). To address these issues, this study was conducted to assess changes in body composition, with particular emphasis on the proportion of muscle mass and adipose tissue, among adolescents aged 11–15 in Kraków during the COVID-19 pandemic. The results of this study suggest that restrictions related to limiting the spread of the SARS-CoV-2 had contributed to changes in muscle mass and %BF among adolescents in Kraków. Among girls, a decrease in muscle mass was observed among most of the age groups. Conversely, boys showed the opposite trend, as an increase in muscle mass was observed in most of the age categories. Girls exhibited a decrease in the percentage of body fat in all age categories, whereas boys showed an increase in the percentage of body fat in most of the age groups. In addition, an increase in the average muscle mass was observed in most the age groups, depending on the BMI category in both sexes. Furthermore, an increase in body fat was observed in both girls and boys across all BMI categories.

Physical activity

Similar results were observed in young basketball players, as during the quarantine period caused by the SARS-CoV-2 virus, higher values of body fat and lower percentages of total muscle mass were noted. In addition, a lower level of

explosive strength in the lower limbs was observed among the subjects, which was accompanied by lower aerobic endurance. One study suggests that the interruption of the training process and a decrease in physical activity due to the restrictions imposed during the coronavirus pandemic had a negative impact on the condition of young basketball players (Pelemiš et al. 2023). A study conducted in the Kraków population also showed that the level of physical fitness in children during the pandemic worsened markedly (Artymiak et al. 2024). For proper functioning and maintenance of muscle mass during the developmental period, it is crucial to achieve the level of daily physical activity recommended by the WHO, which is at least 60 minutes of moderate- or vigorous-intensity activity per day, covering the age group from 5 to 17 years. Unfortunately, over 80% of teenagers worldwide are not sufficiently active physically (Kutac et al. 2020; Mondaca et al. 2023; WHO 2022). A survey-based study conducted internationally with participants primarily from Asia, Africa, and Europe reported that, amidst the lockdown imposed by the coronavirus pandemic, there was a 33.5% reduction in the amount of time dedicated to daily physical activity. In addition, the study reported an uptick in sedentary behaviour, amounting to an increase of 3 hours per day (Ammar et al. 2020). Similar studies were conducted among children and adolescents aged 6–18 living in Italy showing a decrease in sports physical activity by 2.3 hours per day. Furthermore, an extension of sedentary time and screen time by 4.85 hours/day was observed (Kirwan et al. 2020). These results correspond to findings of this study, as a decrease in physical activity was observed, which may be associated with a reduction in muscle mass among surveyed girls in all age categories. It could be suggested that the introduced isolation measures due to the SARS-CoV-2 contributed to a decrease in physical activity, which may be associated with an increase in sedentary lifestyle and screen time.

Dietary habits

Longer time spent in front of the screen may adversely affect the younger generation, both in terms of sleep quality and the loss of muscle mass associated with stress and sleep restriction (Kirwan et al. 2020; Ito et al. 2022). Recommendations regarding 24-hour movement suggest limiting screen time to less than two hours per day and ensuring an adequate amount of sleep, depending on the age group. Studies on Swedish youth indicated that after the pandemic, the time dedicated to sleep has shortened, while screen time has lengthened (Helgadóttiret al. 2023). Shortened sleep duration may also affect appetite and eating habits, increasing the consumption of snacks, fast foods, and sugary drinks (Morselli et al. 2010; Chang et al. 2021). This, in turn, could lead to unfavourable changes in the relationship between calories consumed and expended, influencing fat storage and BMI increase. It is worth noting that youth showing normal body fat content typically exhibits better dietary patterns compared to their overweight and obese peer. Childhood and early adolescence are crucial for developing physical skills that form the foundation of a healthy lifestyle throughout life (Maltoni et al. 2021; Kutac et al. 2022; Syukrina et al. 2023). Moreover, a study conducted in Italy using online questionnaires showed an improvement in eating habits exhibited by a higher consumption of fruits, vegetables, and legumes during

the isolation caused by the coronavirus pandemic (Grant et al. 2021). Similarly, cross-sectional studies involving the adult population in Spain revealed a positive impact of isolation caused by SARS-CoV-2 on dietary habits and physical activity (López-Bueno et al. 2020).

This study has several limitations. Firstly, due to the prolonged isolation caused by the COVID-19 pandemic, a limited number of students from the oldest age group consented to participate in the study. Secondly, the long period of break in school activities caused by the pandemic could have caused discomfort for some students with higher body mass during anthropometric measurements. This phenomenon could have affected the representativeness of the sample in the context of body composition.

In this cross-sectional study, minor changes in muscle mass and body %BF among the examined population during the COVID-19 pandemic. The results of this study may reflect changes in physical activity or increased time spent in a sitting position. On the other hand, not all results showed a decreasing trend, which may be attributed to participation in online or outdoor activities and the improvement of diet quality during the isolation associated with the coronavirus pandemic. In addition, minor changes in the results may be associated with the process of easing restrictions, which favours increased physical activity and outdoor time among children and adolescents, including the possibility of using outdoor gyms. Therefore, the results of this study suggest that promoting physical activity and healthy eating habits among young people is important to encourage them to maintain a healthy lifestyle and prevent potential health problems, especially in extraordinary situations.

Authors' contributions

PA, MŻ, ŁK have made substantial contributions to conception and design. PA, MŻ, MŻ contributed to the acquisition of data. PA, MŻ prepared analysis and interpretation of data. PA, MŻ have been involved in drafting the manuscript and revising it critically for important intellectual content. PA, MŻ, ŁK have given final approval for the version to be published.

Acknowledgements

This study has been sponsored by the University of Physical Education in Kraków (grant number 189/BS/INB/2018, 330/BS/INB/2023).

Conflict of interest

The authors have no conflicts of interest to declare.

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References

Ammar A, Brach M, Trabelsi K, Chtourou H, Boukhris O, Masmoudi L, et al. 2020. Effects of COVID-19 Home Confinement on Eating Behaviour and Physical Activity: Results of the ECLB-COVID19 International Online Survey. Nutrients 12(6):1583. https://doi.org/10.3390/nu12061583

Artymiak P, Żegleń M, Kryst Ł. 2024. Analysis of Changes in Physical Fitness in

Children and Adolescents (11–15 Years) From Kraków (Poland) During COVID-19 Pandemic. J Phys Act Health 2024 Mar 13:1–8. doi: 10.1123/jpah.2023-0577.

Brambilla I, Delle Cave F, Guarracino C, De Filippo M, Votto M, Licari A, et al. 2022. Obesity and COVID-19 in children and adolescents: a double pandemic. Acta Biomed 93(Suppl 3): e2022195. https://doi.org/10.23750/abm.v93iS3.13075

Chang TH, Chen YC, Chen WY, Chen CY, Hsu WY, Chou Y, et al. 2021. Weight Gain Associated with COVID-19 Lockdown in Children and Adolescents: A Systematic Review and Meta-Analysis. Nutrients 13(10), 3668. https://doi.org/10.3390/nu13103668

Chen W, Hammond-Bennett A, Hypnar A, Mason S. 2018. Health-related physical fitness and physical activity in elementary school students. BMC Public Health 18(1):195. https://doi.org/10.1186/s12889-018-5107-4

Chew CSE, Davis C, Lim JKE, Lim CMM, Tan YZH, Oh JY, et al. 2021. Use of a Mobile Lifestyle Intervention App as an Early Intervention for Adolescents With Obesity: Single-Cohort Study. J Med Internet Res 23(9): e20520. https://doi.org/10.2196/20520

Damanti S, Cristel G, Ramirez GA, Bozzolo EP, Prat VD, Gobbi A, et al. 2022. Influence of reduced muscle mass and quality on ventilator weaning and complications during intensive care unit stay in COVID-19 patients. Clin Nutr 41(12):2965–2972. https://doi.org/10.1016/j.clnu.2021.08.004

de Girolamo G, Ferrari C, Candini V, Buizza C, Calamandrei G, Caserotti M, et al. 2022. Psychologicalwell-beingduring the COVID-19 pandemic in Italyassessed in a four-wavessurvey. Sci Rep 12: 17945. https://doi.org/10.1038/s41598-022-22994-4

Dunton GF, Do B, Wang SD. 2020. Early effects of the COVID-19 pandemic on physical activity and sedentary behavior in children living in the U.S. BMC Public Health 20(1):1351. https://doi.org/10.1186/s12889-020-09429-3

Grant F, Scalvedi ML, Scognamiglio U, Turrini A, Rossi L. 2021. Eating Habits during the COVID-19 Lockdown in Italy: The Nutritional and Lifestyle Side Effects of the Pandemic. Nutrients 13(7): 2279. https://doi.org/10.3390/nu13072279

Helgadóttir B, Fröberg A, Kjellenberg K, Ekblom Ö, Nyberg G. 2023. COVID-19 induced changes in physical activity patterns, screen time and sleep among Swedish adolescents - a cohort study. BMC Public Health 23(1):380. https://doi.org/10.1186/s12889-023-15282-x

Hernández-Ortega A, Osuna-Padilla IA. 2020. Agreement between body composition techniques in children and adolescents: narrative review of the literature. Rev Med Inst Mex Seguro Soc 13;58(2):181–196. https://doi.org/10.24875/RMIMSS.M20000016

Ito T, Sugiura H, Ito Y, Noritake K, Ochi N. 2021. Effect of the COVID-19 Emergency on Physical Function among School-Aged Children. Int J Environ Res Public Health 18(18), 9620. https://doi.org/10.3390/ijerph18189620

Ito T, Sugiura H, Ito Y, Narahara S, Noritake K, Takahashi D, et al. 2022. Physical Functions among Children before and during the COVID-19 Pandemic: A Prospective Longitudinal Observational Study (Stage 1). Int J Environ Res Public Health 19(18): 11513. https://doi.org/10.3390/ijerph191811513

Jarnig G, Kerbl R, van Poppel MNM. 2022. The Impact of COVID-19-Related Mitigation Measures on the Health and Fitness Status of Primary School Children in Austria: A Longitudinal Study with Data

from 708 Children Measured before and during the Ongoing COVID-19 Pandemic. Sports (Basel) 10(3):43. https://doi.org/10.3390/sports10030043

Jeong JF, Park HK, Hwang HS, Park KY, Lee MH, Shin SH, et al. 2023. Body mass index and prevalence of metabolic syndrome among Korean adults before and after the COVID-19 outbreak: a retrospective longitudinal study. Epidemiol Health 45: e2023081. https://doi.org/10.4178/epih.e2023081

Karatzi K, Poulia KA, Papakonstantinou E, Zampelas A. 2021. The Impact of Nutritional and Lifestyle Changes on Body Weight, Body Composition and Cardiometabolic Risk Factors in Children and Adolescents during the Pandemic of COVID-19: A Systematic Review Children (Basel) 8(12):1130. https://doi.org/10.3390/children8121130

Kirwan R, McCullough D, Butler T, Perez de Heredia F, Davies IG, Stewart C. 2020. Sarcopenia during COVID-19 lockdown restrictions: long-term health effects of short-term muscle loss. GeroScience 42(6): 1547–1578. https://doi.org/10.1007/s11357-020-00272-3

Kovacs VA, Starc G, Brandes M, Kaj M, Blagus R, Leskošek B, et al. 2022. Physical activity, screen time and the COVID-19 school closures in Europe - An observational study in 10 countries. Eur J Sport Sci 22(7):1094–1103. https://doi.org/10.1080/17461391.2021.1897166

Krams IA, Luoto S, Rantala MJ, Jõers P, Krama T. 2020. Covid-19: Fat, Obesity, Inflammation, Ethnicity, and Sex Differences. Pathogens 9(11): 887. https://doi.org/10.3390/pathogens9110887

Kutac P, Bunc V, Sigmund M, Buzga M, Krajcigr M. 2022. Changes in the body composition of boys aged 11–18 years due to COVID-19 measures in the Czech Republic. BMC Public Health 22(1):2254. https://doi.org/10.1186/s12889-022-14605-8

Lesser IA, Nienhuis CP. 2020. The Impact of COVID-19 on Physical Activity Behavior and Well-Being of Canadians. Int J Environ Res Public Health 17(11), 3899. https://doi.org/10.3390/ijerph17113899

López-Bueno R, Calatayud J, Casaña J, Casajús JA, Smith L, Tully MA, et al. 2020. COVID-19 Confinement and Health Risk Behaviors in Spain. Front Psychol 11: 1426. https://doi.org/10.3389/fpsyg.2020.01426

Loza AJ, Child I, Doolittle B. 2023. Rates of Body Mass Index Increase in Children During the COVID-19 Pandemic. Child Obes 19(5):353–356. https://doi.org/10.1089/chi.2022.0047

Malavazos AE, Romanelli MMC, Bandera F, Iacobellis G. 2020. Targeting the Adipose Tissue in COVID-19. Obesity (Silver Spring) 28(7): 1178–1179. https://doi.org/10.1002/oby.22844

Maltoni G, Zioutas M, Deiana G, Biserni GB, Pession A, Zucchini S. 2021. Gender differences in weight gain during lockdown due to COVID-19 pandemic in adolescents with obesity. Nutr Metab Cardiovasc Dis 31(7):2181–2185. https://doi.org/.1016/j.numecd.2021.03.018

Mondaca MI, Silva Garrido S, Rodriguez Orellana T, Roa AM, Quezada CO, Osorio-Fuentealba C. 2023. COVID–19 lockdown effects on the anthropometrics, aerobic capacity, muscle function and metabolic control in children and adolescents with overweight and obesity. J Pediatr 99(5): 471–477. https://doi.org/10.1016/j.jped.2023.03.008

Morselii L, Leproult R, Balbo M, Spiegel K. 2010. Role of sleep duration in the regulation of glucose metabolism and appetite. Best Pract Res Clin Endocrinol Metab 24(5): 687–702. https://doi.org/10.1016/j.beem.2010.07.005

Musa S, Elyamani R, Dergaa I. 2022. COVID-19 and screen-based sedentary behaviour: Systematic review of digital screen time and metabolic syndrome in adolescents. PLoS One 17(3):e0265560. https://doi.org/10.1371/journal.pone.0265560

Pelemiš V, Zoretić D, Prskalo I. 2023. Physical Performance and Morphological Characteristics of Young Basketball Players before and after COVID-19. Children (Basel) 10(3): 493. https://doi.org/10.3390/children10030493

Pinto AJ, Bergouignan A, Dempsey PC, Roschel H, Owen N, Gualano B, et al. 2023. Physiology of sedentary behavior. Physiol Rev 103(4):2561–2622. https://doi.org/10.1152/physrev.00022.2022

Rúa-Alonso M, Rial-Vázquez J, Nine I, Lete-Lasa JR, Clavel I, Giráldez-García MA, et al. 2022. Comparison of Physical Fitness Profiles Obtained before and during COVID-19 Pandemic in Two Independent Large Samples of Children and Adolescents: DAFIS Project. Int J Environ Res Public Health 19(7):3963. https://doi.org/10.3390/ijerph19073963

Scarmozzino F, Visioli F. 2020. Covid-19 and the Subsequent Lockdown Modified Dietary Habits of Almost Half the Population in an Italian Sample. Foods 9(5):675. https://doi.org/10.3390/foods9050675

Stierman B, Ogden CL, Yanovski JA, Martin CB, Sarafrazi N, Hales CM. 2021. Changes in adiposity among children and adolescents in the United States, 1999–2006 to 2011–2018. Am J Clin Nutr 114(4): 1495–1504. https://doi.org/10.1093/ajcn/nqab237

Syukrina F, Sartika RAD, Utri RM. 2023. Impact of COVID-19 Pandemic on Dietary Patterns and Physical Activity in Overweight and Obese Adolescents Based on Body Fat Percentages. J Community Health 9(2) : 409–417. https://doi.org/10.25311/keskom

Tison GH, Avram R, Kuhar P, Abreau S, Marcus GM, Pletcher MJ, et al. 2020. Worldwide Effect of COVID-19 on Physical Activity: A Descriptive Study. Ann Intern Med 173(9), 767–770. https://doi.org/10.7326/M20-2665

Trang LT, Trung NN, Chu DT, Hanh NTH. 2019. Percentage Body Fat is As a Good Indicator for Determining Adolescents Who Are Overweight or Obese: A Cross-Sectional Study in Vietnam. Osong Public Health Res Perspect 10(2): 108–114. https://doi.org/10.24171/j.phrp.2019.10.2.10

Toomey CM, Cremona A, Hughes K, Norton C, Jakeman P. 2015. A review of body composition measurement in the assessment of health. Top Clin Nutr 30(1):16–32. https://doi.org/10.1097/TIN.0000000000000017

Van Eyck A, Eerens S, Trouet D, Lauwers E, Wouters K, De Winter BY, et al. 2021. Body composition monitoring in children and adolescents: reproducibility and reference values. Eur J Pediatr 180(6):1721–1732. https://doi.org/10.1007/s00431-021-03936-0

Wang G, Zhang Y, Zhao J, Zhang J, Jiang F. 2020. Mitigate the effects of home confinement on children during the COVID-19 outbreak. Lancet 395(10228):945–947. https://doi.org/10.1016/S0140-6736(20)30547-X

WOF. 2020. Coronavirus (COVID-19) & Obesity. Available at: https://www.worldobesity.org/news/statement-coronavirus-covid-19-obesity [Accessed 01 March 2024].

WHO. 2020. Obesity significantly increases chances of severe outcomes for COVID-19 patients. Available at: https://www.who.int/europe/news/item/22-10-2020-obesity-significantly-increases-chances-of-severe-outcomes-for-covid-19-patients [Accessed 01 March 2024].

WHO. 2022. Physical activity. Available at: https://www.who.int/news-room/fact-sheets/detail/physical-activity [Accessed 01 March 2024].

Xiang M, Zhang Z, Kuwahara K. 2020. Impact of COVID-19 pandemic on children and adolescents' lifestyle behavior larger than expected. Prog Cardiovasc Dis 63(4): 531–532. doi: 10.1016/j.pcad.2020.04.013

Zheng Y, Liang J, Zeng D, Tan W, Yang L, Lu S, et al. 2020. Association of body composition with pubertal timing in children and adolescents from Guangzhou, China. Front Public Health 10: 943886. doi: 10.3389/fpubh.2022.943886