Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Original Article

Association between COVID-19 morbidity, mortality, and gross domestic product, overweight/ obesity, non-communicable diseases, vaccination rate: A cross-sectional study

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ABSTRACT

Background: The spread of COVID-19 depends on a lot of social and economic factors. The aim: to study the influence of country's gross domestic product, population prevalence of overweight/ obesity, NCD mortality, and vaccination on COVID-19 morbidity and mortality rates.
Methods: A cross-sectional study with two phases: correlation-regression interrelations in 1) all world countries; 2) all world non-island countries. The study includes the following data from 218 world countries: COVID-19 morbidity/mortality rates, GDP per capita, the prevalence of overweight/ obesity, NCD mortality among adults (both sexes), people fully vaccinated against COVID-19.
Results: An average percentage of the prevalence of overweight among adults in world countries by 2019 was 47.31 ± 15.99%, obesity 18.34 ± 9.64%, while the prevalence by 2016 were 39% and 13%, respectively. Overweight and obesity among adults during three years grew by 21.2% and 40.8%, respectively.

Data from the world countries provide significant correlations ($p < 0.0001$) between COVID-19 morbidity, and: GDP ($r = 0.517$), overweight ($r = 0.54$), obesity ($r = 0.528$), NCD mortality ($r = 0.537$); COVID-19 mortality, and: GDP ($r = 0.344$), overweight ($r = 0.514$), obesity ($r = 0.489$), NCD mortality ($r = 0.611$); GDP, and: overweight ($r = 0.507$), obesity ($r = 0.523$), NCD mortality ($r = 0.35$), fully vaccinated people ($r = 0.754$). An increase in fully vaccinated people, from 3% to 30% of world population, decreases new confirmed COVID-19 cases, although the dependence was not significant ($p = 0.07$).

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Data from non-island world countries provides more highly significant correlations ($p < 0.0001$) between COVID-19 morbidity, and: GDP ($r = 0.616$), overweight ($r = 0.581$), obesity ($r = 0.583$); COVID-19 mortality, and: GDP ($r = 0.43$), overweight ($r = 0.556$), obesity ($r = 0.539$); GDP, and: overweight ($r = 0.601$), obesity ($r = 0.633$). The differences of correlation coefficients between data of 176 world countries and data of 143 world non-island countries were not significant (Z-scores < 1.29; $p > 0.05$).

Conclusion: The study provides evidence of a significant impact of overweight/obesity prevalence on the increase in COVID-19 morbidity/mortality. Countries with higher GDP have a high overweight/obesity prevalence and possibility to get vaccinated.

Introduction

Novel coronavirus disease 2019 (COVID-19) represents a challenge to the health systems around the world because of easy dissemination, lack of effectual therapy despite of a lot of vaccines, and elevated burden of cardiac and respiratory conditions that exacerbate COVID-19 risk among the world population. COVID-19 has become a headache for healthcare systems of all world countries, but it has also begun to tangibly and globally affect the political life and economic situation in all countries around the world with no exception [1,2].

The battle against COVID-19 is being conducted both in therapeutic-diagnostic methods with development of drugs and diagnostic tools, and preventive methods such as development of vaccine preparation directions. However, no victorious paths are foreseen [3–5].

Some studies have shown that mortality and morbidity rates from COVID-19 are uneven across world countries. The spread of the infection depends on a lot of social and economic factors: population density, healthcare system level, urbanization, cultural factors, net migration, poverty ratio, awareness for sanitary practices, social distancing, mortality rate of non-communicable chronic diseases (NCD), especially from malignant neoplasms (cancer) and cardiovascular diseases (CVD), also following government regulation for management of COVID-19, etc [6,7].

There is a conspicuous fact from the official statistical data that COVID-19 dissemination is comparatively more in the countries with the economically developed systems. Certainly, these countries have a good system for data gathering and data sharing. Nevertheless, the economically prosperous countries differ in other specific features, for instance, these countries have a lot of people with NCD, and BMI more than 25 kg per meter square [8–11].

Several studies have been published showing detailed data based on studies of medical charts of specific groups of patients [3–5,9–12]. To date, it is not known whether there has been progress in the degree of influence of prevalence of overweight/ obesity and vaccination rate on COVID-19 morbidity and mortality. The aim of the study was to study the influence of the country's gross domestic product, population prevalence of overweight, obesity, NCD mortality, and vaccination rate on COVID-19 morbidity and mortality.

Methods

In this study were included data from 218 world countries: COVID-19 morbidity rate, COVID-19 mortality rate, GDP at purchasing power parity (GDP at PPP) per capita, prevalence of overweight among adults (both sexes), and prevalence of obesity among adults (both sexes), NCD mortality among adults (both sexes), percent of people fully vaccinated against COVID-19.

Study design

An observational cross-sectional study with correlation-regression analysis. The study has two phases: 1) to study the correlation-regression interrelations in all included world countries; 2) to study the correlation-regression interrelations in world countries excluding island countries.

Interventions

Correlation-regression tests between: 1) COVID-19 morbidity and prevalence of overweight among adults (both sexes); 2) COVID-19 morbidity and prevalence of obesity among adults (both sexes); 3) COVID-19 morbidity and NCD mortality including cancer and CVD, among adults (both sexes); 4) COVID-19 mortality and prevalence of overweight among adults (both sexes); 5) COVID-19 mortality and prevalence of obesity among adults (both sexes); 6) COVID-19 mortality and NCD mortality including cancer and CVD, among adults (both sexes); 7) country's GDP and COVID-19 morbidity; 8) GDP and COVID-19 mortality; 9) GDP and prevalence of overweight among adults (both sexes); 10) GDP and prevalence of obesity among adults (both sexes); 11) GDP and NCD mortality, including cancer and CVD mortality; 12) country's fully vaccinated people (% of population) when a total percent in the world was less than 3% (=2.98%) that reached by April 24, 2021, and biweekly new confirmed COVID-19 cases by the end of April, 2021; 13) country's fully vaccinated people (% of population) when a total percent in the world was > 30% (=30.15%) that reached by Sept 13, 2021 and biweekly new confirmed COVID-19 cases by the end of September, 2021; 14) country's GDP and fully vaccinated people (% of population) when a total percent in the world was > 30% (=30.15%).

Inclusion criteria

All world countries with official data of: 1) COVID-19 morbidity (per 1M); 2) COVID-19 mortality (per 1M); 3) GDP (at purchasing power parity) per capita; 4) prevalence of overweight (% of population) among adults (both sexes) over 18 years old; 5) prevalence of obesity (% of population) among adults (both sexes) over 18 years old; 6) NCD mortality including cancer and CVD (per 1M), among adults (both sexes) over 18 years old; 7) fully vaccinated people (% of population); 8) biweekly new confirmed COVID-19 cases.

Exclusion criteria

All world countries with no data for the inclusion criteria.

Counts of COVID-19 morbidity and mortality rates in all countries were collected by the WHO data by May 1, 2021. The data on COVID-19 morbidity included all cumulative total cases up to 1 May, 2021. The data on COVID-19 mortality included all cumulative total deaths

up to 1 May, 2021. Counts of NCD mortality including from cancer and CVD in all countries were collected by the WHO data in 2019 [13]. Counts of percent of fully vaccinated people in all countries were collected by the Our World in Data [14]. Biweekly new confirmed COVID-19 cases were collected also by the Our World in Data [14].

People are considered fully vaccinated if: 2 weeks after their second dose in a 2-dose series, or 2 weeks after a single-dose vaccine.

The data on GDP (PPP) per capita in 2019 was taken from World Bank, before COVID-19 pandemic [15]. The data on the prevalence of overweight (BMI less than 25) and obesity (BMI greater or equal to 25) among adults in both sexes (% of population) was taken from the World Obesity Federation [8].

Statistical analysis

Pearson correlation and regression analysis were used. *P*-value < 0.05 was considered significant and < 0.0001 was set as highly significant. Pearson correlation and regression statistical analysis were performed using SPSS Statistics ver.21.0 for Windows (SPSS: An IBM Corp.©) and Excel-2020. Comparing correlation coefficients was conducted by transforming the correlation coefficient values (r values) into z scores, known as Fisher's r to z transformation (Z-score). *P*-value of less than 0.05 indicates that the two correlation coefficients are significantly different from each other.

Results

Some world countries didn't present full data for COVID-19 cases and deaths or overweight and obesity prevalence, NCD mortality. Therefore, in the first phase of the study from 218 countries 42 countries without full data were excluded, and a total of 176 world countries are considered for further analysis.

An average percentage of prevalence of overweight among adults (both sexes) in the world by 2019 year in considered 176 countries was 47.31 ± 15.99%, and a mean percentage of prevalence of obesity among adults (both sexes) was 18.34 ± 9.64%.

From the data taken from 176 countries, we found linear correlations between each other: country's COVID-19 morbidity, mortality (per 1M), GDP (per capita), NCD mortality, including from cancer, CVD (per 1M), and prevalence of overweight and obesity (% of population) (Table 1).

Table 1 including data from 176 world countries provides significant correlations between COVID-19 morbidity and: GDP ($r = 0.517$; $p < 0.0001$), overweight prevalence ($r = 0.54$; $p < 0.0001$), obesity prevalence ($r = 0.528$; $p < 0.0001$), NCD mortality ($r = 0.537$; $p < 0.0001$) including from cancer ($r = 0.597$; $p < 0.0001$), CVD ($r = 0.460$; $p < 0.0001$); COVID-19 mortality and: GDP ($r = 0.344$; $p < 0.0001$), overweight prevalence ($r = 0.514$; $p < 0.0001$), obesity prevalence ($r = 0.489$; $p < 0.0001$), NCD mortality ($r = 0.611$; $p < 0.0001$) including from cancer ($r = 0.636$; $p < 0.0001$), CVD ($r = 0.521$; $p < 0.0001$); GDP and: overweight prevalence ($r = 0.507$; $p < 0.0001$), obesity prevalence ($r = 0.523$; $p < 0.0001$), NCD mortality ($r = 0.35$; $p < 0.0001$) including from cancer ($r = 0.552$; $p < 0.0001$), CVD ($r = 0.152$; $p < 0.05$).

The regression model of interrelations between COVID-19 morbidity/ mortality (per 1 M) and country's GDP (per capita), prevalence of overweight and obesity (% of population), NCD mortality (per 1 M); between GDP (per capita) and prevalence of overweight and obesity in 176 world countries, is provided in Supplements 1–4.

The regression model of interrelations between country's fully vaccinated people (%) and biweekly new confirmed COVID-19 cases when total percent of fully vaccinated people in the world were < 3% and > 30% of population are presented in Table 2.

Table 2 including data from 176 world countries provides significant linear correlations between country's fully vaccinated people, when total percent in the world was < 3%, and biweekly new confirmed COVID-19 cases by the end of April, 2021 ($r = 0.421$; $p < 0.0001$); country's fully vaccinated people, when total percent in the world was > 30%, and biweekly new confirmed COVID-19 cases by the end of Sept, 2021 ($r = 0.288$; $p < 0.0001$). However, the difference between the two correlation coefficients, $r = 0.421$ and $r = 0.288$, was not significant (Z-score =1.24; $p = 0.075$; Z-score critical value > 1.28 at n_1, n_2 =176 and 176).

Table 2 also shows significant linear correlations between country's GDP and fully vaccinated people (%) when total percent in the world was > 30% ($r = 0.754$; $p < 0.0001$).

The second phase of the study included 143 world countries excluding the following 33 island countries: Antigua and Barbuda, Bahrain, Barbados, Brunei, Comoros, Cuba, Cyprus, Dominica, Dominican Republic, Fiji, Grenada, Haiti, Iceland, Indonesia, Ireland, Jamaica, Japan, Madagascar, Maldives, Malta, Mauritius, New Zealand, Papua New Guinea, Philippines, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, São Tomé and Príncipe, Singapore, South Korea, Sri Lanka, Taiwan, Trinidad and Tobago.

Excluding the island countries from the analysis revealed an increase in correlations between COVID-19 morbidity/ mortality and: country's GDP (per capita), overweight / obesity rates (%) in the considered 143 non-island world countries (Table 3). Taking data from these 143 countries, we found linear correlations between the country's COVID-19 morbidity/ mortality rates (per 1M) and: the country's GDP (per capita), prevalence of overweight and obesity (% of population).

Table 3 which includes data from 143 non-island world countries also provides highly significant correlations between COVID-19 morbidity and: GDP ($r = 0.616$; $p < 0.0001$), overweight prevalence ($r = 0.581$; $p < 0.0001$), obesity prevalence ($r = 0.583$; $p < 0.0001$); COVID-19 mortality and: GDP ($r = 0.43$; $p < 0.0001$), overweight prevalence ($r = 0.556$; $p < 0.0001$), obesity prevalence ($r = 0.539$; $p < 0.0001$); GDP and: overweight prevalence ($r = 0.601$; $p < 0.0001$), obesity prevalence ($r = 0.633$; $p < 0.0001$). Table 3 correlation coefficients compared to Table 1 corresponding correlation coefficients are relatively higher, but the differences are not significant (Z-scores < 1.29, $p > 0.05$; at n_1, n_2 = 176 and 143).

The regression model of interrelations between COVID-19 morbidity/ mortality (per 1 M) and GDP (per capita), prevalence of overweight and obesity (% of population); between GDP (per capita)

Table 1
Linear correlation coefficients between COVID-19 morbidity/ mortality (per 1M), and GDP (per capita); overweight/ obesity prevalence (% of population); and NCD mortality, including cancer, CVD (per 1M) in the 176 world countries.

	COVID-19 morbidity (per 1 M) and…	COVID-19 mortality (per 1 M) and …	GDP (per capita) and …
…GDP (per capita)	+ 0.517 ($p < 0.0001$)	+ 0.344 ($p < 0.0001$)	–
…overweight prevalence (%)	+ 0.540 ($p < 0.0001$)	+ 0.514 ($p < 0.0001$)	+ 0.507 ($p < 0.0001$)
…obesity prevalence (%)	+ 0.528 ($p < 0.0001$)	+ 0.489 ($p < 0.0001$)	+ 0.523 ($p < 0.0001$)
…NCD mortality (per 1M)	+ 0.537 ($p < 0.0001$)	+ 0.611 ($p < 0.0001$)	+ 0.350 ($p < 0.0001$)
… cancer mortality (per 1M)	+ 0.597 ($p < 0.0001$)	+ 0.636 ($p < 0.0001$)	+ 0.552 ($p < 0.0001$)
…CVD mortality (per 1M)	+ 0.460 ($p < 0.0001$)	+ 0.521 ($p < 0.0001$)	+ 0.152 ($p < 0.05$)

Table 2
Linear correlation coefficients between country's fully vaccinated people (% of population), when total percent in the world were < 3% (=2.98%) and > 30% (=30.15%), and an appropriate amount of biweekly new confirmed COVID-19 cases (per 1M) by the end of April and September, 2021; GDP (per capita) in the 176 world countries.

	Country's fully vaccinated people when < 3% in the world (%) and …	Country's fully vaccinated people when > 30% in the world (%) and …
…biweekly new confirmed COVID-19 cases by the end of April, 2021 (per 1M)	+ 0.421 ($p < 0.0001$)	–
…biweekly new confirmed COVID-19 cases by the end of Sept, 2021 (per 1M)	–	+ 0.288 ($p < 0.0001$)
…GDP (per capita)	–	+ 0.754 ($p < 0.0001$)

and prevalence of overweight and obesity (% of population) in the 143 non-island world countries is provided in Supplements 5–8.

Discussion

COVID-19 which started at the end of 2019, keeps healthcare systems of all world countries in the iron gauntlet. There are still no visible and definitive ways to defeat the disease. Many studies showed that a high BMI is a cause of a lot of complications during COVID-19 [9,11,16,17].

The severity of inflammatory and infectious diseases depends on the activity of causative agent(-s). Nevertheless overweight and obesity are significant risk factors for breaking immune system activity, chronic inflammation, cancer, CVD and other NCDs [12,18,19]. In the study we used NCD mortality statistic because it is more rigorous and precise than NCD prevalence [13,14].

Our study has shown that COVID-19 morbidity and mortality rates were significantly higher ($p < 0.0001$) in these world countries where the population had a higher prevalence of overweight/ obesity and NCD mortality. At the same moment, our study has also shown the more GDP the higher a prevalence of overweight and obesity ($p < 0.0001$).

Having overweight/obese directly depends on the social and economic status of a population [20,21]. It is indeed true, as our study results have shown that GDP as an indicator of an economic status of a country directly influences the increase in a population of people with overweight and obesity.

An average percentage of the prevalence of overweight among adults of both sexes in the world was 47.31 ± 15.99% and the prevalence of obesity among adults of both sexes was 18.34 ± 9.64% (by 2019 year). The prevalence of overweight and obesity among adults of both sexes have grown since 2016 year when the prevalence was 39% and 13%, respectively [22]. Thus, during the three years the prevalence of overweight and obesity among adults has grown by 21.2% and 40.8%, respectively.

The study results showed the depending trend between the number of new confirmed COVID-19 cases and percent of fully vaccinated people. With increase in percent of fully vaccinated people, from 3% to 30% of population in the world, correlation coefficients between the percent and new confirmed COVID-19 cases decreased, although the dependence was not significant. Probably, the trend will aim for a negative value with increase in percent of fully vaccinated people in the world. Further investigations are needed.

Countries with a higher GDP can also have a higher percentage of elderly people and people with many associated diseases. Therefore, NCD mortality statistic was included in the study to advance the analysis.

The study has also shown the more country's GDP the higher percent of country's fully vaccinated people ($r = 0.754$; $p < 0.0001$).

Most island countries have a distinctive diet due to the greater availability of seafood that has low calorie content [23]. Therefore, on the second phase of the study the island countries were excluded due to fact that they have a local seafood diet with low-calorie content. Also island countries have territorial limitation/ bound for dissemination of the disease, and the natural restriction for population migration. Some of the island countries with high GDPs had low prevalence and mortality rates from COVID-19. Therefore, in the second phase of the study we repeated the study of these relationships, but without the 33 island countries.

When we excluded the island countries, there was a noticed trend of increase in the correlation-regression coefficients between COVID-19 morbidity and mortality rates, and the prevalence of overweight and obesity and GDP.

Apparently, overweight and obesity directly impact on COVID-19's prevalence and severity. However, it can be formulated as a hypothesis about the probability of obesity/overweight having an effect on morbidity/mortality on COVID-19.

COVID-19 death rates are 10 times higher in countries where more than half of the adult population is classified as overweight, according to a comprehensive report from the World Obesity Federation. Of the 2.5 million COVID-19 deaths reported by the end of February 2021, 2.2 million were from the countries where over half of the population is classified as overweight-defined with a body mass index above 25 [8,24].

Many inflammatory diseases have a tendency to cause unintentional weight loss [25–27]. COVID-19 also leads to unintentional weight loss and malnutrition in COVID-19 survivors [10]. More than 80% patients who lost weight had greater systemic inflammation [28]. Unintentional weight loss is specific to people with advanced progressive illness [29].

The COVID-19 pandemic uncloses world health problem. The obesity burden presents a common serious problem for development of major death-causing diseases such as cardiometabolic diseases including: endocrine, nutritional, and metabolic diseases (e.g., diabetes, obesity); hypertensive heart disease; and ischemic heart disease and other diseases of the circulatory system (e.g., arrhythmia, cardiomyopathy, heart failure) [30].

In the last ten years life expectancy has declined primarily due to the increase in mortality among working-age adults. The increase in mortality among working-age adults was caused by such reasons as liver cancer, neurological diseases, homicides, transportation

Table 3
Linear correlation coefficients between COVID-19 morbidity/ mortality (per 1 M) and GDP (per capita), overweight/ obesity prevalence (% of population) in the 143 world non-island countries.

	COVID-19 morbidity (per 1 M) and…	COVID-19 mortality (per 1 M) and …	GDP (per capita) and …
…GDP (per capita)	+ 0.616 ($p < 0.0001$)*	+ 0.430 ($p < 0.0001$)*	–
…overweight prevalence (%)	+ 0.581 ($p < 0.0001$)*	+ 0.556 ($p < 0.0001$)*	+ 0.601 ($p < 0.0001$)*
…obesity prevalence (%)	+ 0.583 ($p < 0.0001$)*	+ 0.539 ($p < 0.0001$)*	+ 0.633 ($p < 0.0001$)*

* no significant difference (Z-score < 1.29; $p > 0.05$) compared to the corresponding data of Table 1.

injuries [30]. And the causes of liver cancer, neurological diseases, homicides, transportation injuries are overweight and obesity [31,32].

Potentially, population in countries with high GDP could be physically weaker because they are not under such a brutal natural selection as people from countries with low GDP. The physical weakening can be associated with a higher prevalence of overweight/obesity and chronic diseases mortality in countries with high GDP [24,30].

Our study can emphasize the urgency of policy action. Overweight is a serious problem that is affecting adults in the prime of their lives, and is now exacerbated by COVID-19. Taking into account the eight revealed strong correlation-regression relationships between COVID-19 morbidity/ mortality and the prevalence of overweight and obesity, GDP, it is necessary to recommend to healthcare systems of the world to actively prevent overweight and obesity in order to reduce the incidences and deaths from COVID-19.

To improve the battle with COVID-19 countries it is need to keep an action with overweight and obesity among population. Further investigations are needed.

Conclusions

The global cross-sectional study with correlation-regression analysis provided evidence that is a significant direct impact of overweight/obesity prevalence on growth of COVID-19 morbidity and mortality. Countries with a higher GDP have a high overweight/obesity prevalence and possibility to get vaccinated.

During three years (2016–2019) overweight and obesity among adults of both sexes in the world grew by 21.2% and 40.8%, respectively. In 2019, an average percentage of overweight prevalence among adults (both sexes) was 47.31 ± 15.99%, and obesity prevalence among adults (both sexes) was 18.34 ± 9.64%.

Limitations

One limitation of the study is that the study did not include all world countries due to the fact that not every country's data was available. The second limitation is that the study relied on officially reported data, which may be subject to inaccuracies and reporting delays, but those are the only data available. The third, the study focuses on public data, and further longitudinal cohort and/or case-control studies are needed.

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CRediT authorship contribution statement

KO, ZZ, MG and BD had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.Concept and design: KO, ZZ, NO.Acquisition, analysis, or interpretation of data: All authors.Drafting of the manuscript: KO, ZZ, MG, GB, KM, BD.Critical revision of the manuscript for important intellectual content: All authors.Statistical analysis: KO, MG and AT.Obtained funding: All authors. Administrative, technical, or material support: KO, KM, NO, AT. Supervision: KO, NO, AT.

Conflict of Interest Disclosures

The authors declare that they have no any competing interests (financial, professional, or personals) that are relevant to the manuscript. We have read and understood the journal policy on declaration of interests and have no interests to declare.

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Consent for publication

Our manuscript does not contain any individual's personal data in any form. All authors of the manuscript affirm that they had access to the study data, and that they reviewed and approved the final manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jiph.2022.01.009.

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