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# Socio-economic Status and Biological Characteristics of Students from Generation Z in France, Slovakia and Poland

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Abstract: Generation Z, unlike any generation before them, lives in an era of rapid and global technological change, where most activities take place online. This lifestyle has significant implications for the well-being and health of internet users. The question is whether the contemporary socio-economic status (SES) and biological profile of Generation Z 'immersed' in new technologies is a universal phenomenon, independent of the country of residence. This study sets out to identify similarities and differences in the socio-economic and biological characteristics of Generation Z students from three European Union countries. Data were collected directly in France, Slovakia, and Poland. We used a survey questionnaire and non-invasive anthropometric measurements in Generation Z respondents (n=157). Our results show that there is a significant relationship between country of residence and three SES indicators: income, self-rated financial situation and time spent online, as well as three biological measures: body mass index (BMI), relative fat mass (RFM) and waist circumference (WC). Country of residence only partly explains the similarities and differences in the socio-economic status and biological characteristics of Generation Z students. In terms of SES, the participants' profile is significantly influenced by financial situation, i.e. the student's monthly disposable income and self-assessed financial situation, as well as time spent online. In turn, for biological factors, the significant measures are: BMI, RFM and WC.

Keywords: SES, waist circumference, BMI, RFM, dynamometry, EU countries


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## Introduction

People of the same generation tend to share a similar outlook and, as they mature, they develop certain distinctiveness that makes them different from previous generations: behaviors, work ethics, attitudes, learning and motivational skills (Yadav et al. 2017). Generational studies are based on K. Mannheim's classic 1928 concept of cohorts (1952). Mannheim defined a generation as a group of people with common experiences, such as having lived through important historical events, having a similar position in society, or sharing a similar living space. The main argument in favor of a generational approach to research is therefore that each cohort has similar patterns of behaviour in terms of work, leisure and consumption (Barron et al. 2017).

The global prevalence of obesity has almost tripled since 1975, mainly due to increasingly sedentary lifestyles and less healthy diets. In May 2022, the WHO released its latest update on the obesity pandemic in Europe, reporting that 60% of European citizens are either overweight or obese, and highlighting the impact of the obesity pandemic (Boutari et al. 2022).

One measure that can be used to assess the well-being of an individual or group of individuals is socio-economic status (SES) (Sahni et al. 2017). SES is defined by indicators such as occupational status, income level, educational attainment, lifestyle, leisure activities among others. In our investigation of the characteristics of Generation Z, we made two assumptions: place of residence – EU countries, and type of activity – university students of economics.

Generation Z is made up of people who were born between the mid-1990s and 2010 (Lavickaite 2010; Goh et al. 2018), although there is no exact date range. In 2015, one in six people in the world belonged to Generation Z, with an age range of 15 to 24 years (World Populations Prospects 2022). In the European Union, on the other hand, almost 11% of the population could be classified as Generation Z in the year of this study, which corresponds to around 49 million people (Eurostat calculations of the percentage of people aged 15–24).

When describing Generation Z, their immersion in new technologies and constant online presence are highlighted as key characteristics (Kall 2015). No previous generation has lived in an era where technology has changed at such a rapid pace and been so readily available to young people (Turner 2015). In new technologies, Generation Z finds ways to have fun, learn, relax and connect with others.

Generation Z is perceived as a distinct generation, largely due to their relationship with modern technologies. They are also known as 'digital natives', 'zoomers', the 'net generation', 'generation next' or 'generation C' (connected), the 'Facebook generation', and the first truly global generation. It is a generation of university students these days, but soon they will become the leading workforce (Mladkova 2017). Generation Z will most likely make more intensive and more efficient use of new technologies in their own work and in their careers than their older colleagues. The use of the internet in almost every aspect of life provides Generation Z with tremendous opportunities to gain knowledge, skills and information. It is difficult to predict now how such widespread use of digital tools will affect their professional development, their personal lives and whether it will affect their health. On the one hand, it is predicted that, in the near future, higher paid jobs

will involve the use of new technologies and that using them will become a downright necessity (World Economic Forum 2023). Digital skills gaps will undermine earning capacity, increasing social stress (Lin et al. 2017; Stark 2023). On the other hand, a growing number of authors are drawing attention to the adverse health effects associated with excessive use of new technologies, including the problems of sedentary behavior and obesity. Excess body fat is particularly dangerous as it has been implicated as a causative factor in a number of lifestyle diseases (Ashwell et al. 1996; 2014). Obesity, which can be caused by too much sugar in the diet, too little physical activity, chronic stress and too little sleep, is a particular threat to Generation Z because of their almost constant and widespread use of the internet. In 2019, 98.4% of individuals aged 16–24 years used the internet and less than 1% did not use the internet at all (Eurostat on internet use among 16–24-year-olds). At the same time, a significant percentage (94%) used the internet on a daily basis (Eurostat Daily use of the Internet).

The aim of this paper is to identify similarities and differences in the socio-economic and biological characteristics of students from Generation Z in France, Slovakia and Poland. The following hypothesis was formulated: the socio-economic and biological condition of Generation Z is independent of country of residence. In this study, SES was determined by the following indicators: monthly income (pocket money), work, self-assessed financial situation, having career plans for the next five years, time spent online and frequency of exercise. The analysis of biological factors was based on the following somatic indicators: body mass index (BMI), relative fat mass (RFM), waist circumference (WC) and hand grip strength (HGS), as well as self-assessed health status. Although the students surveyed were representative of Generation Z, this study does not claim to offer conclusions about Generation Z as a whole, as the sample size is too small to reach such conclusions.

## Material and methods

Our study did not require ethics clearance as confirmed by the Bioethics Committee of Uniwersytet Szczeciński (10 March 2025). The research material consisted of data collected from students (n=157) in three countries: France n=36 (17 malex and 19 femalex), Slovakia n=56 (15 malex and 41 femalex) and from Poland n=65 (26 malex and 39 femalex) (Table 1). The mean calendar age of the respondents was 20.95 years (max=25.23; min=17.24; Me=20.71), with the mean age in France below 20 years. Convenience sampling was used (Teddlie and Yu 2007). Material was collected in 2019 and 2020 (prior to the COVID-19 pandemic). The French respondents were students at the Université Grenoble Alpes, the Slovak students at the Matej Bel University, Faculty of Economics, Banská Bystrica, and the Polish students at the University of Szczecin in Szczecin. All respondents were studying business-related programmes.

The material was collected through non-invasive anthropometric measurements taken by the authors and through a questionnaire completed by the students. We conducted a pilot study to pre-test the questionnaire structure and a survey to determine the amount of monthly disposable income available to students according to their subjective assessment by country.

Table 1. Key numerical characteristics of the study group

| | Variant | Number | [%] | |
|---|---|---|---|---|
| Gender | M | 58 | 36.94 | |
| | F | 99 | 63.06 | |
| Country | France | 36 | 22.93 | |
| | Slovakia | 56 | 35.67 | |
| | Poland | 65 | 41.40 | |
| | | all | M | F |
| Mean calendar age [years] | France | 19.56 | 19.47 | 19.64 |
| | Slovakia | 21.33 | 21.97 | 21.10 |
| | Poland | 21.38 | 21.78 | 21.12 |

The research form was designed with a clear graphic layout. For each question, you had to mark your answer by putting an X in the appropriate box, choosing one of the available options. The questionnaire was developed in three language versions: Polish, English and French. The research form (questionnaire and anthropometry) was anonymous. All respondents gave verbal consent to participate in the study. Immediately after the interview, the date of the interview was recorded on each form, which was roughly checked for the completeness of the answers and anthropometric measurements. It is important to note the high level of interest among students in their body measurements and the health consequences of abnormal body weight in all three countries included in the study.

The following personal information was collected:

- date of birth – calendar age calculated in years and decimals,
- gender,
- country of residence.

Body measurements were taken according to the anthropometric technique (Martin 1958):

- body height *(B-v) (Basis-vertex)* [in cm], using an anthropometer, with 0.1 cm accuracy,
- body weight [in kg], with 100 g accuracy,
- waist circumference [in cm], using a metric tape, with 0.5 cm accuracy,
- dynamometry (hand grip strength, HGS) [in kg], readability 0.1 kg, capacity 80 kg, measured with KERN&Sohn GmbH dynamometer (version 1.0) and Grip Strength Ratings for Males and Females source: Camry Electronic Hand Dynamometer Instruction manual. Hand grip strength was measured three times in the dominant hand, with appropriate rest periods between trials. The highest recorded HGS value was used for analysis.

Body measurements were used to calculate somatic indices:

- Body Mass Index (BMI) BMI=body weight [in kg]/(B-v)$^2$ [in m] interpreted according to the WHO classification: underweight, normal weight, overweight, obese, morbidly obese. WHO standards for BMI (WHO 2023a).
- Waist Circumference (WC) WC=waist circumference $\leq$½ body height [in cm] (Ashwell et al. 1996). Waist circumference should be less than half the person's height. Ratio of waist circumference to height is a strong predictor of intra-abdominal fat. In

this article, the authors use the abbreviation WC for this indicator, where normal WC is ≤½ of body height and abnormal WC is >½ of body height.
- Relative Fat Mass (RFM) index; for men RFM = 64 – (20 × height/waist circumference), for women RFM = 72 – (20 × height/waist circumference); normal RFM: <25% for men, <35% for women (Woolcott et al. 2018; Woolcott and Seuring 2022).

The questionnaire included questions on:
- The student's monthly disposable income: low (up to EUR 100 in France; up to EUR 50 in Slovakia; up to PLN 300 in Poland), medium (EUR 101–150 in France; EUR 51–100 Slovakia; PLN 301–500 in Poland), high (more than EUR 150 in France; more than EUR 100 in Slovakia; more than PLN 500 in Poland).
- Self-assessment of financial situation: very bad; bad; average; good; very good.
- Student's paid work: yes; no.
- Career plans for the next 5 years: Yes, I have; No, I have not; I do not know.
- How many hours a day the student spends online: 0 hours; 1–3 hours; 4–6 hours; 7 and more hours.
- How often does the student do sports during the week: Not an all; 1 time; 2–3 times per week; 4 times or more.
- Self-assessment of health status: very bad; bad; average; good; very good.

The data collected in this study were analysed using univariate and bivariate data analysis. In terms of univariate analysis, the classic measures of descriptive statistics were used: frequency distribution, arithmetic mean (x), minimum (min), maximum (max), median (Me) and standard deviation (SD). To determine the similarities and differences in the analysed characteristics of the respondents, the Mann-Whitney U test (Z) was used if there were only two variants (e.g. gender) and otherwise, the Kruskal-Wallis ANOVA by ranks (H) was used. In order to measure the strength and causality of the relationships between variables, we used the adjusted Pearson contingency coefficient (C). The relationships between variables were tested for significance using Pearson's $\chi^2$ test of independence.

## Results

### Characteristics of Generation Z respondents

Respondents described their financial situation as good (46%) or average (40%). Almost 60% of the students surveyed were working. They reported a high level of monthly disposable income (67%) and had specific career plans for the next five years (62%). Respondents described their health as good (48%) or very good (25%) and said they exercised 2–3 times a week (45%). Almost half of those surveyed (48%) spent between four and six hours a day online.

The objective assessment of the respondents' health status, based on their somatic indicators, is generally consistent with their subjective assessment. Sixty percent of respondents had a normal BMI, 78% had a normal ratio of waist circumference to height (WC), 76% had a normal RFM, and over 41% had above average hand grip strength. Detailed information on the distribution of these biological characteristics by country and gender of respondents is presented in Tables 2 and 3.

Table 2. General biological characteristics of respondents

| | Country | Gender | x | Me | Min | Max | SD |
|---|---|---|---|---|---|---|---|
| Body height [cm] | France | all | 170.89 | 171.50 | 156.00 | 189.00 | 8.66 |
| | | M | 178.26 | 178.00 | 169.00 | 189.00 | 4.72 |
| | | F | 164.29 | 164.00 | 156.00 | 173.00 | 5.36 |
| | Slovakia | all | 171.53 | 169.50 | 153.00 | 203.00 | 10.06 |
| | | M | 182.73 | 181.00 | 170.00 | 203.00 | 8.51 |
| | | F | 167.43 | 167.00 | 153.00 | 183.00 | 7.03 |
| | Poland | all | 171.16 | 170.00 | 152.50 | 190.60 | 9.10 |
| | | M | 179.32 | 178.60 | 164.50 | 190.60 | 6.72 |
| | | F | 165.73 | 167.00 | 152.50 | 176.40 | 5.81 |
| Body weight [kg] | France | all | 65.23 | 63.5 | 46.90 | 92.60 | 12.91 |
| | | M | 75.93 | 76.90 | 57.00 | 92.60 | 9.76 |
| | | F | 55.66 | 55.50 | 46.90 | 64.60 | 5.90 |
| | Slovakia | all | 69.17 | 63.70 | 44.60 | 116.00 | 17.07 |
| | | M | 84.10 | 83.00 | 63.70 | 116.00 | 16.63 |
| | | F | 63.58 | 58.75 | 44.60 | 112.50 | 13.65 |
| | Poland | all | 75.84 | 75.80 | 44.90 | 178.70 | 19.85 |
| | | M | 87.34 | 82.80 | 44.90 | 178.70 | 23.62 |
| | | F | 68.17 | 68.40 | 48.80 | 96.10 | 12.07 |
| Hand strength [kg] | France | all | 34.93 | 34.25 | 20.30 | 55.70 | 10.24 |
| | | M | 44.49 | 44.20 | 37.00 | 55.70 | 4.71 |
| | | F | 26.37 | 25.90 | 20.30 | 38.20 | 4.54 |
| | Slovakia | all | 35.01 | 31.50 | 14.80 | 59.80 | 11.77 |
| | | M | 51.01 | 51.60 | 32.00 | 59.80 | 7.78 |
| | | F | 28.53 | 28.20 | 14.80 | 37.90 | 4.77 |
| | Poland | all | 37.72 | 34.40 | 20.40 | 62.70 | 11.58 |
| | | M | 49.21 | 51.25 | 20.40 | 62.70 | 9.04 |
| | | F | 30.05 | 28.20 | 23.50 | 38.60 | 4.63 |

Table 3. Self-assessment of health [by category]

| | Country | Very bad | Bad | Average | Good | Very good |
|---|---|---|---|---|---|---|
| How would you describe your health status? [%] | France | 0.00 | 2.78 | 16.67 | 33.33 | 47.22 |
| | Slovakia | 0.00 | 1.85 | 29.63 | 53.70 | 14.82 |
| | Poland | 1.54 | 1.54 | 26.15 | 50.77 | 20.00 |

## Effect of country of residence on SES

### Financial and working status

Respondents from different countries differed statistically significantly in terms of their reported disposable income (C=0.4854, $p$=7.0E-06) and the associated self-assessment of financial situation (C=0.3868, $p$=1.33E-02). A high level of monthly income was reported by more than 47% of French respondents, 55% of Slovaks and 86% of Poles. At the same time, 57% of the French, 43% of the Slovak and 66% of the Polish respondents considered their financial situation to be at least good (Table 4).

Table 4. Monthly income and financial situation of respondents

| | Country | Low | | Medium | | High |
|---|---|---|---|---|---|---|
| What is your monthly disposable income? [%] | France | 30.56 | | 22.22 | | 47.22 |
| | Slovakia | 10.71 | | 32.14 | | 55.35 |
| | Poland | 1.54 | | 12.31 | | 86.15 |
| | | Very bad | Bad | Average | Good | Very good |
| How would you describe your financial situation? [%] | France | 0.00 | 0.00 | 33.33 | 28.89 | 27.78 |
| | Slovakia | 1.79 | 1.79 | 53.57 | 39.29 | 3.56 |
| | Poland | 0.00 | 1.54 | 32.31 | 55.38 | 10.77 |

Respondents' country of residence had virtually no effect on their attitude to working while studying (C=0.0182, $p$=0.9851). Having a paid job was reported by 58% of students from France, 59% of students from Slovakia and 60% of students from Poland (Table 5). Students' country of residence had a greater, though still statistically insignificant, effect on their attitudes towards career planning for the next five years (C=0.2480, $p$=0.1520). More than 72% of the French students, half of the Slovak students and nearly 68% of the Polish students reported that they had specific plans in this respect. Eight percent of the French, 21% of the Slovak and 11% of the Polish students had no career plans at all, while the rest said that they did not know what they wanted to do professionally in the near future (Table 6).

Table 5. Respondents with a paid job

| | Country | Yes | No |
|---|---|---|---|
| Do you do paid work? (%) | France | 58.33 | 41.67 |
| | Slovakia | 58.93 | 41.07 |
| | Poland | 60.00 | 40.00 |

Table 6. Respondents with career plans for the next 5 years

| | Country | Yes, I have a plan | No, I have no plans | I do not what I want to do in the nearest future |
|---|---|---|---|---|
| Career plans for the next 5 years (%) | France | 72.22 | 8.33 | 19.44 |
| | Slovakia | 50.00 | 21.43 | 28.57 |
| | Poland | 67.69 | 10.77 | 21.54 |

### Sport and time spent online

Country of residence also significantly influenced the intensity of internet use. All respondents said that they spent at least one hour online during the day. In turn, four or more hours a day online were reported by 43% of the French, more than half of the Slovaks (55%) and almost three quarters of the Poles (72%) (C=0.3512, $p$=7.1E-03). On the other hand, place of residence had no significant effect on the frequency of physical activity. The respondents were physically active. Exercising twice a week or more was reported by 67% of students from France, 57% from Slovakia and 54% from Poland (C=0.2031, $p$=0.3444) (Table 7). Nine per cent of Slovaks and 20% of both French and Polish students did not do any sport at all.

Table 7. Sport and time spent online

| | Country | Never | Once | 2–3 times per week | 4 times or more |
|---|---|---|---|---|---|
| How often do you do sports during the week? [%] | France | 19.44 | 13.89 | 52.78 | 13.89 |
| | Slovakia | 8.93 | 33.93 | 44.64 | 12.50 |
| | Poland | 20.00 | 26.15 | 41.54 | 12.31 |
| | Country | 0 | 1–3 | 4–6 | 7 and more |
| How many hours a day do you spend online? [%] | France | 0.00 | 58.33 | 36.11 | 5.56 |
| | Slovakia | 0.00 | 44.64 | 50.00 | 5.36 |
| | Poland | 0.00 | 27.69 | 52.31 | 20.00 |

## Effect of country of residence on biological characteristics

### Body Mass Index

The place of residence of the respondents was significantly associated with BMI values (C=0.4439 $p$=5.0E-03). Normal BMI was found in 78% of the French, 61% of the Slovaks and 50% of the Poles (Table 8). At the same time, the mean BMI in each country was higher for male students than for female students, and for both males and females, it was lowest for students from France and highest for students from Poland. Obesity and morbid obesity were found only among respondents from Slovakia and Poland, and were more common among males. On the other hand, BMI values indicating underweight were observed in women from Slovakia.

Table 8. BMI by country and gender of respondents

| | Country | Gender | x | Me | Min | Max | SD |
|---|---|---|---|---|---|---|---|
| BMI | France | M | 23.92 | 22.89 | 19.49 | 29.23 | 3.19 |
| | | F | 20.60 | 20.01 | 18.52 | 24.09 | 1.70 |
| | Slovakia | M | 25.19 | 24.63 | 20.22 | 36.30 | 4.75 |
| | | F | 22.69 | 21.69 | 17.08 | 41.83 | 4.86 |
| | Poland | M | 27.17 | 25.19 | 16.59 | 55.96 | 7.43 |
| | | F | 24.78 | 24.14 | 18.59 | 33.85 | 3.97 |

### Waist Circumference

The same, as above, is true for the relationship between the country of residence and the waist adiposity index. Overall, more than 78% of respondents had a healthy waist adiposity index, but there were significant differences in this value according to the respondents' country of residence (C=0.2522, $p$=0.0494). Among French students, 89% (and 100% of women) had a healthy WC, while among Slovaks it was just over 82% (88% of women). Polish students had the worst parameters in this respect, with just under 70% (74% of women) not having excessive abdominal fat (Table 9).

Table 9. WC by country and gender of respondents

| | Country | Gender | Normal WC | Abnormal WC |
|---|---|---|---|---|
| WC [%] | France | M | 76.47 | 23.53 |
| | | F | 100.00 | 0.00 |
| | Slovakia | M | 66.67 | 33.34 |
| | | F | 87.80 | 12.20 |
| | Poland | M | 61.54 | 38.46 |
| | | F | 74.36 | 25.64 |

### Relative Fat Mass

Country of residence of the respondents also had a statistically significant effect on changes in RFM (H=6.17, $p$=0.0457). With a mean of 27.3% for all students examined (22.03% for males and 30.45% for females), normal values were observed in 82.35% of French males, 66.67% of Slovak males and 65.38% of Polish males and 100% of French females, 80.49% of Slovak females and 69.23% of Polish females. Detailed information on RFM values in each country, by gender of the students examined, are shown in Table 10.

Table 10. Relative Fat Mass (RFM) index by country and gender

| | Country | Gender | x | Me | Min | Max | SD |
|---|---|---|---|---|---|---|---|
| RFM [%] | France | all | 24.92 | 26.39 | 12.22 | 33.94 | 6.24 |
| | | M | 19.90 | 20.47 | 12.22 | 27.67 | 5.05 |
| | | F | 29.41 | 29.04 | 25.03 | 33.94 | 2.83 |
| | Slovakia | all | 27.14 | 27.14 | 15.95 | 43.84 | 6.17 |
| | | M | 22.10 | 20.10 | 15.95 | 31.34 | 5.31 |
| | | F | 29.08 | 28.06 | 19.86 | 43.84 | 5.38 |
| | Poland | all | 28.75 | 28.32 | 14.15 | 42.63 | 6.51 |
| | | M | 23.38 | 22.57 | 14.15 | 33.93 | 4.79 |
| | | F | 32.32 | 32.05 | 24.06 | 42.63 | 4.85 |

### Hand strength

In contrast to the above, the maximum hand strength values were not significantly associated with the place of residence of the respondents (H=3.2336, $p$=0.053). In nominal terms, the highest mean

strength was found among the male students from Slovakia (51.01±7.78 kg), followed by those from Poland (49.21±9.04 kg), and the lowest among the male students from France (44.49±4.71 kg). On the other hand, among the female students, the strongest average grip was recorded by Polish students (30.05±4.63 kg), followed by Slovak (28.53±4.77 kg) and the French (26.37±4.54 kg). Statistics for the maximum grip strength by country and gender are presented in Table 11.

Table 11. Hand Grip Strength (HGS) by country and gender

| | Country | Gender | x | Me | Min | Max | SD |
|---|---|---|---|---|---|---|---|
| Max HGS [kg] | France | M | 44.49 | 44.20 | 37.00 | 55.70 | 4.71 |
| | | F | 26.37 | 25.90 | 20.30 | 38.20 | 4.54 |
| | Slovakia | M | 51.01 | 51.60 | 32.00 | 59.80 | 7.78 |
| | | F | 28.53 | 28.20 | 14.80 | 37.90 | 4.77 |
| | Poland | M | 49.21 | 51.25 | 20.40 | 62.70 | 9.04 |
| | | F | 30.05 | 28.20 | 23.50 | 38.60 | 4.63 |

Grip strength is an indicator of overall skeletal muscle strength. After all, hands are used in most daily physical activities. Dynamometry can be used as a complementary parameter in the diagnosis and prognosis of health, as well as in the course of recovery (Rantanen et al. 2003; Sasaki et al. 2007).

### Self-assessment of health

In the analysis of self-assessed health status, there is no statistically significant relationship between the country of residence of the respondents and self-perceived health (C=0.3487, $p$=0.0530). Irrespective of country of residence, men were more likely to rate their health as bad or very bad. This was the case for almost 5% of French male students and just over 1% of French female students, 7% of Slovak males and no Slovak females, more than 3% of Polish males and just under 2% of Polish females. At the same time, men were also more likely to rate their health as very good. Almost 22% of French males and 15% of French females, 35% of Slovak males and 26% of Slovak females and 31% of Polish males and 26% of Polish females made such a self-assessment (Table 12).

Table 12. Self-assessed health status by country and gender

| | Country | Gender | Very bad | Bad | Average | Good | Very good |
|---|---|---|---|---|---|---|---|
| How would you describe your health status? [%] | France | M | 2.44 | 2.44 | 21.95 | 51.22 | 21.95 |
| | | F | 0.00 | 1.28 | 30.77 | 52.56 | 15.39 |
| | Slovakia | M | 2.33 | 4.65 | 18.60 | 39.53 | 34.89 |
| | | F | 0.00 | 0.00 | 25.86 | 48.28 | 25.86 |
| | Poland | M | 0.00 | 3.13 | 28.12 | 37.50 | 31.25 |
| | | F | 0.00 | 1.73 | 22.41 | 50.00 | 25.86 |

## Summary of results

The results of our study suggest that the place of residence of Generation Z respondents has an impact on both their socio-economic and biological characteristics (Table 13). Even though the countries included in the study are all member states of the European Union, which is committed to reducing economic inequalities, and although the respondents represent the same 'occupation', income and the associated subjective assessment of financial situation is a differentiating factor. On the other hand, one would expect that growing up surrounded by new technologies in every aspect of life would result in similar and significant amounts of time spent online by Generation Z. However, French members of Generation Z spend significantly less time on these activities than their Polish and Slovak counterparts. What members of Generation Z have in common is having career plans and working while studying, which could be attributed to the similar 'occupational' status of the respondents. In turn, the findings related to sports participation are interesting – this aspect of Generation Z's life appears to be universal. The majority of respondents in each country participate in sport, with the highest number in Slovakia, and in each country doing sport 2–3 times a week was the most common answer. This may explain the high self-assessment of health status regardless of the country. However, objective indicators such as BMI, RFM and WC appear to contradict the above. In this respect, French respondents have the best biological body parameters, while Generation Z students from Poland have the worst.

Table 13. Associations between SES and biological characteristics and country of residence

| | Measure | Magnitude of relationship | *p-value* | Significant relationship* |
|---|---|---|---|---|
| SES | monthly income | C=0.4854 | 7.00E-06 | yes |
| | time spent online | C=0.3512 | 7.08E-03 | yes |
| | self-assessment of financial situation | C=0.3868 | 1.33E-02 | yes |
| | career plans | C=0.2480 | 1.52E-01 | no |
| | sport | C=0.2414 | 3.44E-01 | no |
| | work | C=0.0182 | 9.85E-01 | no |
| Biological indicators | BMI | C=0.4493 | 5.00E-03 | yes |
| | RFM | H=6.1700 | 4.57E-02 | yes |
| | WC | C=0.2522 | 4.94E-02 | yes |
| | self-assessment of health | C=0.3487 | 5.30E-02 | no |
| | hand strength | H=3.6899 | 1.58E-0.1 | no |

*p-value≤0.05

## Discussion

The relationship between SES and human biological characteristics is the subject of much research and scientific interest in economics, human biology, sociology and other disciplines concerned with the environmental determinants of human life.

The components of SES are selected according to the objectives of the particular study, its scope and the availability of data. The cultural differences of the environment being studied must also be taken into account. But whatever the cultural factors, Generation Z, 'immersed' in new technologies, may end up paying a very high price for being constantly connected. A sedentary lifestyle promotes excessive body weight, leading to overweight and obesity, which are associated with premature mortality, cardiovascular disease, hypertension, degenerative joint disease, certain cancers, diabetes, among others. (WHO 2023b). More than one billion people worldwide are obese – 650 million adults, 340 million adolescents and 39 million children. This number continues to grow. The WHO estimates that by 2025, approximately 167 million people – adults and children – will become less healthy because they are overweight or obese (WHO 2022).

The lifestyles of today are very different from those of just 20 years ago. People living today still remember a world without constant access to the internet, the telephone and the many sources of information that are now commonplace and almost indispensable. Generation Z, on the other hand, has never known a life without internet technology. This characteristic is universal, just as new technologies are universal and global. The presence of technology in every aspect of life, together with the time spent online, influences lifestyles and, consequently, well-being. This suggests that members of Generation Z will share many common characteristics, regardless of where they live. Arseni et al. (2020) studied students and found a moderate relationship between BMI and the number of hours spent on smartphones over the weekend. The authors found that smartphone use, irrespective of purpose, led to reduced engagement in physical activity. This phenomenon is concerning, due to the increasing amounts of time spent online.

Meanwhile, the Generation Z respondents differ both in terms of SES and the biological characteristics of their bodies. In the first place, they differ in terms of their economic situation, both monthly disposable income and subjective assessment of financial situation, which could be attributed to the different level of economic development in each country. In turn, one would expect them to spend similar amounts of time online. However, it turned out that the Polish students spent the most time online, followed by the Slovaks, with the French spending the least time online. Time spent online may influence adiposity rates in Generation Z representatives from different countries, despite similar levels of physical activity. We found that adiposity rates of Generation Z, as measured by BMI, RFM as well as WC, also vary from country to country. In fact, the best results in this regard were observed among the students from France, followed by those from Slovakia, with Polish students coming in last. This suggests that there is a direct correlation between the amount of time spent online and the biological body characteristics of Generation Z. A more in-depth exploration of this correlation will be the subject of future research.

Socio-economic status is strongly influenced by the living environment. Therefore, in order to minimise the number of confounding factors influencing the variables of SES, the study focused on students, i.e. people in a similar life situation and at the same stage of life, living in the EU. It was assumed that

they would also share the same lifestyle associated with new technologies, which they use as a source of both knowledge and entertainment.

The socioeconomic status of a family affects the upbringing of the children growing up in it. According to Hemmerechts et al. (2017), early involvement of parents and carers in reading with their child speeds up the reading process and helps them to be more successful at school. Attitudes to education, sport, health, the environment and much more are formed from an early age. Parental involvement in the child's overall education is strongly associated with parental education and the SES of the family environment. In our study, the French students had the lowest rates of overweight and obesity, which may be related to higher SES and greater parental awareness in the French academic community under study. Similar observations have been made by other researchers regarding the effect of parental education and family SES on children's success. Azhar et al. (2014) showed a correlation of student success with parental education and family SES. Parental education increases the chances of educational success for the children. In our study, we did not examine the education of the parents of the students analysed, but self-assessment of financial situation is related to family SES and indirectly to parental education. In addition, the fact that the student is earning extra money (student's paid work) is an indication of the student's determination and resourcefulness.

Interesting research was done by Sainz et al. (2021), who found that lower socio-economic status positively correlated with more meta-dehumanisation and poorer well-being. Brown et al. (2005) in their study set out to answer the question of whether individual socio-economic status (as determined by income from work) and community-level SES predicted the onset of stroke (taking into account patients' lifestyle and health status). Using logistic regression, they were able to confirm that both individual and community socio-economic status can predict the onset of stroke. They found that average household income was the most powerful community-level measure of socio-economic status for predicting stroke. The onset of stroke was significantly predicted by individual income and average household income both independently and after taking into account individual behavioural and medical risk factors. The study found that individual income was a significant predictor of smoking and obesity, while community socioeconomic status was significantly associated with heart disease, alcohol and tobacco use, diabetes and obesity (Brown et al. 2005).

The association between SES and hypertension was analysed by Colhoun et al. (1998) based on the available literature from 1966–1996. Mortality rates from hypertension-related disorders, including coronary heart disease, hypertensive heart disease, stroke and kidney failure, showed an inverse relationship with SES. Lower SES was associated with higher mean blood pressure in almost all studies conducted in developed countries. This phenomenon was observed more frequently in women. In contrast, in undeveloped or developing countries, a direct relationship between SES and blood pressure was often found, potentially due to higher rates of obesity and higher consumption of salt and alcohol among those with higher SES. Understanding and preventing SES differences in obesity, which are particularly marked

in women, is a major challenge in reducing the impact of SES on hypertension.

Bapat et al. (2017) studied physical activity, screen time and academic work in the context of socio-economic status and sleep duration in school-aged children in India. The authors found that children of the highest socio-economic status slept nearly an hour and a half less than those of the lowest socio-economic status. Children of lower SES were more physically active and had more screen time, and children of higher SES spent more time studying. While screen time was inversely related with sleep duration, the biggest influence on the relationship between socio-economic status and sleep duration was academic work. Physical activity did not play a significant role. In India, there is a strong inverse relationship between academic work and sleep duration in children and adolescents (Bapat et al. 2017).

Huikari et al. (2021) studied Finns (6,169 men and 5,889 women) and found that people with higher socio-economic status were more likely to be physically active in their leisure time. This was true whether SES was defined by income level, education or occupation. After dividing the population studied (mean age 46, unfortunately not Generation Z) into different socio-economic groups, based on education, income and occupation, the authors found that income was not significantly associated with physically active leisure time in any of the SES groups. The study demonstrated an inverse relationship between leisure-time physical activity and time spent in front of a screen (TV or computer) and other aspects of an unhealthy lifestyle, and a positive relationship with self-perceived health (Huikari et al. 2021).

Time spent online and the availability of a wide range of information on the internet has created a misconception among Generation Z that everything they need for real life can be found online. Unfortunately, the web cannot replace human interaction; it severely limits physical activity and emotional communication in family, school and work life. It is currently difficult to predict the consequences for health (physical and mental) of 'immersion' in new technologies.

## Conclusions

Generation Z has been brought up in a world of ubiquitous internet access, which has had a role in shaping the traits and values they have in common. They see the world very differently from those who came before them. Representatives of Generation Z are forward-looking, while remaining conservative in many aspects. Generation Z is both fashionable and timeless. As members of Generation Z have already entered or are about to enter the labour market, it is important that national social policies to include health promotion programmes aimed at the physical and mental wellbeing of young people. It is interesting to note that young people in Generation Z want to stand out from the crowd, through clothing styles, unusual passions, invasive body decoration. Generation Z strives for authenticity by fulfilling their needs, taking care of themselves and expressing themselves boldly, often shocking older generations.

Country of residence is partly responsible for differences in the SES and biological characteristics of people in Generation Z. On the other hand, irrespective of where they live, Generation Z have similar specific career plans, work at similar rates while studying, rate their health, similarly, engage in physical ac-

tivity with similar frequency and have similar hand grip strength.

It is most likely that the lack of a clear relationship between country of residence and the variables analysed in this study can be attributed to environmental differences. The living environment has an impact on economic and social situation as well as on body shape. For Generation Z, new technologies are a key element shaping the living environment. It can be concluded that natural factors (ambient fauna and flora) continue to explain socio-economic and health status. Nevertheless, research findings show that the amount of time spent online influences eco-sensitive traits, especially body adiposity, in the young adults in this study. This aspect is something the authors plan to address in future analyses. Due to the small sample size, it is not possible to draw conclusions about Generation Z as a whole. We plan to explore this topic in more depth and with a larger group of respondents.

The strength of the study is that it presents an original look at SES combined with biological characteristics of Generation Z. It is also interesting to note that the statistical analyses combine anthropometric characteristics, referred to in the paper as biological factors, with socio-economic factors in an international context. The limitations of the study include covering only a certain fraction of Generation Z, namely students of economics. The different ranges of birth years used for Generation Z also make it difficult to compare research results. The sample size is too small to be representative of Generation Z as a whole.

Key concluding points:

1. The place of residence of Generation Z respondents has an impact on both their socio-economic and biological characteristics.
2. Socio-economic status was determined by the following indicators: monthly income (pocket money), work, self-assessed financial situation, having career plans for the next five years, time spent online and frequency of exercise.
3. Generation Z respondents differ both in terms of SES and the biological characteristics of their bodies.
4. Time spent online may influence adiposity rates in Generation Z representatives from different countries, despite similar levels of physical activity.
5. It is predicted that, in the near future, higher paid jobs will involve the use of new technologies and that using them will become a downright necessity.

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**Conflict of interest statement**

The authors declare that they have no conflict of interest regarding the publication of this paper.

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**Author contributions**

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Draft, Review & Editing, Funding acquisition, Bibliography search, Corresponding author; RC: Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing Original Draft, Visualization; GP: Data collection; JM: Data collection

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# Forensic Anthropological Significance of Dental Calculus Deposits as Proxy Identifier of the Host and the Oral Microbiota: A Scoping Review

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Abstract: Dental calculus is a creamish-yellow to brownish-black hard crust deposited on teeth, having the dietary micro-remains, biomolecules, oral microbes and the secretions preserved in it over a long period of time. It has served as a valuable source material for research in diverse scientific disciplines such as anthropology, archaeology, microbiology and forensic sciences. The host and microbial DNA extracted and sequenced from dental calculus deposits (DCD) have helped to establish the identity of unknown individuals, and also the use of certain drugs, tobacco products by the individuals of the past as well as contemporary human populations. The entrapped cellular as well as tissue fragments in calculus can help in identification, reconstruction of dietary habits, food practices, manner of death/pathologies the geographical and occupational affinity of ancient human remains. Calculus deposits gleaned from the archaeological or paleontological specimens can be used to assess the shifts in oral microbiota compositions and host-pathogen co-evolution as researchers have found calculus as rich source of oral microbiomes, pathogens, dietary biomolecules, and host DNA. Advancing dental calculus research through validation studies, technological innovations, interdisciplinary collaborations, longitudinal research, and ethical considerations holds promise for its robust forensic anthropological utilizations. The current status of anthropological, archaeological and microbial research involving dental calculus deposits, future challenges, and its forensic anthropological significance are presented in this review article.

Keywords: forensic anthropology, dental calculus, dietary and disease status, host and oral microbiome DNA, identification


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## Introduction

Reconstructing life-histories and health status of past human populations has remained a major subject of discussions and debates in the anthropological research domain (Wasterlain et al. 2011). Teeth and bones have served as excellent reservoirs of biomaterials, appropriately suitable for identification of unknown human remains and/or missing persons. Among osseous human remains, teeth are the strongest structures generally found well preserved in most forensic anthropological contexts (Raj et al. 2013). During the routine lifetime of an individual, the oral microbiome and the micro-debris circulating in human oral cavity often build up to preserve as a tightly adhered calcified dental plaque, called dental calculus deposits (DCD). Dental calculus is a creamish-yellow to brownish-black hard crust deposited on the inner surface of tooth or the dental prosthesis. The calcified diverse bacterial biofilm (i.e., DCD) structurally preserves and protects bacterial cells from multiple external factors more precisely than any other substrate, and thus has potential to reveal the living conditions of an individual (Willmann et al. 2018). Dental calculus is a densely mineralized microbial biofilm formed from assimilation of mineral salts in salivary and gingival fluids and it harbors the dietary, microbial and environmental information about an individual (Hardy et al. 2009; Buckly et al. 2014; Warinner and Lewis 2015; Weyrich et al. 2015; Gismondi et al. 2018). The nature of material and microbial remnants entrapped in calculus depends upon the lifestyle, oral hygiene, dietary habits, environmental conditions, genetics, disease and health status such as periodontitis and dental crowding of the host (Weyrich et al. 2015; Singh and Goel 2017; Fons-Badals et al. 2020; Blatt et al. 2022). Dietary, microbial and host relationships can be conveniently established by examining only one source material i.e., dental calculus (Weyrich et al. 2015; Mann et al. 2018; Ottoni et al. 2019; Ozga et al. 2019; Modi et al. 2020).

Calculus is a sturdy and rigid material that can be collected non-invasively from jaw fragments and/or tooth surfaces. Even very minute quantities of calculus can provide deep insights about the geolocality, ecology and socio-cultural affinity of an individual; thus, presenting a more holistic ante-mortem profile of the unidentified individuals (Mackie et al. 2017; Blatt et al. 2022). Dental calculus serves as a vital bio-material in situations where only heavily decomposed or badly degraded, damaged and fragmented human remains of disturbed skeletal conformity are available for forensic anthropological identifications. Thus, it can be taken as a compelling biological material having crucial forensic implications, especially in identification of heavily damaged and severely degraded human remains.

Medically, the development and accumulation of dental calculus is considered an oral health problem by periodontists, so calculus deposits are routinely removed to maintain sound dental health, and are discarded as a clinical waste material. However, its scientific scrutinization has significant forensic anthropological and bio-archaeological implications. Its deposition below the cervical line may be the indicative of periodontitis or other non-infectious diseases which, in turn, may have different forensic or bio-archaeological interpretations (Muro and Cucina 2024). Building up of calculus deposits usually compromises oral hygiene

by promoting increments in pathogenic plaque, resulting into excessive destruction of periodontal tissues, thus enhancing the risks of systemic diseases like diabetes (Preshaw et al. 2012; Mealey and Klokkevold 2019).

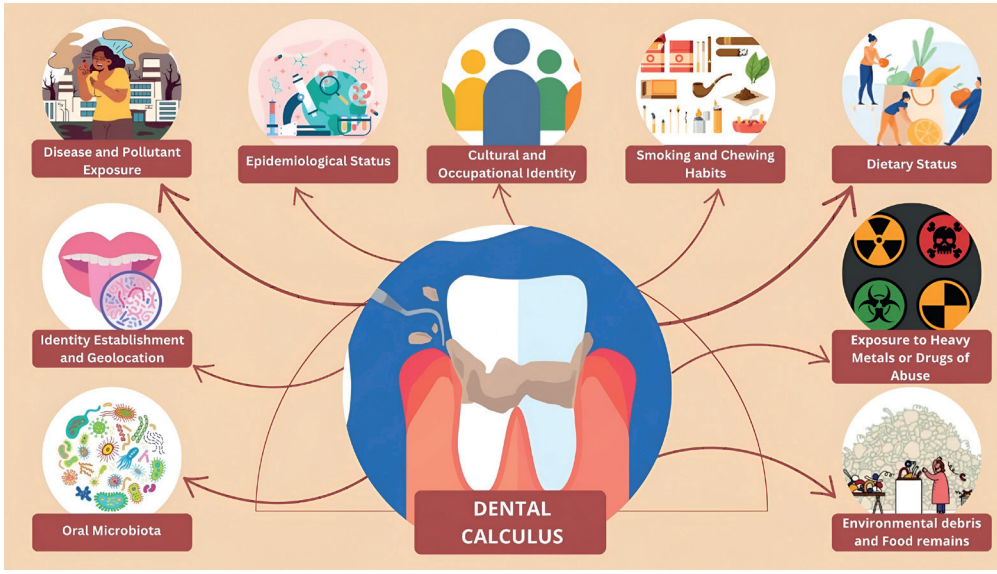


Figure 1. Anthropological importance of dental calculus

In addition to mineral components, calculus contains a variety of inorganic and organic remnants (of salivary, dietary or bacterial origin) incorporated either during the mineralization or post-calcification of the calculus. It has been reported to be present on the supra- and/or sub-lingual surfaces of teeth. Supra-gingival calculus is primarily anchored to the mandibular lingual surfaces of anterior teeth and the buccal surfaces of maxillary molars, whereas the sub-gingival calculus is found adhered to the entire set of teeth, specifically on their proximal tooth surfaces. Formation and accumulation of dental calculus also varies with tooth type; maxillary molars and mandibular incisors being more prone to supra-lingual calculus (White 1997). Further, removal of calculus from teeth of skeletal remains is non-invasive and comparatively less destructive than the traditional method of DNA extraction and analysis in such contexts.

The prevalence of calculus deposits has been reported among individuals of almost all known human populations (ancient or contemporary); though its formation and presence is highly population-specific (Warriner et al. 2015; Mann et al. 2018). The frequency distribution of calculus deposits is largely dependent upon the available living conditions of the affected individual, such as oral hygiene (Anerud et al. 1991; Blank et al. 1994; MacPherson et al. 1995), age (Beiswanger et al. 1989; Anerud et al. 1991; MacPherson et al. 1995), sex (Beiswanger et al. 1989; Anerud et al. 1991), ethnicity, diet (Schroeder 1969; Bhat 1991), dental

cares (Beiswanger et al. 198; Anerud et al. 1991; Blank et al. 1994; MacPherson et al. 1995), systemic disease (Emrich et al. 1991), medicine intake (Turesky et al. 1992; Breuer et al. 1996), educational status, as some examples. In non-westernized populations, calculus formation starts soon after tooth eruption and is found to continue up to the maximum age of 30 years (White 1997), however, no such trends have been reported for the individuals of westernized world.

Dental calculus undergoes continuous, though periodic mineralization to incorporate oral microbiota, phytoliths, pollens, fat grains and toxic micro-remains into it (Putrino et al. 2024), and acts as an authentic and prolonged storehouse of such remnants (Jin and Yip 2002; Adler et al. 2013; Warinner et al. 2013). Food and non-food micro-particles like starch granules, pathogens, parasites, pollens, diatoms, seeds, hair, dietary/vegetal fibers, cereals, the accidently entrapped small insects, mineral salts and crystals are frequent inclusions in human dental calculus matrix (Dobney and Brothwell 1986; 1988). The plant remnants in the form of phytoliths and starch grains have potential utility in estimating ancient dietary habits as well as population-level food variations. Starchy foods constitute 50–70% of energy intake in modern as well as pre-agriculturist human diets (Hardy et al. 2009). The sophisticated dietary regime of Neanderthals, primarily based on plant-based foods, has been revealed through dental calculus (Henry et al. 2011). Dental calculus extracted from ancient and modern dental remains has been widely used for studying the composition and profiling of oral microbiota, remnant food debris, disease microbes entrapped within calcium phosphate mineral salts of saliva and dental plaque (Henry and Piperno, 2008; Henry et al. 2011; Warinner et al. 2014).

The aim of this article is to provide an updated review focused on the formation, prevalence, composition and forensic anthropological significance of dental calculus deposits.

## Methods

To scrutinize the current status of dental calculus research for forensic anthropological purposes, scientific databases were searched using search engines including: PubMed, ScienceDirect, SAGE, Springerlink, Clinical Key, WoS and Google-Scholar, using the following key terms: 'Dental calculus, Forensic identification', 'Microbial forensics and oral microbiome', 'Ancient DNA and dental calculus', 'Occupation and dietary status from calculus, Oral microbiota and forensic odontology, 'Dental calculus and stable isotope analysis'. Snowball sampling technique of cross-referencing was used to identify related articles and the PRISMA guidelines were followed to include eligible research articles. Full-text articles published until 2022, and containing information relevant to the scope of present systematic review were further analyzed in-depth. The inclusion criteria considered studies related to forensic identification based on dental calculus and those published until 2022. Studies not satisfying the inclusion criteria were excluded from further analyses.

A total of 89 research articles were identified through search from the above scientific databases. Thirty studies were removed from consideration of further analysis as they were either modified or unrelated to the scope of present review, published in languages other than English, or marked as 'ineligible' by the an-

notation tools. Out of 59 articles selected on the basis of their title and abstract, another 16 studies were neglected as being duplicates, reviews, or not commenting upon the accuracy of dental calculus for forensic anthropological purposes. Another set of 16 studies were discarded for final analyses as their full-text version could not be found or arranged for scrutinization and analysis. Finally, 31 studies were found within the ambit/scope of the aim and objectives of present study (Figure 2).

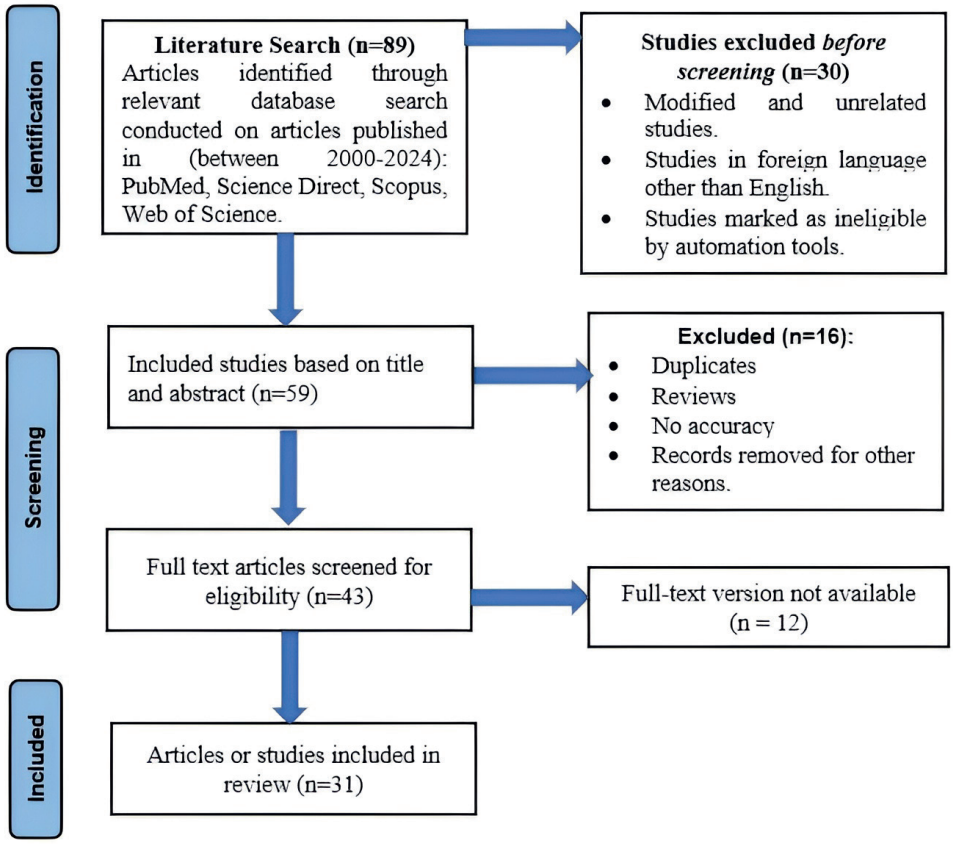


Figure 2. Flowchart showing stages of selection of articles for systematic review

## Results

The systematic review revealed that dental calculus is a promising biological material for establishing identity, assessing health and dietary status, estimating geo-affinity, exposure to heavy metals or drugs of abuse and establishing other identity credentials of an unknown individual. It serves as a rich source of host-associated biomolecules, ingested or inhaled during the routine daily life of an individual. The present systematic review found that the majority of dental calculus studies were

reported in Europe where the dental remains from archaeological sites and cemeteries were most commonly used for the purpose. Only one pilot study (Singh and Goel 2017) was reported from India. The literature review indicated that the majority of calculus research is limited to reporting its quantity and location on teeth, the microbiota preserved in it, its clinical and pathological significance and forensic importance for identifying archaeological or contemporary human remains (Brothwell 1981; Dobney and Brothwell, 1988). The type of teeth or the site (supra-/sub-lingual) from where calculus was collected for analysis was not mentioned in most of the studies. Until very recently, the scientific importance of dental calculus for forensic anthropological casework was not recognized as it could not attract the desired attention of the scientific community. Calculus has been appreciated as a significant population and individuality marker as it abundantly preserves the host-associated routine micro-particles and biomolecules in it (Radini et al. 2017). The observations of present systematic review can be summarized in the following categories.

**Collection and analysis of dental calculus**

The proper collection, sampling, preparation and analysis of dental calculus is generally done according to the standardized established protocols. Dental calculus can be collected from ancient as well as modern teeth/jaw fragments in individuals reporting to dental clinics for their routine dental check-up such as cleansing or screening purposes. Enough dental calculus can be easily collected either from the lingual or buccal surfaces of different mandibular as well as maxillary teeth without scratching or scraping tooth surfaces (Scott and Poulson, 2012). Two 3-5 mm long fragments of supra-lingual calculus are generally removed (particularly from 2 to 3 maxillary molars or mandibular incisors) using sterile or decontaminated hand or ultrasonic scaler (White 1997; Velsko et al. 2019). For forensic identification purposes, the supragingival calculus is preferred to the sublingual one as the latter is heavily mineralized, contaminated with gingival haemorrhigal components and is tightly anchored to the teeth. Detailed demographic, nutritional and disease information of an individual is crucial for objective analysis of calculus samples for anthropological or forensic purposes.

The material, molecular and chemical information entrapped in calculus deposits can be analyzed with multiple morphoscopical, analytical, cytological, histological, biochemical, molecular and optical techniques. The more sophisticated methods include optical microscopy, scanning electron microscopy, energy-dispersive x-ray spectroscopy, ultra-performance liquid chromatography-mass spectrometry, to provide information about not only identity credentials of an individual (Dobney and Brothwell 1986; 1988; Lieverse 1999; Henry et al. 2011; De la Fuente et al. 2012; Radini et al. 2017; Strömberg et al. 2018; Fotakis et al. 2020; Godoy Allende and Samplonius 2022) but also for quantifying traces of nicotine alkaloids in calculus for better understanding the consumption of such intoxicants by the smokers (Eerkens et al. 2018). The entrapment and preservation of the cellular fragments, starch granules and other inclusions in dental calculus can be examined by microscopic and spectroscopic techniques (Henry and Piperno 2008; Charlier et al. 2010; Power et al. 2015). Dosseto et al. (2024) reported that measuring strontium (Sr) isotopes from fossil calculus using multicollector inductively coupled plasma mass spectrometry helped

in correctly identifying the composition of soil where the remains were buried which, in turn, helped in estimating the geolocality of unknown human remains.

**Forensic archaeological reconstructions**

Microscopic examination of calculus deposits is highly useful in providing decisive data for forensic or medico-legal provenance or identity establishment purposes (Figure 3). Dental calculus deposition is generally considered as an ectopic growth which provides an alternate to the destructive processing of human skeletal remains. Cultural identity, individualized habits (smoking/drugs/tooth-brushing), occupational hazards (painting, mining, farming), disease or pollution exposures, even COVID-19 infections of an individual can be objectively assessed from the trace elemental analysis of dental calculus (Bergstrom 1999; Radini et al. 2017; Yaprak et al. 2017; Eerkens et al. 2018; Sørensen et al. 2021; Berton et al. 2021; Li et al. 2022). Phytoliths and plant fibers entrapped in dental calculus can help in the identification of eaten plant sources, the season or environment in which they grew, the travel routes followed and the burial location of unknown individuals (Blatt et al. 2011); thus, it can also serve as possible geographical and occupational marker of identity of an individual. The particles embedded in calculus can help in identifying occupations such as metal-workers, carpenters, and other artisans. Heavy metals deposited in calculus of production workers can be used as occupational exposure marker (Abdazimov 1991). Researchers have found that drug residues are better entrapped in the interior of the calculus material than in blood, and few drugs are found in comparatively higher concentrations in dental calculus (Sørensen et al. 2021). Thus, the manner of death, work-related intoxication or individualized habits can be reconstructed from the toxicological analysis of calculus (Charlier et al. 2010). Among the typical sources of endogenous DNA, saliva, oral fluids, proteins and mucosal or epithelial cells are found commonly found embedded in dental calculus, endorsing the possibilities of isolating mtDNA from dental calculus.

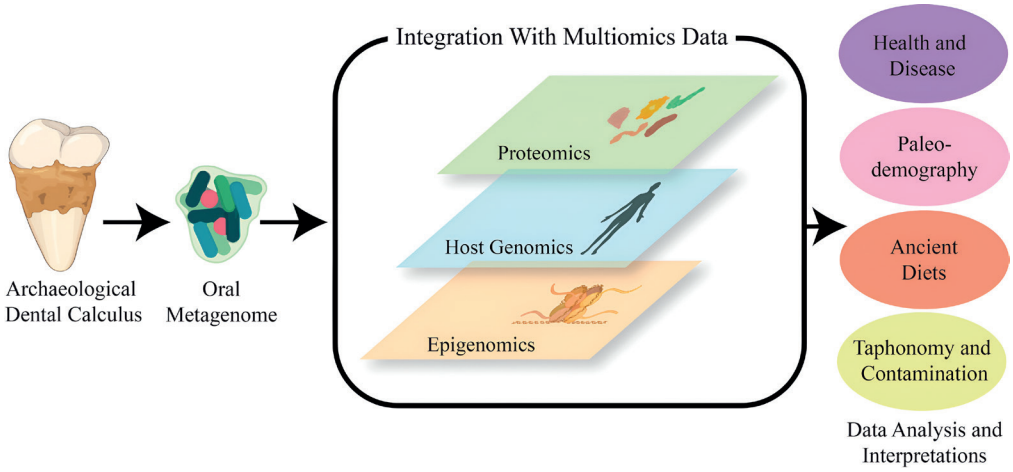


Figure 3. Multiple applications of archaeological dental calculus (reprint used with Open Access permission from Wright et al. 2021)

**DNA from dental calculus: deciphering host-oral microbiota interactions**

Calculus is a calcified form of oral microbial plaque biofilm and is a rich source of host and oral microbiome DNA (Preus et al. 2011; Brealey et al. 2020). It has been widely used as a tool in microbial forensics to estimate microbial health and the oral hygiene of the deceased. The comparative analysis of DCD from ancient and modern dentition can help understand the issues related to the abundance and diffusion of different microorganisms in the environments of the past or contemporary biospheres (Brundin et al. 2013; Weiß et al. 2020). The host mt-DNA and bacterial DNA, along with micro-particles entrapped in calculus matrix can be conveniently extracted, sequences and analyzed using advanced bio-molecular, spectroscopic or microscopic methods which, in turn, have revolutionized our understanding of the identity, diets, ancestry, occupations, migration patterns, disease, pollutant/metallic exposures, health and environmental conditions of past individuals and the populations. The molecular and chemical analysis of dental calculus can help understand the intricate dynamic relationship that existed between humans and their microbes (Warinner et al. 2015). Recent improvements in genome sequencing strategies, bioinformatics armamentarium, laboratory workflow designs and contamination controls have significantly enhanced the potential of ancient microbial research (Gilbert et al. 2005; MacLean et al. 2009; Kaczynski et al. 2012; Weyrich et al. 2015).

Microbial cells constitute about 70% of total dry weight of calculus, highlighting that the majority of calculus DNA is microbial in nature (Aas et al. 2005; Dewhirst et al. 2010; Human Microbiome Project Consortium 2012; Warinner et al. 2014; Velsko et al. 2019; Kazarina et al. 2021; Ottoni et al. 2021). The constantly evolving microbes have helped in laboratory studies of bacterial evolution which, in turn, has increased our information about the dynamics of evolution, adaptive changes, and respond to queries impacting human health (Bonczarowska et al. 2022). Ancient oral microbiota is considerably more heterogeneous than the modern one and this heterogeneity of ancient oral microbiome composition can offer more insights into human evolution (Jersie-Christensen et al. 2018) as good oral hygiene discourages calculus formation (2022). The dental calculus harbors past human oral microbiota that can provide deep insights into decedents' lifestyle, diet, health, disease, possible geolocation, environmental conditions and the cultural affiliation of an individual; thus presenting a more comprehensive ante-mortem profile of the unknown ones (Blatt et al. 2022), even from its minute quantities (Mackie et al. 2017). The application of advanced genetic techniques to detect microbial communities in ancient skeletal remains has revolutionized paleopathological research towards pathogenic evolution and identification from profiling of human oral microbiome (Bos et al. 2019; Arning and Wilson 2020; Li et al. 2022; Naud et al. 2022).

Human oral microbiome research based on dental calculus and transitions in oral microbiota has significantly contributed to our understanding of the functional diversity of microbial ecologies, oral diseases, interactions between humans, microbes and the abiotic factors the during lifetime of an individual (Warinner et al. 2015). It is the mineralization process of calculus happening during life that makes it resistant to environmen-

tal contamination and lets the microbial community get preserved in it (Jin and Yip, 2002). The temporal and spatial variations in oral microbiota can provide crucial information not only to the forensic anthropologists and archaeologists, but also to medical researchers like microbiologists, and evolutionary biologists. Microbial evolution provided deep insights into major changes in human condition like diseases, epidemiological transitions, biogeographic range expansions, colonialism and industrialization (Warinner et al. 2015; Blatt et al. 2022).

### Detection of drugs and related metabolites

Plant-based pharmaceutical or psychoactive substances and other stimulants have been commonly used in modern as well as ancient times, particularly for treatment of some medical conditions (Fiorin et al. 2018; Gismondi et al. 2018; Godoy Allende and Samplonius 2022). Revealing smoking or chewing habits, use of pharmaceutical products, illicit psychoactive drugs/stimulants and their metabolites by past populations is a crucial forensic archaeological inquiry. Recovery of plant food debris from archaeological dental calculus has helped in reconstruction of past food practices. Sørensen et al. (2021) reported that such plant inclusions found entrapped and preserved in dental calculus can be easily detected and quantified. Dental calculus can also be helpful for monitoring betel nut chewing or tobacco smoking (containing numerous heavy metal) exposure to the human oral cavity (Yaprak et al. 2017, Zhang et al. 2019). Many instances have been reported in literature when the craft and trade related by-products like stone crystals, cellulose fibers or ceramics have been found preserved in dental calculus to provide information about such practices in ancient populations worldwide (Blatt et al. 2011; Coccato et al. 2017). Supragingival dental calculus is the best choice for monitoring heavy metal (like cadmium, mercury) exposures to oral cavity which helps in assessing the risks of oral cancers due to heavy metal poisoning (Zhang et al. 2019; Charlier 2013), specifically using the analytical techniques like transmission electron microscopy (McDougall 1985).

Though dietary reconstructions from calculus have been widely studied, relatively fewer studies have considered the deposition of pharmaceutical or phototherapeutic residues in DCD (Hardy et al. 2018; Gismondi et al. 2018). In post-mortem cases, calculus may serve as a valuable adjunct to the existing analyses where traditional investigations do not provide any leads. Direct oral ingestion of substances, inhalation of smoke/vapor, and/or the release of cellular or serum residuals into the saliva and gingival crevicular fluid may facilitate entrapment and preservation of a large variety of pharmaceutical and psychoactive drugs in dental calculus. The variations in entrapment and deposition of this matter in calculus from different individuals may depend upon differences in the diet, health, local pH, salivary flow, and, lastly, the stability of the substances entrapped in the calculus (Sorensen et al. 2021). Use of medicinal plants in ancient times has been deciphered from chemical indicators in archaeological dental calculus samples (Hardy et al. 2009; Gismondi et al. 2018). Smoking or chewing of tobacco (nicotine) or any other product having skewed concentrations of toxic heavy metals like arsenic, mercury, silicon, lead or cadmium have been revealed from archaeological calculus

(Yaprak et al. 2017; Eerkens et al. 2018; Zhang et al. 2019); inductively coupled plasma mass spectrometry analysis of dental calculus being a novel non-invasive technique for analysis of environmental exposure to heavy metals (Zhang et al. 2015, 2019). Drug residues of cocaine, heroin, 6-monoacetylmorphine (6-MAM) and tetra-hydrocannabinolic acid A (THCA-A) have been found trapped in the interior of the modern calculus material (Sorensen et al. 2021). Saliva has higher affinity to accumulate basic drugs in higher concentrations than the blood owing to generally lower pH of the former.

## Discussion

Until recently, the anthropological, archeological and forensic research potential of calculus was not recognized fully, and it was overlooked with calculus being a discarded material. It is now fully understood that dental calculus houses crucial information about the past human life in the form of host-associated micro-particles and biomolecules embedded within its hardened and rough matrix, ingested/inhaled (intentionally or accidentally) during routine daily life of an individual (Buckley et al. 2014; Radini et al. 2017). It is the porous nature of DCD which makes it ideal for a variety of research. It has been recently recognized as an informative material to understand ancient diet and health in archaeological sciences (Forshaw 2022). It has immensely helped in revealing human prehistory, dietary variations and shifts, and disease signatures from ancient oral microbiome analysis of past populations (Hansen et al. 1991; Dobney 1994). The material and molecular information contained within DCD is vast and ever-expanding and it can prove more useful than the bones in the identification of fragmented or burnt human remains.

Anthropological and molecular examinations of dental calculus collected from historical, archaeological, or forensic specimens may help in biological profiling, establishing cultural and geographical identity of such unknown human remains as calculus contains DNA in sufficient quantity required for such identifications and revealing microbial and host-DNA diversity (Lisman et al. 2023). Dental calculus is a rich reservoir of ancient host biomolecules and human DNA; both mitochondrial and nuclear DNA (Warinner et al. 2015; Singh and Goel 2017; Mann et al. 2018; Lisman et al. 2023). It is the rough and porous surface of the calculus deposits which promotes bacterial deposition, sometimes under standard hygiene conditions. It is this unique structure and mineralized nature of calculus that strongly embodied DNA within it and prevents the acidic or exogenous microbial attacks in the hardened matrix of calculus (Warinner et al. 2014; Mann et al. 2018). Genomics and forensic experts are well acquainted with the advantages of analyzing dental calculus which can be conveniently obtained from the living and recently dead individuals or even the skeletonized archaeological human remains (Singh and Goel, 2017). Dental calculus may contain up to 1000 times more DNA than any other skeletal element and has huge potential to revolutionize ancient biomedical research. It can be used as an alternative source material for ancient human DNA analyses when other skeletal tissues do not yield the desired results (Warinner et al. 2014; Forshaw, 2022). Dental calculus serves as an adjuvant and non-invasive evidence in

forensic human identification by establishing human-host DNA profile, living conditions, behavior, lifestyle, and the dietary status of the decedent (Blatt et al. 2022; Bonczarowska et al. 2022).

Highly degraded and challenged samples generally contain low amounts of DNA (with PCR inhibitors), which presents a very tough task for their forensic identification pursuits. Calculus provides a clean, stable, durable and hospitable environment for microbial communities, food and non-food particles and thus, serves as a viable source of forensic identification based on autosomal and Y-STR markers extracted from it (Sawafuji et al. 2020, Lisman et al. 2023). Human DNA bound in calculus hydroxyapatite is comparatively well preserved; thus it can be taken as potential investigative tool for forensic purposes (Higgins and Austin, 2013). The gingival secretions, shed epithelial cells, macrophages and oral inflammatory processes are the probable sources of DNA incorporation into dental calculus deposits (Warinner et al. 2015; Mann et al. 2018). Calculus DNA is relatively low in quantity and is fragmented, with the highest concentration found in subgingival plaque. The majority of available dental calculus research is primarily focused on estimating dietary habits, oral microbiota and mtDNA haplogroup affiliations of archaeological human remains (Black et al. 2011; Damle 2016).

The quality of DNA isolated from calculus significantly differs from that obtained from teeth. Dentine DNA is more degraded and damaged than the fragmented and shorter length (but more stable and less challenged) DNA obtained from dental calculus. A comparison of DNA yields from paired dental calculus and dentine samples from the same tooth of an individual has endorsed that dental calculus is the richest known source of ancient biomolecules in human hard tissues (Willmann et al. 2018; Li et al. 2022). As calculus DNA provides only preliminary identity affiliations of the contaminated samples (Lisman et al. 2023), it can be more useful than bones towards identification strategies of such challenged human remains. Human DNA embedded in calculus hydroxyapatite is comparatively well preserved and can be used as a potential investigative tool for both forensic as well as microbiological research purposes (Higgins and Austin 2013). A minimal 20 mg of dental calculus is ideally collected, though higher amounts of calculus may provide better DNA amplification results (Lisman et al. 2023). The Next Generation Sequencing (NGS) strategies like Amplicon and Shotgun Metagenomics have been used to characterize oral microbiome from the collected dental calculus deposits. Amplicon sequencing of microbial DNA is done to focus on one or more of the nine variable regions of the 16S rRNA gene to characterize the taxonomic structure and diversity of the extracted microbiome (Cappellini et al. 2014).

Mann et al. (2018) reported that DNA obtained from dental calculus is consistently more abundant and less contaminated than DNA extracted from dentin. Most of the DNA obtained from calculus is microbial in origin, derived from the entrapped oral microbial communities in it. The bonafide microbial taxa can be profiled and compared from the identification of microbiomes in ancient or historical dental calculus samples (Belstrom et al. 2018; Weiß et al. 2020). Dagli et al. (2015) identified dental calculus as one of the rich sources of ancient microbial DNA from the microbial colonies entrapped in it and thus, highlighted the implications

of ancient DNA research in palaeo-microbiology. Similarly, calculus can be an alternate source of mtDNA for biological profiling of unknown human skeletal remains older than 1,000 years, which tell us about some benefits and limitations of DNA research from calculus (Black et al. 2011). Adler et al. (2013) sequenced and amplified the 16S rRNA gene of oral microbiota from 5,500 BCE–1,600 CE old dental calculus samples, using the next-generation sequencing technique. Singh and Goel (2017) collected dental calculus from lingual surfaces of mandibular incisors from 20 dental students of Moradabad (UP) and found that majority of dental calculus samples yielded DNA ranging from 21 to 37 $\mu$g/ml (mean quantity of 23.5 $\mu$g/ml). The extraction and sequencing of ancient microbial DNA and its comparison with contemporary microbial strains has significant relevance to practice of modern medicine and dentistry for understanding host-microbiome interactions (Akcalı and Lang 2018). As human oral microbiota is both culture and geography specific, the genetic mutations in ancient microbial DNA help in tracking human migrations that happened in past populations, highlighting the potential ability of microbiota DNA as genetic signal of cultural affinity of pre-historic populations (Dominguez-Bello and Blaser 2011; Eisenhofer et al. 2019). Changes in human oral microbiome signify changes in dietary patterns over time, indicating a marked change in oral pathologies and dental calculus deposition.

## Challenges, future probabilities and implications

In most forensic situations, highly degraded and contaminated or challenged samples (containing PCR inhibitors) containing low amounts of DNA are retrieved for identification purposes which presents a very tough and challenging task for extraction of DNA; dental calculus is one of such materials. The concentration of DNA isolated from calculus does not significantly differ from that obtained from teeth. Dental DNA is comparatively more degraded than the undamaged DNA extracted from calculus, so calculus DNA is more stable and less challenged than dentin DNA (Lisman et al. 2023). However, calculus DNA is more fragmented and shorter in length, it is merely sufficient to obtain a putative profile of an individual; suitable enough, at least, for preliminary forensic identification strategies (Lisman et al. 2023). The biggest challenge for geographic identification of vegetal or faunal inclusions in calculus is the lack of comprehensive reference libraries, and alteration of geolocation signatures due to travel, illness and diet.

Secondly, very limited literature is available about the quantification of human DNA content in dental calculus for human identification purposes. The quantity of collected dental calculus (ideally 20 mg) is crucial as significantly higher amounts of calculus yield better DNA amplification results (Lisman et al. 2023). The benefits and limitations of using dental calculus as an alternate source for DNA should be weighed prior to suggesting its efficacy for forensic purposes. Calculus offers an indirect method of DNA analysis that is more closely linked to a specific individual than other sources which are used for indirect DNA analysis (Black et al. 2011).

Research involving higher numbers of jaw fragments is certainly needed to authenticate the forensic utility of dental calculus for forensic identification purposes. The pioneer research work utilizing the 'to-be-thrown' calculus will cer-

tainly help future forensic, anthropology, public health, and dentistry experts as an important biological material towards establishing identity, geolocality and exposure to heavy metals, and drug abuse of an unknown individual. Forensic anthropologists and geneticists should explore collaborative research possibilities in the field to explore the full potential of dental calculus as an adjuvant and non-invasive evidentiary material towards forensic human identification (Modi et al. 2020). Though the prospect of dental calculus as a biomaterial has yet to be rigorously and systematically scrutinized (Mann et al. 2018), it is expected to help forensic anthropologists for provenance of unknown human remains retrieved from forensic scenarios, even when only some teeth are retrieved from such contexts.

## Conclusions

Calculus finds its extensive utility in forensic and archaeological reconstructions such as assessing host-oral microbiota interactions, the microbial health and oral hygiene of past individuals, screen out their dietary status, food diversity, exposures to heavy metal and drug of abuse, and, lastly, to estimate the geographical and occupational affiliations of past individuals. Dental calculus houses a multitude of diverse biomolecules than provide information about diet, health, culture, behavior, ancestry and identity of past populations (Wright et al. 2021). Dental calculus entraps cellular or tissue fragments, past human oral microbiota that can provide deep insights into decedents' lifestyle, disease status, occupational habits, possible geolocation, environmental conditions and the cultural affiliation of an individual; thus presenting a more comprehensive ante-mortem profile of the unknown individuals (past or contemporary). Microbial forensics has significantly contributed as a useful tool in medicine, bioterrorism, biosecurity, food trade and human identifications (Castro and de Ungria 2022).

Very limited published research work is available about the extraction and analysis of human DNA content from dental calculus for forensic anthropological purposes, thus the anthropological and archaeological research involving dental calculus is still in its nascent stage; so comprehensive research in different population groups is needed for fruitful research avenues and utilization of DCD as an alternative material for ancient genomics research. Anthropological insights into ancient population dynamics, migrations, social stratification, oral health and environmental adaptations can be unraveled from the complex biomolecular composition of dental calculus. Studying DNA from prehistoric bacteria or viruses may lead to the discovery of techniques and approaches to fight contemporary strains/forms of such infectious agents. Recent studies have necessitated that for ancient DNA analysis of current microbial diseases, information about the past genotypic and phenotypic signatures of the responsible bacteria needs to be collected. Thus, crucial knowledge about the past oral microbiome may also help medical professionals and physicians use ancient microbial DNA signatures to track/identify such infectious agents in modern day populations.

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### Conflict of interest

The authors have no conflicts of interest to declare.

### Author contributions

JSS conceptualized and validated the idea and framework/outline of the manuscript, designed the methodology, scrutinized and finalized the relevant literature on the topic, wrote the rough and final drafts of the manuscript and revised its final version; ST reviewed the final manuscript, edited its English language and generated one figure.

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# Association between COVID-19 Pandemic, Blood Pressure and Pulse Rate in Young Slovak Women

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Abstract: This study investigates the relationships between the COVID-19 pandemic, lifestyle factors, and their impact on blood pressure (BP) and pulse rate in young adult women from Slovakia. We assessed 552 adult women aged 18 to 30 years who were categorized into subgroups based on their pandemic status. The individual's lifestyle was evaluated using a detailed questionnaire. BP and pulse rate were measured in the sitting position using a digital sphygmomanometer. Linear regression analysis tested the associations. The results showed no significant difference in physical activity and the proportion of fat mass (%) before and during the pandemic. Smoking prevalence increased during the pandemic compared to pre-pandemic levels ($p = 0.152$). While there were no significant differences in coffee consumption, the use of hormonal contraceptives was significantly higher during the pandemic ($p = 0.021$). In addition, systolic blood pressure (SBP) and pulse rate were significantly higher during the pandemic than before, indicating possible cardiovascular effects (SBP with $p < 0.001$ and pulse rate with $p = 0.001$). Regression analysis revealed that pandemic and fat mass (%) were significant predictors of SBP, while only physical activity and fat mass (%) were predictors of diastolic blood pressure (DBP). In addition, pandemic and physical activity were significant predictors of pulse rate. We observed significantly higher SBP and pulse rates during the pandemic than before in young adult women. Further studies are needed to investigate the long-term effects of the pandemic on SBP and pulse rate.

Keywords: pandemic, lifestyle, young women, systolic blood pressure


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## Introduction

Coronaviridae is a diverse family of viruses that infect various organisms, including not only animals but also humans. When organisms are infected with these viruses, there is a high risk of respiratory infections that can lead to various serious diseases that affect the physiology of systems in the human body. At the end of 2019, a novel coronavirus identified as SARS-CoV-2 emerged in Wuhan, China, causing an unusual outbreak of viral pneumonia. The novel coronavirus disease, also known as coronavirus disease 2019 (COVID-19), is highly contagious and has spread rapidly worldwide (Gao et al. 2020; WHO 2020; Hu et al. 2021).

The COVID-19 pandemic has impacted public health in many ways. The measures taken to prevent the spread of the virus have disrupted daily routines and activities. Research has shown that physical activity has decreased during this time, accompanied by an increase in physical inactivity, body weight, blood pressure and the prevalence of type 2 diabetes (Flanagan et al. 2021; Robinson et al. 2021; Capra et al. 2022). In addition, young adult women who were already prone to certain physiological problems were in an unprecedented situation that could potentially affect their BP dynamics. Understanding the link between pandemic-related stress and BP fluctuations is crucial for deciphering the broader health implications (Kobayashi et al. 2021; Laddu et al. 2022; Laffin et al. 2022; Yoshihara 2023).

The study by Laffin et al. (2022) found that BP in adults in the USA was significantly higher from April to December 2020 than in 2019. During the pandemic period, the mean monthly changes from the previous year were between 1.10 and 2.50 mmHg for systolic blood pressure (SBP) and between 0.14 and 0.53 mmHg for diastolic blood pressure (DBP); the increases in SBP and DBP applied to men and women and all age groups; larger increases were found in women for both SBP and DBP, in older participants for SBP and in younger participants for DBP. In addition, Gotanda et al. (2022) found that SBP and DBP increased by 1.79 mm Hg and 1.30 mm Hg, respectively, during the pandemic period compared to the pre-pandemic period. Celik et al. (2021) found that both SBP and DBP levels increased significantly during the day, at night and over a full 24-hour period compared to pre-pandemic levels. Notable lifestyle changes, such as reduced physical activity and increased stress levels, may also affect resting pulse rate and its variability. In addition, women tend to have a higher resting heart rate than men, around 3 to 5 beats per minute, largely due to physiological factors such as smaller heart size, hormonal differences and differences in the regulation of the autonomic nervous system (Reimers et al. 2018).

In addition, regular physical activity is known to lower resting pulse rate by improving parasympathetic tone, which is consistent with the study by Wyatt et al. (2025), who reported that pulse rate decreased by 1.5% during lockdowns, which was associated with lower activity levels.

In addition to reduced physical activity, many factors may have influenced BP during the pandemic. During the pandemic, we observed differences in smoking habits that may affect cardiovascular health. Al Ghadban et al. (2022) reported that about a quarter of their study participants were stressed by the COVID-19 pandemic and related economic crises, which were strongly associated with increased smoking behavior. Coffee consumption has also changed.

From a purely psychological and emotional perspective, coffee is a good energy source that can improve mood, combat drowsiness, and improve cognitive function, which could explain the increased coffee consumption due to the pandemic (Castellana et al. 2021). However, the relationship between caffeine consumption and BP remains interesting (Han et al. 2022). The possible effects of contraceptive methods on BP in young women are also the subject of research (Gao et al. 2023; Schmidt-Lauber et al. 2023; Basile and Bloch 2024). Despite the benefits of hormonal contraception, there is evidence that it may increase the risk of adverse effects, including cardiovascular disease, obesity, hypertension, hemorrhagic stroke, breast cancer, and cerebral venous thrombosis (Rosano et al. 2022).

In addition to lifestyle-related factors, it is also important to consider the physiological mechanisms that may underlie pandemic-related changes in BP and pulse rate. The COVID-19 pandemic has been a prolonged stressor, and chronic psychological stress is known to activate the hypothalamic-pituitary-adrenal (HPA) axis and sympathetic nervous system, leading to increased cortisol and catecholamine levels. These neurohormonal changes contribute to increased vascular tone, heart rate and elevated BP (Esler et al. 2020). Overactivity of the sympathetic nervous system is also associated with reduced baroreflex sensitivity and impaired parasympathetic modulation, which can affect resting pulse rate and its variability. In women, these autonomic responses may be additionally modulated by hormonal fluctuations, including the effects of estrogen and progesterone, which influence vascular reactivity and cardiac autonomic control (Hart et al. 2009). Therefore, pandemic-related psychosocial stress may have had both direct and indirect effects on cardiovascular parameters, particularly in young women who may be more susceptible to such influences.

While previous studies from countries such as the United States, Japan and Turkey provide valuable insights into pandemic-related changes in BP parameters, it is important to consider that cultural, healthcare and lifestyle differences may limit direct comparability. For example, differences in access to healthcare, perception of stress, contraceptive use and public health responses to COVID-19 could influence the magnitude or direction of physiological effects. Therefore, studying a specific population of young women of European origin is essential to understanding the context-specific impact of the pandemic.

We hypothesise that the above lifestyle factors and the COVID-19 pandemic have a potential impact on SBP and DBP levels and pulse rate in young adult women (we expect higher SBP, DBP and pulse rate during the pandemic); therefore, we investigated the relationships between these factors.

## Material and methods

### Participants

Relatively healthy Slovak women were recruited non-randomly and voluntarily and evaluated in the biomedical laboratory of the Department of Anthropology at Comenius University in Bratislava, Slovakia. Data were collected in two cross-sectional surveys from 2019 to 2022.

Our sample included 552 young adult university students and graduates aged 18 to 30 with a mean of 21.30 ± 2.18 SD. The analyzed sample was divided into two groups, which were collected according to the same study design: (1) one group

included those whose measurements were taken from February 2019 to March 2020 before the COVID-19 pandemic. This group included 241 women aged at least 19 and at most 29 years with a mean age of 22.14 ± 2.25 SD, and (2) the second group of 311 women aged 18 to 30 years with a mean age of 20.63 ± 1.89 SD was measured from September 2020 to November 2022 during the pandemic. One of the conditions for data collection was that women, were only allowed to participate in the study once, before or during the pandemic. The anonymised data were analysed solely for scientific purposes. Women who were unable to respond due to severe physical or mental illness and who could not undergo anthropometry or blood measurement were excluded from the study. Each participant gave written informed consent to this study, per the principles of the Declaration of Helsinki. The biomedical research was also approved by the Faculty of Natural Sciences Ethics Committee at Comenius University – number ECH19021. The methods of the present study were also previously applied in another study but with different goals (Falbová et al. 2024).

### Questionnaire

The study used a standardised and validated questionnaire (modified WHO expert questionnaire from 2014 – STEPwise approach to surveillance – instrument v.3.2 in the Slovak version), which was used to collect information on the baseline characteristics of the study participants and their socio-demographic background. The following lifestyle variables were collected by self-report and personal interview: (a) physical activity was assessed by the question „How often do you exercise or engage in physical activity?" with responses grouped into seven categories: daily, 5−6 days per week, 3−4 days per week, 1−2 days per week, 1−3 days per month, less than once per month, or never. For the purposes of the study, we grouped these seven categories into four categories (5−7 days per week, 1−4 days per week, 1−3 days per month and less, never); (b) smoking was categorized as current smoker or non-smoker; (c) coffee consumption was assessed by the question „How often do you consume coffee? " and responses were categorized into „yes" and „no" groups; (d) hormonal contraception was assessed by the question „Do you use hormonal contraception?" and responses were categorized into „yes" and „no" groups.

### BP analysis

BP and pulse rate were measured in a sitting position using a digital sphygmomanometer OMRON M3 (Omron Healthcare Co., Ltd., Kyoto, Japan). All measurements were performed in the morning hours between 8:00 and 11:00 a.m. in a quiet room at a stable room temperature (approx. 22–24 °C). Women were instructed to refrain from caffeine, physical activity and smoking for at least 30 minutes before the measurement. After a rest period of at least five minutes in a seated position, three consecutive measurements were taken and the average values of SBP, DBP and pulse rate were calculated.

### Analysis of body composition

The InBody 770 Body Composition Analyzer (Biospace Co., Korea) was used to determine human body composition parameters based on the recommendations in the user manual. Participants were tested in the morning in a quiet state. Participants stood barefoot on the pedal plate electrode. The hands hung down naturally and held the hand electrode

gently, with the angle between the trunk and the upper limbs at 15°. The analyzer evaluated various body composition parameters, but only fat mass (FM, %) was analyzed in this study.

### Statistical analysis

All statistical analyses were performed with IBM SPSS for Windows (Statistical Package for the Social Science, version 25.0, Chicago, IL), with statistical significance at $p \leq 0.05$. The obtained frequencies and percentages determined participants' responses, and the normality assumption hypothesis for continuous variables was tested using a one-sample Kolmogorov–Smirnov test. The Parametric Independent Sample T-test and the non-parametric Mann-Whitney U test were used based on the normality distribution of the quantitative variables. The effect size was calculated using Cohen's d=2 t /(df^1/2) (small effect: < 0.5; medium effect: 0.5 – 0.8; large effect: > 0.8). Backward linear regression analyses considered the following independent variables: pandemic presence, physical activity, smoking, coffee consumption, and use of hormonal contraception. Only predictors with p value less than 0.05 influenced body composition parameters.

## Results

Table 1 summarises the baseline descriptions. These included age, physical activity, smoking status, coffee consumption and the use of hormonal contraceptive. Our results showed no significant difference in physical activity and fat mass percentage between the groups before and during the COVID-19 pandemic, but smoking prevalence was higher during the pandemic than before (19.60% vs. 14.90% and p = 0.152), although this difference was not statistically significant. In addition, there are no significant differences in coffee consumption, but the use of hormonal contraceptives is significantly lower during the pandemic at 10.30% than before at 17.01% and p = 0.021.

Table 1. Baseline characteristics of the participants

| | Before the COVID-19 pandemic | During the COVID-19 Pandemic | |
|---|---|---|---|
| Number of participants | | | |
| Women | 241 | 311 | |
| | Mean±SD | Mean ± SD | p |
| Age, y | 22.14 ± 2.25 | 20.63 ± 1.89 | **< 0.001** |
| Physical activity | N (%) | N (%) | |
| 5−7 days per week | 15 (6.22) | 28 (9.00) | 0.208 |
| 1−4 days per week | 162 (67.22) | 185 (59.49) | |
| 1−3 days per month and less | 34 (14.11) | 59 (18.97) | |
| Never | 30 (12.45) | 39 (12.54) | |
| Smoking status | N = 241 | N = 311 | |
| Smokers | 36 (14.90%) | 61 (19.60%) | 0.152 |
| Non-smokers | 205 (85.10%) | 250 (80.40%) | |

| | Before the COVID-19 pandemic | During the COVID-19 Pandemic | |
|---|---|---|---|
| Coffee consumption | N = 241 | N = 310 | |
| Yes | 190 (78.80%) | 243 (78.40%) | 0.898 |
| No | 51 (21.20%) | 67 (21.60%) | |
| Use of hormonal contraception | N = 241 | N = 311 | |
| Yes | 41 (17.01%) | 32 (10.30%) | **0.021** |
| No | 200 (82.99%) | 279 (89.70%) | |
| FM % | N (Mean ± SD) | N (Mean ± SD) | |
| | 241 (27.67 ± 7.08) | 310 (26.81 ± 7.81) | 0.096 |

Note: p values in bold are significant at $p < 0.05$

Abbreviations: N, number of participants; p, value of statistical significance; SD, standard deviations; FM, fat mass

Table 2 documents the BP parameters in young adult women before and during the COVID-19 pandemic. The women had significantly higher SBP (mmHg) and pulse rates during the COVID-19 pandemic than before the pandemic, with SBP during the pandemic: 119.25 ± 11.96 (mmHg) and before 114.79 ± 9.66 (mmHg); $p < 0.001$ and pulse rate during the pandemic: 81.32 ± 12.92 and before: 77.08 ± 12.69; $p = 0.001$. DBP (mmHg) showed no significant difference between the pre-pandemic and pandemic periods ($p = 0.399$).

Table 2. Blood pressure parameters in young adults women before and during the COVID-19 pandemic

| | Before the COVID-19 pandemic | | | | | During the COVID-19 pandemic | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Women | N | Min | Max | Mean | SD | N | Min | Max | Mean | SD | p | Cohen´s d |
| SBP (mmHg) | 240 | 89.00 | 156.00 | 114.79 | 9.66 | 309 | 89.00 | 162.00 | 119.25 | 11.96 | **< 0.001** | 0.410 |
| DBP (mmHg) | 240 | 51.00 | 91.00 | 69.16 | 7.15 | 309 | 50.00 | 99.00 | 70.12 | 8.41 | 0.399 | 0.123 |
| Pulse rate | 240 | 50.00 | 124.00 | 77.08 | 12.69 | 309 | 54.00 | 136.00 | 81.32 | 12.92 | **0.001** | 0.331 |

Note: p values in bold are significant at $p < 0.05$

Abbreviations: N, number of participants; p, value of statistical significance; SOS, Speed of sound; SD, standard deviations; SBP, systolic blood pressure; DBP, diastolic blood pressure, d-effect sizes calculated using Cohen´s formula

Table 3 shows the backward linear regression analysis used to test the independent influence of the pandemic and lifestyle factors and FM% on BP parameters in women. The Durbin-Watson test showed that there was no autocorrelation. The pandemic and FM% were significant predictors of SBP. A positive B coefficient was found for SBP, suggesting that pandemic and FM% were associated with higher SBP levels. Physical activity and FM% were significant pre-

dictors of DBP. A positive B coefficient was found for these predictors, suggesting that these predictors were associated with higher DBP levels. In addition, pandemic and physical activity were significant predictors of pulse rate, with $p < 0.001$. The positive B coefficient for these predictors suggests that the pandemic and physical activity may lead to higher pulse rates. Not statistically significant variables were excluded from the models, including coffee consumption, smoking, and hormonal contraception, since despite showing a significant difference between groups, they did not remain a significant predictor when controlling for other variables in the multivariate analysis. The overall significance of the models, as measured by the coefficient of determination ($R^2$), ranged from 0.068 to 0.122, suggesting that these variables explained only a small to moderate proportion of the variation in the dependent variables. This represents a limitation of our models and suggests that other unmeasured factors may contribute significantly to BP variations in this population.

Table 3. Linear regression analysis of selected predictors with blood pressure parameters in women

| Dependents variables | Predictors | B | 95 % CI for B | SE for B | p | $R^2$ | Durbin-Watson | T |
|---|---|---|---|---|---|---|---|---|
| Women | | | | | | | | |
| SBP (mmHg) | Pandemic | 4.774 | 2.987 – 6.560 | 0.909 | **< 0.001** | 0.122 | 1.943 | 5.249 |
| | FM% | 0.437 | 0.318 – 0.556 | 0.061 | < 0.001 | | | 7.221 |
| excluded variables: physical activity, coffee consumption, smoking, hormonal contraception | | | | | | | | |
| DBP (mmHg) | Physical activity | 0.500 | 0.050 – 0.950 | 0.229 | **0.029** | 0.095 | 1.976 | 2.184 |
| | FM% | 0.288 | 0.201 – 0.375 | 0.044 | **<0.001** | | | 6.529 |
| excluded variables: pandemic, coffee consumption, smoking, hormonal contraception | | | | | | | | |
| Pulse | Pandemic | 4.137 | 2.019 – 6.256 | 1.078 | **< 0.001** | 0.068 | 1.925 | 3.837 |
| | Physical activity | 1.866 | 1.132 – 2.599 | 0.373 | **< 0.001** | | | 4.997 |
| excluded variables: FM%, coffee consumption, smoking, hormonal contraception | | | | | | | | |

Note: p values in bold are significant at $p < 0.05$

Abbreviations: B, beta coefficient; CI, confidence interval; p, value of statistical significance (regression analysis, backward method; ); R2, coefficient o determination; SE, standard error; SBP, systolic blood pressure; T, tolerance (collinearity analysis), and FM, fat mass

## Discussion

### The pandemic and lifestyle factors

Our results show no significant differences in the frequency of physical activity and fat percentage between the groups before and during the COVID-19 pandemic. In addition, the most frequent frequency observed was 1 – 4 days per week in women in both study groups, regardless of pandemic status. These results may suggest a relative stability in the frequency of physical activity in young adult women in Slovakia, even though a non-significant

decrease was observed in the most common category (1–4 days/week). When interpreting these results, it is important to consider the specific national context. During the pandemic, strict but relatively short lockdown periods were imposed in Slovakia compared to some other countries. Cultural factors such as a preference for outdoor activities and access to nearby natural environments may have facilitated the maintenance of physical activity levels. We hypothesise that despite the closure of gyms and sports clubs, women in Slovakia continued to engage in structured physical activities, such as exercising at home, outdoor activities, online fitness classes or virtual challenges. These findings are similar to those of López-Vaneciano et al. (2021), who indicated that students who met current minimum physical activity recommendations before the lockdown generally continued to meet these recommendations during the pandemic-related lockdown. Although Shaun et al. (2021) observed that the proportion of students who engaged in physical activity one to three times per week remained relatively stable before and after lockdown — 37.6% and 36.3%, respectively — a study conducted in Bangladesh reported a sharp decline in students' physical activity, dropping from 43.6% before lockdown to only 7.5% after lockdown. On the other hand, research with students, cyclists and athletes found a notable increase in physical activity during this period (Romero-Blanco et al. 2020; Venter et al. 2020). In addition, another study by Ingram et al. (2020) observed a decrease in physical activity associated with negative mood during lockdown. This difference suggests that fluctuations in physical activity levels may affect psychological well-being differently depending on context and individual factors.

The prevalence of smokers was higher during the pandemic than before, ranging from 19.60% to 14.90%, $p = 0.152$. Comparing smoking status with another study by Koyama et al. (2021), both studies address changes in smoking behavior during the COVID-19 pandemic, albeit in different contexts. While our study found an increased prevalence of smokers during the pandemic, the Osaka Health App study showed other changes in the smoking habits of current smokers amid Japan's state of emergency. Our findings are in line with those of Ghadban et al. (2022), who found that about a quarter of their participants experienced stress due to the COVID-19 pandemic and the associated economic challenges, which was closely associated with higher smoking rates. However, pandemic-related stress appears to influence smoking behaviour in different ways — while some people reported smoking more, others reduced their tobacco consumption (Bommelé et al. 2020; Elling et al. 2020; Chen 2020).

Our results on coffee consumption show that the majority of women did not change their habits (78.80% vs. 78.40%, $p = 0.898$). However, it is important to point out that our methodology was based solely on self-report comparing the periods before and during the pandemic. In contrast, other studies have reported increased coffee consumption during quarantine (Alhusseini and Alqahtani 2020; Al-Musharaf et al. 2021). In addition, the study by Bakaloudi et al. (2022) found that some individuals increased their coffee consumption during quarantine while others decreased or maintained their consumption and that factors such as changes in routine, working from home, and stress influenced caffeine consumption behavior during the pandemic.

Use of hormonal contraception before the pandemic was significantly higher (17.01%) than during the pandemic (10.30%), with $p = 0.021$. Although hormonal contraceptive use differed significantly between groups in the descriptive analysis, it was excluded from the regression models due to lack of statistical significance after adjustment. This suggests that its effect was not independent of other variables in the model. Our findings are consistent with those of Walker (2022), who observed a 22% decrease in prescriptions for the combined contraceptive pill during the withdrawal period compared to the same three months in 2019. In contrast, there was no significant change in prescriptions for progestogen-only pills. Prescriptions for long-acting methods decreased, with the largest decreases for implants (76% less than before the lockdown), intrauterine devices (79% less than before the lockdown), and intrauterine devices (76% less than before the lockdown). In another study by Chiu et al. (2023), no increase in the use of hormonal contraceptives was found. But this study compared contraceptive sales before and during the COVID-19 pandemic. It examined the changes in sales of different contraceptive methods, including hormonal contraceptives, to assess trends in contraceptive use during the pandemic.

**The pandemic and BP parameters**

SBP and pulse rate were higher in the pandemic group of women than in the pre-pandemic group, with $p < 0.001$. Although the regression models showed statistically significant associations between pandemic exposure and SBP or pulse rate, their explanatory power was limited ($R^2$ between 0.068 and 0.122). This indicates that the models explained only a small proportion of the variance in cardiovascular outcomes, suggesting that other unmeasured factors may also play a role. Furthermore, in contrast to the observed increases in SBP and pulse rate, no significant difference in DBP was found between the two groups ($p = 0.399$). This null finding suggests that the cardiovascular changes observed during the pandemic are more likely due to increased sympathetic activity or acute stress responses, which increase SBP and heart rate rather than DBP. In the literature consulted, we found very few studies investigating changes in BP during COVID-19 lockdown in young adult women. The mechanisms underlying these findings are not yet clear, but there are several possible explanations for the increased SBP and pulse rate in the population during the COVID-19 pandemic. Most importantly, BP was influenced by housework, increased housework and sedentary behaviour, isolation, pandemic-related stress and major changes in personal lifestyle. In addition, alcohol consumption is known to increase BP, and several studies have shown an increase in alcohol consumption and binge drinking during the pandemic (Grossman et al. 2020; Pollard et al. 2020). Our results are similar to those of Nagata et al. (2023), who observed an increase in BP in early adolescence. The results of another study by Nolde et al. (2024) provide clear evidence of higher BP in individuals in Australia during the COVID-19 pandemic compared to the pre-pandemic period. In the study by Gotanda et al. (2022), the number of BP measurements decreased significantly at the beginning of the pandemic and then gradually increased. During the pandemic, SBP and DBP increased compared to the pre-pandemic

period. In the study by Laffin et al. (2022) among US adults, annual changes in SBP and DBP showed no differences between 2019 and January to March 2020. In this study, the annual increase in BP from April to December 2020 was significantly higher than in 2019. During the pandemic period, mean monthly changes from the previous year ranged from 1.10 to 2.50 mm Hg for SBP and from 0.14 to 0.53 mm Hg for DBP. The increase in SBP and DBP applied to men, women and all age groups. Larger increases were observed in women for both SBP and DBP, in older participants for SBP and in younger participants for DBP (all $p < 0.001$).

In our study, pulse rate was significantly higher in the pandemic group compared to the pre-pandemic group ($p < 0.001$), suggesting a potential physiological response to pandemic-related stress or lifestyle changes. This finding contrasts with the results of Wyatt et al. (2025), who reported a 1.5% decrease in pulse rate during lockdowns, attributing the reduction to lower physical activity levels among participants.

**Limitations of the study**

Our study provides unique results, but these are limited by the cross-sectional design of the study. While we compared two cross-sectional data sources, we did not interview the same women over time. Nevertheless, both are population-representative surveys, and we used identical measures to assess the results to allow for cross-study comparison. A notable limitation is the sample size ($n = 552$), which is moderate but may not be sufficient to detect small effect sizes in subgroup analyses. We did not perform an a priori power analysis, which limits the interpretation of non-significant results. Future studies with larger samples are needed to confirm our findings and better estimate effect sizes of pandemic-related changes in cardiovascular parameters. We also acknowledge concerns regarding the representativeness of the sample. The participants were not randomly and voluntarily recruited among Slovak university students and graduates. While this group represents a specific and relevant population group (i.e. young, educated women), the generalisability of the results to the wider population of young Slovak women may be limited. It should be noted that general limitations of this study include the subjective nature of the lifestyle assessment, which was obtained by self-report, and that important data may not have been fully captured. This potential limitation was at least partially addressed through face-to-face interviews with all women. Although we used a validated digital sphygmomanometer and body composition analyzer, we did not provide information on device calibration, precision, or measurement error that may have affected the reliability of the recorded values. Furthermore, although the regression models showed statistically significant relationships, their explanatory power was limited ($R^2$ between 0.068 and 0.122), meaning that only a small proportion of the variance in the results was explained. This should be taken into account when interpreting the predictive power of the models. Although the multivariable regression models were used to control for known confounding factors, the possibility of residual confounding remains. Unmeasured variables such as psychological stress, alcohol consumption or socioeconomic status may have influenced the cardiovascular outcomes and should be considered in future studies.

## Conclusions

We found significant differences in SBP and pulse rate between the group of women before the pandemic and the group of women during the pandemic. We observed significantly higher SBP and pulse rate in young adult women during the pandemic than before. However, no significant difference was observed in DBP between the two groups. Given the demographic specificity of our sample—young Slovak women who were university students or recent graduates—the generalizability of our findings to broader populations is limited. Additionally, while we adjusted for several covariates, we cannot rule out the influence of unmeasured factors such as psychosocial stress, alcohol consumption, or socioeconomic status, which may have contributed to the observed changes in cardiovascular parameters. Nevertheless, these results highlight a potential public health concern. In light of these findings, targeted follow-up and cardiovascular monitoring specifically for young adult women should be considered, especially after a pandemic, to assess the persistence and long-term health effects of these changes.

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### Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [DF], [LV], [SS], [LK], [VP] and [RB]. The first draft of the manuscript was written by [DF], [LK], [VP] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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### Conflict of interest

None to declare.

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# Dynamics of Growth in 9–14-year-old Bulgarian Boys and Girls

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Abstract: The physical development of the human body is used as an objective indicator of the health status and work capability of the population. Height and weight are the main anthropometric traits which vary and change significantly during the growth period and are used as a base for the development of anthropometric standards at different ages. The aim of this study is to assess the basic anthropometric traits in adolescent boys and girls in Bulgaria in order to establish age- and sex-specific variation in growth. During the period 2016–2018, a transversal anthropometric study in five secondary schools in Sofia, Bulgaria was conducted. A total of 424 adolescents (211 boys and 213 girls) aged 9 to 14 years were studied. Anthropometric measurements were performed according to the classic 1957 methodology of Martin-Saller. Statistically significant sex differences ($p<0.05$) were indicated for height and weight in the age periods: 10–11 years, with priority for girls and 13–14 years, with priority for boys. Age-related differences ($p<0.001$) in the age period 9–14 years were also observed. Physical development of adolescent Bulgarian students follows the general trends of the postnatal ontogenesis, reflected in increasing the sizes of anthropometric features highlighted in 10–11-year-olds girls and 13–14-year-olds boys. These new data for height, weight, and BMI in 9–14-year-old Bulgarian students might be a practical addition in the pediatric practice of monitoring of children's health.

Keywords: adolescents, height, weight, body mass index


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## Introduction

Physical development is an objective indicator for the health status and work capability of the population. Anthropometric measurements are the most preferred clinical tool for screening normal child growth and predicting disease risk factors from childhood (Freedman et al. 1999; Revenga-Frauca et al. 2009; Nagy et al. 2014; Andaki et al. 2018). Height and weight are the main anthropometric traits that exhibit great adaptive potential and which change significantly during the growth period. Their metric characteristics are used as a base for developing anthropometric standards at different ages and vary significantly in populations of different climatic and geographical areas (Theis et al. 1993; Honigman et al. 1993; Алексеева 1998; Roach and Hackett 2001; Malkoç et al. 2012). According to Eveleth (1987), children of different nationalities differ in both size and shape of the body and rate of their growth (Eveleth 1987). Following the physical development of children from the Northern part of Russia, Kozlov and Vershubskaya (1999) found that they are characterized by lower height and body weight compared to their peers from the central parts of Russia. It has been established that these peculiarities are due to the ethnicity of individuals and are not the result of the adverse climatic conditions in which they live (Kozlov and Vershubskaya 1999).

Body mass index (BMI) is used to assess nutritional status in children and adolescents as well as adults. Elevated BMI in childhood is related to adult obesity and a high risk of various diseases. Other, more direct ways of measuring adiposity are known to correlate well with BMI, and consistent links are known between BMI and comorbidities associated with obesity and overweight. Body mass index is thus still regularly implemented as a child's measure of weight. Elis et al. (1999) declared a close relation between BMI and percent body fat (%BF) assessing 438 Caucasian, 283 African, and 258 Hispanic children and adolescents aged 3–18 years, and confirmrd the suggestion for relation with the age and ethnicity.

The standards for height and weight used in pediatric practice in Bulgaria are based on international or national data collected more than fifty years ago, and they may be out of date due to secular trends. This highlights the need to create newer and more competitive norms for assessing body weight, body height and BMI in children and adolescents. Thus, the aim of this study was to assess the basic anthropometric traits in adolescent Bulgarian boys and girls in order to establish age- and sex-related variation in adolescent growth.

## Materials and Methods

### Study design and participants

The present transversal anthropometric study was carried out in the period 2016–2018 and included 424 (211 boys and 213 girls) children and adolescents from Sofia, Bulgaria, aged 9 to 14 years. Anthropometric measurements were performed according to the classic methodology of Martin Saller (1957). Body height and weight were measured by standard anthropometric equipment. For BMI calculations, weight in kgs was divided by height in $m^2$. The ethics protocol for this study was reviewed and approved by the Ethical Committee of the Institute of Experimental Morphology, Pathology, and Anthropology with Museum – Bulgarian Academy of Sciences (Protocol No

3/11.04.2018 ). The study was conducted in agreement with the principles stated in the Declaration of Helsinki for human studies and researches (WHO 2008). All participants and their parents gave a completed informed consent for voluntary participation in the study.

### Statistical analysis

The statistical data processing was carried out using the Statistical Package for the Social Sciences 16.00 (SPSS 16.00) software. Student t-tests at $p<0.05$ were performed to detect sex-related differences in the above outlined variables. To establish age-related differences, one-way ANOVA with Tukey's post hoc tests at $p<0.05$, $p<0.01$, $p<0.001$ was applied.

## Results

The linear growth of the body increases significantly throughout the assessed age period. The average body height of 9–year-old boys (140.37 cm) has greater values than than of girls (138.48 cm) of the same age. Between 10 and 12 years, girls are taller than boys and their peak height velocity occurs at about 11 years. The maximum increase in boys' height is between 11–12 years (Figure 1).

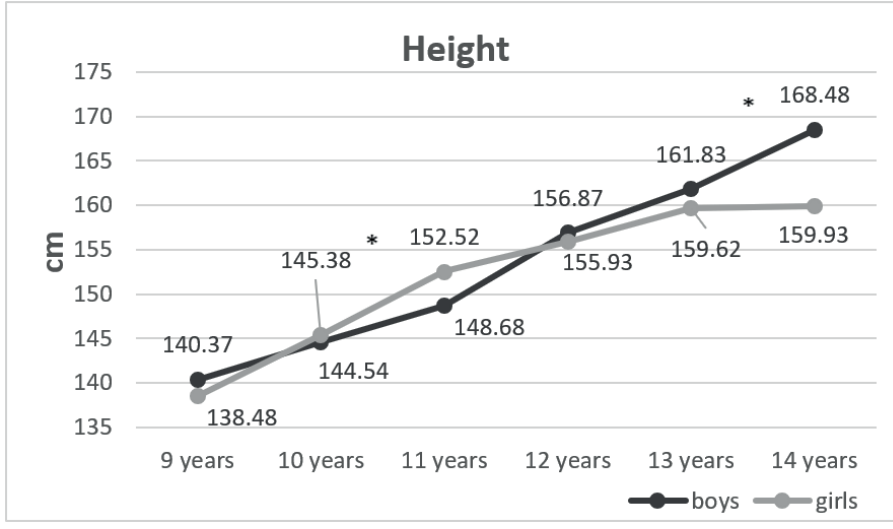


Figure 1. The average values of height in 9–14-year-olds Bulgarian children and adolescents

The average value of weight in girls varies from 33.26 kg at the age of 9 to 53.63 kg at the age of 14 years. The girls' weight increased significantly between 9 and 10 years. The boys' mean weight values range from 35.04 kg to 59.41 kg in the age period from 9 to14 years. Their peak weight velocity occurs two years later, than the girls – between 11 and 12 years (Figure 2).

Statistically significant sex differences ($p<0.05$) for height and weight in the age periods 10–11 years with priority for girls, and 13–14 years for boys,

were observed. Age-related differences for height and weight ($p<0.001$) in the period 9–14 years were also established. The assessed age period is characterized by a slight increase of the values of BMI in both sexes: from 17.78 kg/m$^2$ to 20.77 kg/m$^2$ in boys and from 17.28 kg/m$^2$ to 21.03 kg/m$^2$ in girls. Incremental change in BMI in both sexes follows the trend determined by height and weight, but there were no statistically significant sex- and age-related differences (Figure 3).

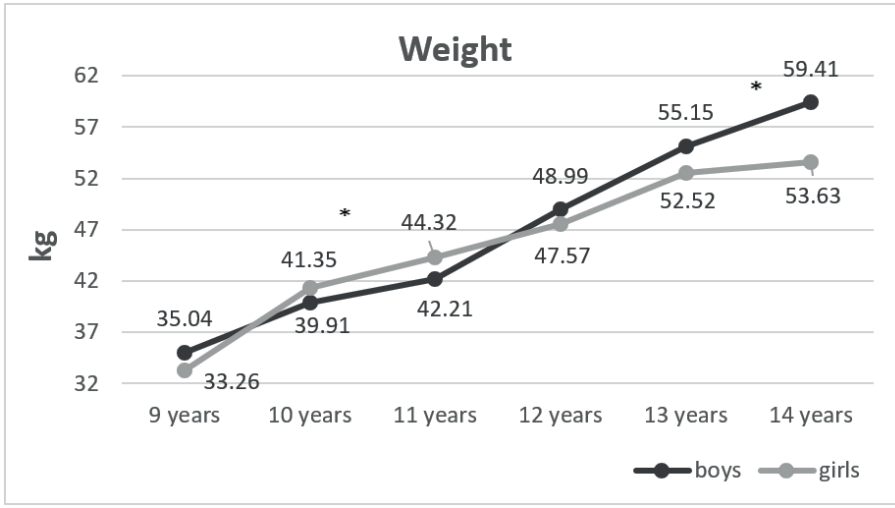


Figure 2. The average values of weight in 9–14-year-olds Bulgarian children and adolescents

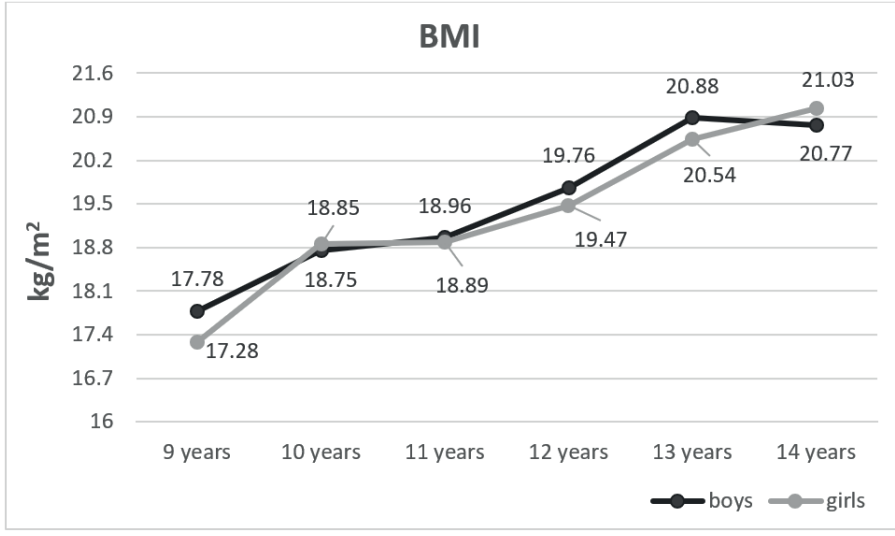


Figure 3. The average values of body mass index (BMI) in 9–14-year-olds Bulgarian children and adolescents

## Discussion

The present study emphasizes the specifics of the physical development of 9–14-year-old healthy Bulgarian boys and girls. The results of our study confirmed that 9–14-year-old boys and girls grow up significantly when it comes to their height and weight. The increment of change in boys' and girls' height is 28.11 cm, and 19.56 cm, respectively. Reaching their maximum occurs in different age periods according to sex. The girls reached their peak height and weight velocity earlier than boys (between 10 and 11 years) and also have earlier onset of puberty. The largest absolute year alteration for this period was observed: 7.14 cm in girls' height and 8.09 kg in their weight. Puberty in boys occurs between the ages of 13–14 when height and weight reach values of 168.48 cm and 59.41 cm, respectively. The maximal year alteration in boys' height and weight is 8.19 cm and 8.09 kg at the age of 12 when the line of growth is crossed and the boys are ahead of girls in terms of the assessed anthropometric traits (Table 1).

Sex differences in the age periods 10–11 and 13–14 years are the most pronounced. Assessing the anthropometric characteristic of children and adolescents from the Smolyan region (Bulgaria), Mladenova (2003) determined close to our results. Analysis of the data shows that the first peak of linear growth was observed between 4 and 7–8 years. The second peak height velocity is established in the period of 9–10 years in girls, while in boys it occurs about three years later (Mladenova 2003). Earlier data for Bulgarian children and adolescents showed that between 9 and 12 years girls gradually outstrip the boys but at 14 years they nearly stopped their growth in height and weight. Contrary, boys continue to grow significantly after 14 years (Nacheva et al. 2012). The data from a transversal study of 9–16-year-olds students from Sofia, Bulgaria showed a spurt in their morphological development, with a peak between 10 and 11 years, and 13 years with girls. For boys aged 13–14 years, the author registered a puberty growth spurt peak, and the beginning of post-puberty between ages of 15–16 is an exception (Mitova 2009).

Table 1. Heigth, weight, and body mass index (BMI) data for 9–14-year-old Bulgarian boys and girls

| Age period (years) | Absolute Year Alteration (AYA) | |
|---|---|---|
| | ♂ | ♀ |
| | HEIGHT (cm) | |
| 9–10 | 4.17* | 6.88* |
| 10–11 | 4.14* | 7.14* |
| 11–12 | 8.19* | 3.41 |
| 12–13 | 4.96* | 3.69 |
| 13–14 | 6.65* | 0.31 |
| | WEIGHT (kg) | |
| 9–10 | 4.87 | 8.09* |
| 10–11 | 2.30 | 2.97 |
| 11–12 | 6.78* | 3.25 |
| 12–13 | 6.16* | 4.95 |
| 13–14 | 4.26 | 1.11 |
| | BMI (kg/m$^2$) | |
| 9–10 | 0.97 | 1.57 |
| 10–11 | 0.21 | 0.04 |
| 11–12 | 0.80 | 0.58 |
| 12–13 | 1.12 | 1.07 |
| 13–14 | 0.00 | 0.49 |

*$p<0.05$ – statistically significant age differences

Overweight and obesity have been noted as a pandemic of the 21st century (Popkin and Doak 1998; Moreno et al. 2000). Obesity has been known as a risk factor for the development of type 2 diabetes, cardiovascular and other health

disorders (Pischon et al. 2008; Di Angelantonio et al. 2016; Bluher 2019). In developed countries, part of overweight and obese individuals increased from 16.9% of males and 16.2% of females in 1980 to 23.8% of males and 22.6% of females in 2013 (Ng et al. 2014). Aranceta-Bartrina et al. (2016) declared that in Spain, the prevalence of overweight in the adulthood reaches 39.3%, and the global prevalence of obesity in 2014–2015 was estimated at 21.6% (Aranceta-Bartrina et al. 2016). An anthropometric assessment of Bulgarian 8–15-year-old students from the Smolyan region showed they have higher BMI values than girls in all ages, with statistically insignificant differences between the sexes (Mladenova and Andreenko 2015). Over last decade, an increament in overweight and obesity prevalence among Bulgarian pupils from Smolyan region was registered by Mladenova and Andreenko (2015).

Assessing BMI is the most popular method to track the changes in nutritional status from childhood to adulthood. Whereas in adult age only, the thresholds that define BMI in terms of overweight and obesity are not associated with age or sex. In growing children, however, BMI links with sex and age. In accordance with the standards of the International Obesity Task Force (IOTF) and the World Health Organisation (WHO), Cole et al. (2000; 2007) developed specific BMI cut-offs for children and adolescents under 18 years. According to the IOTF BMI thresholds, all 9–14-year-old boys and girls who took part in the present study fall in the category of normal weight status. In further studies, we are going to present reference standards of BMI-for-age in Bulgarian children and adolescents (WHO 1987; Cole 2000, 2007).

## Conclusion

Physical development of Bulgarian children and adolescents follows the general tendency of the postnatal ontogenesis, shown in increasing the sizes of anthropometric features highlighted in 10–11-year-old girls and 13–14-year-old boys. These new data for height, weight, and BMI in 9–14-year-old Bulgarian students might be a practical addition in the pediatric practice to the monitoring children's health. Despite the benefits observed, a limitation in this study is the small sample size when separated by age and sex, especially in the last age group.

### Acknowledgments

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### Author contributions

AD designed the study, collected the data, oversaw the statistical analysis/interpretation and agree to be accontable for all aspect of the work.

### Funding

None to declare.

### Conflict of interests

No conflict of interests were declared by the author.

### Ethics statement

Ethical approval was issued by the Ethics Committee of the Institute of Experimental Morphology, Pathology, and Anthropology with Museum – Bulgarian Acade-

my of Sciences (Protocol № 3/11.04.2018) and was conducted in agreement with the principles stated in the Declaration of Helsinki for human studies (2008).

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# Human Biology Research in Anthropological Review: 2025 Onwards Editorial and Polish Anthropological Society Perspectives

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Abstract: Human biology research in the 21st century takes on a whole new meaning with an improved range of methodological, ethical, and technological advancements. Human biologists working in diverse sub- and inter-disciplinary areas now have at their disposal access to more efficient technical toolkits than ever before, producing data that can be rapidly shared through open access platforms. However, we also face challenges with the ever-increasing presence of artificial intelligence (AI), and continued ethical concerns around 'helicopter research' using human personal and tissue data in developing countries. Anthropological Review (AR), the flagship journal of the Polish Anthropological Society (PTA), is an open access journal with a long history of publishing inter-disciplinary human biology research and continued commitment to sharing high quality findings. In this piece, as PTA is celebrating its 100th anniversary in 2025, and as the editorial board of AR with a new Editor-in-Chief, and the President of PTA, we outline the stance of AR on key issues in today's human biology research. We focus on open access, early career researcher opportunities, AI, the need for multi-methodological approaches and inter-disciplinarity, and commitment to the application of ethical framework in human biology research featured in our journal.

Keywords: open access, artificial intelligence, ethics, human biology

Original article

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Abstrakt: Badania nad biologią człowieka w XXI wieku nabierają zupełnie nowego znaczenia, dzięki wykorzystaniu postępów badawczych w obszarze metodologii, etyki czy technologii. Biolodzy zajmujący się badaniem człowieka zarówno w obszarze poszczególnych poddyscyplin, jak i z wykorzystaniem badań interdyscyplinarnych, mają teraz dostęp do najnowocześniejszego sprzętu laboratoryjnego oraz zestawów narzędzi technicznych i informatycznych. Umożliwiają one gromadzenie danych, które można szybko udostępniać za pośrednictwem platform o otwartym dostępie. Stajemy jednak również przed wyzwaniami związanymi ze stale rosnącą obecnością sztucznej inteligencji (AI) i ciągłymi obawami etycznymi dotyczącymi uprawiania nauki neokolonialnej z wykorzystaniem danych osobowych i tkankowych ludzi w krajach rozwijających się. „Anthropological Review" (AR), sztandarowe czasopismo Polskiego Towarzystwa Antropologicznego (PTA), to czasopismo o otwartym dostępie, z długą historią publikowania interdyscyplinarnych badań z zakresu biologii człowieka i stałym zaangażowaniem w udostępnianie wysokiej jakości wyników. W niniejszym artykule, świętując 100-lecie PTA w 2025 roku, jako redakcja AR z nową redaktorką naczelną, i przewodniczącym PTA, przedstawiamy stanowisko AR w kluczowych kwestiach dotyczących współczesnych badań nad biologią człowieka. Koncentrujemy się na otwartym dostępie, możliwościach dla młodych naukowców, sztucznej inteligencji, potrzebie stosowania podejścia multimetodologicznego i interdyscyplinarnego oraz zaangażowania w stosowanie ram etycznych w badaniach nad biologią człowieka, o których mowa w naszym czasopiśmie.

Słowa kluczowe: otwarty dostęp, sztuczna inteligencja, etyka, biologia człowieka

In January 2025, Anthropological Review (AR), the flagship journal of the Polish Anthropological Society (PTA), welcomed a new Editor-in-Chief, Dr Justyna Miszkiewicz of the University of Queensland (Australia), taking over from Professor Sławomir Kozieł of the Polish Academy of Sciences after his many years of dedicated service. With further changes to the Assistant Editors of the journal, including welcoming Dr Joanna Nieczuja-Dwojacka of Cardinal Stefan Wyszyński University in Warsaw in place of Dr Agnieszka Tomaszewska, we take this opportunity to pen an editorial piece overviewing our perspectives on the next few years of research published in AR. As PTA is celebrating its 100$^{th}$ anniversary in 2025, we highlight key current issues in human biology and comment on topics we are particularly interested in featuring in future editions of AR.

## Open access and data sharing

We are a fully open access (OA) journal, meaning that none of our articles are published behind a paywall. Combined with the fact that we do not collect article processing charges (APC), our journal is one of a handful of journals within human biology to operate using such a model. Financial support for the processing of our articles stems from local university support (University of Łódź), the Ministry of Science and Higher Education in Poland, and the PTA, creating an opportunity to have results communicated free of charge under the Creative Commons license Attribution-NonCommercial-NoDerivatives (BY-NC-ND) international deed. Open access research tools and publishing have long been recognised as benefiting science by accelerating innovation, data and findings dissemination and fostering transfer of knowledge across diverse fields (Nishikawa and Murakami 2005; Eysenbach 2006; Miszkiewicz 2020). We believe our journal's model is particularly important for breaking down global inequalities in publishing, and for early career researchers (ECRs) who nowadays find themselves in precarious research employment positions and need to accumulate citations and h-index records, which can

be accelerated through OA publishing (Huang et al. 2024). Around the world, tenured and tenure-track positions are less common, and research contracts are increasingly reliant on 'soft' grant money, which is also difficult to secure in an ever-increasing competitive research environment where there are disproportionately more PhD graduates than there are research and academic positions. The research landscape prospects for ECRs have become even more challenging since the COVID-19 pandemic (Johnson and Weivoda 2021), and ECR publication trends have been plagued with confusion and disappointment about the commercialisation of OA by major publishers (Nicholas et al. 2024). We hope that, in this context, AR allows ECRs to trust in ethical publishing offering OA publishing opportunities at no cost.

Further, in the context of the Polish academic system, the number of points assigned by the Ministry of Science and Higher Education to a journal is a decisive factor in career progression, influencing evaluations, promotions, and grant competitiveness. The number of points assigned by the Ministry reflects the ranking of the journal on the official ministerial list and is used in evaluating the scientific output of researchers and institutions. In the past, our journal was assigned 140 points, and it currently holds 70. We are actively working to restore the higher rating and raise our journal's point allocation by aiming to increase AR's visibility, improving its indexing status, and welcoming more international submissions. We recognise the critical role of ministerial rating in enhancing the professional prospects of our authors, so maintaining the journal's standing within the national and international research landscape is a priority.

Related to the importance of making articles openly accessible is the issue of data sharing. In 2019, the American Association of Physical (now Biological) Anthropologists held a workshop titled „Data Sharing in Biological Anthropology" which resulted in a publication of guidelines for good practice in this space (Turner and Mulligan 2019). The guidelines were received both with a positive response praising their commitment to data sharing, transparency and replicability (e.g., Leigh 2020), and critical views highlighting issues such as a lack of considerations given to Indigenous data sovereignties (Tsosie et al. 2020) and poor guiding on the reporting, meaning, and various practicalities of data sharing practices within biological anthropology (Wagner 2020). In the past few years, an increasing number of biology journals have introduced mandatory data availability statements (Hrynaszkiewicz et al. 2020; Tedersoo et al. 2021), but few still offer opportunities to publish data papers associated with published datasets. We are pleased that, as of 2025, AR now facilitates the publication of data papers, which are short, peer-reviewed publications discussing an existing dataset within a trusted, accredited repository, and the possibilities of its reuse. These should describe the contents, methods used to generate, and the reuse potential, of the dataset. Our journal's commitment to OA dissemination of articles and data aligns with the scientific values of PTA, contributing to global efforts in fostering knowledge exchange within human biology research. This may prove particularly relevant in Poland, where research assessment increasingly values both open access and robust data management. Publishing data papers will allow Polish scholars to gain formal recognition

for the significant work of generating and curating datasets—effort often overlooked in evaluations. In a system where publication points are pivotal for career advancement, a peer-reviewed data paper linked to an open dataset can boost visibility, citations, and impact. Promoting data sharing in Polish anthropology and human biology will also strengthen international collaborations.

## Artificial intelligence: ethical use or no use at all?

It would be imprudent to write an editorial article in 2025 without discussing the matter of artificial intelligence (AI) as it is ever-increasingly making its way into research. Universities are globally grappling with integrity issues due to students using AI in their assignments (Alsharefeen and Sayari 2025; Kovari 2025), while conference organising committees, research grant awarding bodies and journals have been issuing statements on a total ban of, or conditions under which, AI can be used in written work or peer review activities (Dwivedi et al. 2024). Of particular concern is Generative AI (GenAI), which can conduct and synthesise literature reviews and draft manuscripts based on the given prompts. This, naturally, creates serious ethical and copyright problems. While some plagiarism software now includes detection for possible AI use, the text and content created by GenAI are increasingly difficult to discern in writing due to manipulation and paraphrasing by authors (Baron 2024). In 2025, our journal released its policy on the use of GenAI in manuscripts submitted for consideration, requiring all authors to declare whether they did, or did not, use such tools in the preparation of their submissions (see our journal's Author Declaration Form). While we do not have a ban in place, we do give authors an opportunity to provide further information on any use of GenAI that is then evaluated by editors to decide whether the use can be deemed appropriate and acceptable for the submission not to be desk rejected. The request for such further information includes details on the name of the GenAI tool, the purpose for which it was used with detailed description of the use, and confirmation that the author(s) undertook a critical review of the generated text ensuring false, incomplete, biased information, plagiarism, and any authorship or attribution issues are removed, addressed, or revised. As generative AI is an evolving space, we will continue to dynamically review it and revise our stance on it going forward.

## Interdisciplinary and multimethodological studies

Human biology research is in many ways inherently interdisciplinary because we are social animals, so understanding our biology must occur within a social framework (Weingart et al. 2013). Biological anthropologists work with a range of theoretical paradigms that stem from different disciplines and often 'borrow' methods from cognate disciplines to explain human and evolutionary phenomena. Our journal has a long history of publishing such research, and while, of course, we welcome manuscripts on all topics in human biology, we have had great success specifically in attracting submissions from auxology and bioarchaeology. Auxology draws theories and methods from diverse biological fields such as health sciences, med-

icine, and nutrition (Hermanussen and Bogin 2014), whereas bioarchaeology is a classic example of an area that bridges humanities, arts and social sciences (HASS) and science, technology, engineering, and mathematics (STEM) approaches combining archaeological context with biological and anatomical data (Stojanowski and Duncan 2015).

Reflecting on the expertise of our editors (which also spans HASS and STEM disciplines), as submissions to our journal in these areas increase, we hope to see interdisciplinary work in auxology address ongoing issues with growth standards, especially in underrepresented populations and within a framework that acknowledges ongoing human evolution (Bender et al. 2024). We also hope for future bioarchaeology submissions to AR to incorporate multimethodological approaches in dental and bone analyses, considering skeletal data at more than one hierarchical level. Combining gross anatomical observations with histological, microanatomical, chemical, and/or genetic data where possible has the potential to offer more nuanced interpretations of past lives and lifestyles from human remains (e.g., Miszkiewicz and Mahoney 2016; Jusić et al. 2022; DeMars et al 2023; Nava 2024). However, we stress that this is not always an expectation since there are restrictions around applying some of these techniques to human remains when they are destructive (e.g., extracting bone samples for ground histology or ancient DNA analyses), such as in Indigenous contexts. We also hope for interdisciplinary engagement on modern societal relevance of bioarchaeology as biological data from past populations can shed immense perspectives on contemporary problems including social and economic inequality and climate change (Buikstra 2019; Robbins Schug et al. 2023). The journal also welcomes contributions in palaeopathology, recognising its importance in advancing our understanding of past health, disease, and human–environment interactions (Rühli et al. 2016), which is particularly relevant to modern pandemics and remerging infectious diseases. We are planning to feature thematic issues in the coming years of AR activity, which will certainly have interdisciplinary and/or multimethodological foci.

## Ethical frameworks

Studying humans has always come with its own challenges, but as we navigate today's legal, political, social, and economic developments worldwide, and increasingly witness the recognition of the impact of colonial histories and legacies on human biology research in some countries, improved ethical standards and discussions for our discipline have emerged (e.g., Radin 2018; Turner et al. 2018; Plemons et al. 2025; Stantis et al. 2023; Zuckerman et al. 2025). A range of research design and conduct areas have been identified as needing clear ethical evaluation, including cultural sensitivity, selection of participants, destructive sampling and use of human tissue samples, repatriation, and use of digitised specimens (e.g., Turner 2005, Squires et al. 2020, Thomas 2020; Plemons et al. 2025). Most major journals stipulate the need for reporting of ethics declarations and have policies specifically addressing ethics of human biology research involving living participants or human body bequest programs. In other areas, such as bioarchaeology, this issue has been less straightforward as working with skeletal remains from archaeological contexts

comes with different levels of approvals or permissions, often culture-, institution-, or country-specific (Márquez-Grant and Fibiger 2011). Increasingly though, major bioarchaeology journals are providing clear guidance on ethics involving bioarchaeological studies. For example, since 2020, the editors of *Bioarchaeology International* have required an ethics statement and information on permissions relating to any work conducted on Native American human remains (Halcrow et al. 2024).

This leads us onto another major ethical issue with 'collaboration' between countries and/or populations of different economic and development statuses that has persisted and created 'helicopter' or 'parachute' research (Nguah 2024). Wealthy researchers, often from Westernised countries, conduct research on, and within, populations from developing countries and/or with historical social and economic disadvantage (Haelewaters et al. 2021). This situation negatively impacts local communities who are often not involved in research planning (or are reduced to local logistical support), have no input into data interpretation, no access to any resulting publication (also see our earlier comments about OA), receive no training or education, or any real benefit of such research (Nguah 2024). As journal editors, we are committed to upholding high ethical standards within human biology research submitted for publication to AR. As has been shown elsewhere—e.g., Naidoo et al. (2021) reported that 66.1% of African articles related to COVID-19 did not have an African author—editors carry the responsibility of not only ensuring rigorous peer review and scientific content, but can also evaluate whether a paper suffers from helicopter research and carefully consider whether it is ethical to publish such an article.

At AR, we have clear policies on ethics requirements for human research, including bioarchaeological work on human remains. We require an ethics statement to be declared in submissions where relevant/appropriate. The Editor-in-Chief is the first point of evaluation for all submissions, which always involves ethics checks. All this is in the effort to be part of the global human biology and biological anthropology community working towards a more just, decolonised, and fair science, reflecting the values of us as editors, the PTA, individual researchers, and simply people who are part of a collective society.

In this editorial article, we outlined our stance and interests, as editors of AR, on open access, AI, interdisciplinarity and methodologies and ethics within human biology and biological anthropology research. We are excited for future articles appearing in AR and thank all authors, previous editors, and other contributors who have made the journal a source of fruitful science thus far.

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**Author contributions**

JJM conceptualised the article and wrote the first draft. JT, FMG, MD-M, BM, JN-D, MH edited the article.

### Conflict of interest

As this article is authored by the editors of Anthropological Review and the President of the Polish Anthropological Society, it underwent an open peer review.

### Ethics statement

Not applicable.

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