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## Major Article

## COVID-19 fatalities, latitude, sunlight, and vitamin D

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## Key Words:

Death rates  
Proximity to the equator  
UV radiation  
Insufficient vitamin D

**Background:** Since Vitamin D is known to be vital in regulating the immune system, and sunlight UV radiation exposure on the skin produces Vitamin D and UV intensity is highest nearest the equator, a study was done to examine the correlation between the latitude and COVID-19 fatality rates for countries.

**Methods:** Eighty-eight countries were selected based on their likelihood of providing reliable data. Using death rates/million for each country from the “worldometer” website, a correlation analysis was done between death rates and a country’s latitude.

**Results:** A highly significant, positive correlation was found between lower death rates and a country’s proximity to the equator (Pearson  $r = 0.40$   $P < .0001$ , 2-tailed  $t$  test). The R squared of 0.16 means that 16% of the variation in death rates among nations is accounted for by the latitude of the country. Evidence is presented suggesting a direct correlation between sunlight exposure and reduced mortality.

**Discussion:** This study is the first to document a statistically significant correlation between a country’s latitude and its COVID-19 mortality and is consistent with other research regarding latitude, Vitamin D deficiency, and COVID-19 fatalities. Limitations of this study are noted.

**Conclusions:** Further research is needed to confirm the correlation between latitude and COVID-19 fatalities, and to determine the optimum amounts of safe sunlight exposure and/or vitamin D oral supplementation to reduce COVID-19 fatalities in populations that are at high risk for vitamin D deficiency.

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As the COVID-19 pandemic spread, death rates reported for over 200 countries and territories on the “worldometer” website appeared to be higher in countries farther from the equator compared with those closer to the equator.<sup>1</sup> A striking example of this appeared in the May 11, 2020 data between Ireland and Singapore, whose population size was similar (4.9 million vs 5.3 million, respectively), total number of cases were similar (23,135 vs 23,822, respectively), and number of cases per million of their population was similar (4,685/million vs 4,072/million, respectively). However, the number of deaths in Ireland was 297/million compared with 4/million in Singapore.<sup>1</sup> Despite similar numbers of cases, Ireland had 74 times more fatalities than Singapore.

By the second week of May 2020, several medical studies appeared describing significant correlations between Vitamin D insufficiency, COVID-19 mortality rates, and the suspected pathophysiology of COVID-19 deaths.<sup>2–6</sup> Without adequate Vitamin D levels, the lungs are vulnerable to fatal immune system dysregulation including but not limited to cytokine storms, insufficient protection from epithelial cell apoptosis, and deficient epithelial cell repair.<sup>4,6</sup>

Because direct sunlight on the skin produces Vitamin D in the human body, it has been hypothesized that populations with more regular exposure to natural UV radiation from the sun might have less vitamin D deficiency than those with less UV exposure and consequently lower fatality rates from COVID-19.<sup>5</sup> While UV exposure from sunlight is affected by many factors such as clouds, weather, and pollution, a country’s proximity to the equator also affects UV exposure because the intensity of UV radiation is higher closer to the equator. The present study was undertaken to examine the correlation between proximity to the equator and death rates from COVID-19. Because of the positive correlation between sunlight UV radiation and healthy Vitamin D levels in the body, and reported positive correlation between Vitamin D deficiency and fatality rates to COVID-19, the present study examined the relationship between a country’s proximity to the equator and its death rates from the current pandemic. This study hypothesized that countries closer to the equator would have lower fatality rates from COVID-19 than countries farther away.

## METHODS

To test this hypothesis, a correlation analysis was done comparing a country’s latitude and its COVID-19 identified death rates per

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million members of the country's population. To improve the accuracy of reported death between countries, the present study sought to include only countries whose governments have a favorable history of transparency. "Transparency International" ranks a total of 180 countries listed from most to least transparent based on multiple measures of government transparency.<sup>7</sup> Only the 90 countries in the top 50% were selected for inclusion in this study.

Latitude data were provided by csgnetwork.com<sup>8</sup> using each country's capital, with exceptions made for China and Italy whose vast majority of cases were concentrated in latitudes different from their capitals. Wuhan's latitude was used instead of Beijing for China, and Milan's was used instead of Rome for Italy.

Death rates per million in the population for each country were taken from the "worldometer" website on May 17, 2020.<sup>1</sup> All but 2 of the chosen 90 countries and territories (Vanuatu and Solomon Islands) had data on the worldometer, leaving an N = 88 used for the analysis.

The deaths per million/population and latitude for each of the 88 countries were independently entered twice on separate occasions and compared to insure accuracy. A Pearson r correlation computation was done on both data sets on Google Sheets "Correlation" and compared for accuracy and consistency.<sup>9</sup>

## RESULTS AND INTERPRETATION

The Pearson product-moment correlation on both data sets obtained a correlation coefficient of  $r = 0.40$ . The probability for this outcome was statistically calculated and was found to be extremely low,  $P < .00005$  for 1-tailed probability using the hypothesis of lower mortality in populations closer to the equator. The probability of this outcome occurring with no predicted direction was still very low, at  $P < .0001$  for 2-tailed probability.<sup>10</sup> The  $r = 0.40$  translates to a coefficient of determination (R squared) = 0.16; that is, 16% of the variance in mortality rates is attributed to the country's latitude. Such a high correlation for such a crude factor as latitude is surprising yet credible considering other research showing significant correlations between sunlight exposure and cancers.

Lower risks for cancer have been found in countries with higher levels of sunlight exposure.<sup>11-13</sup> One study compared cancers in sunny countries with lower latitudes with less sunny countries with higher latitudes and concluded "that vitamin D production in the skin decreased the risk of several solid cancers (especially stomach, colorectal, liver and gallbladder, pancreas, lung, female breast, prostate, bladder and kidney cancers)."<sup>13</sup> Significantly lower rates of prostate cancer was found in men whose birth place and longest place of residence was in southern states of the United States, leading the authors to conclude that "residential sunlight exposure reduces the risk of prostate cancer."<sup>14</sup> Deaths from prostate cancer in America were compared with sunlight UVB exposure and the results were highly significant ( $r = -0.0001$ ), meaning that men who received more sunlight were less likely to die from prostate cancer.<sup>12</sup>

The present study finding a strong correlation between latitude and COVID-19 fatalities may be explained by the role of sunlight on the skin producing vitamin D,<sup>5</sup> and the research linking Vitamin D deficiency and COVID-19 fatalities.<sup>2-6</sup> While the present study does not address Vitamin D directly, its production in the human body due to UV sunlight exposure, and the known increase of UV radiation intensity closer to the equator lead to the likelihood that populations closer to the equator have more adequate endogenous vitamin D compared with populations farther away, thereby reducing the likelihood of a fatal dysfunction of the immune system in the presence of COVID-19.<sup>11</sup>

The relevance of sunlight exposure for COVID-19 is illustrated by comparing statistics involving Milan and Naples, Italy. It is claimed that little or no sunlight UV radiation reaches the earth during winter

months in countries whose latitude is above 40°.<sup>5</sup> Milan's latitude is significantly above 40° (45.46N) and its COVID-19 epidemic accelerated rapidly in the winter month of February, 2020 (1). By May 21, 2020, its death rate was 15,729/million.<sup>15</sup> The latitude of Naples is 40.85N, 318 miles south of Milan's latitude; however, Naples has 59% sunny days per year<sup>16</sup> compared with Milan's 43% sunny days.<sup>17</sup> On May 21, 2020 Naples death rate was 403/million compared with Milan's 15,729/million,<sup>15</sup> less than 3% of Milan's death rate. In this comparison, the fact that Naples is closer to the equator is less significant than the difference in their annual sunlight exposure. Compared with Milan, Naples enjoys 58 more sunny days per year ( $[59\% \times 365] - [43\% \times 365] = 58$ ), which is nearly 2 more months of sunshine each year for its population. This comparison supports the hypothesis that the underlying mechanism behind the latitude-mortality correlation is due to differences in sunlight UV radiation and the subsequent levels of endogenous Vitamin D in the respective populations.

Limited sunlight exposure for those in institutional settings, such as prisons and skilled nursing facilities, has been suggested as the reason that 75% of these populations are Vitamin D deficient and suffer disproportionately high levels of COVID-19 mortality.<sup>2</sup> Lower vitamin D levels also are associated with advanced age,<sup>18</sup> diabetes,<sup>19</sup> and hypertension,<sup>20</sup> 3 of the same risk factors associated with COVID-19 fatalities and also common in nursing home populations. Even if patients in nursing homes are ingesting adequate amounts of vitamin D in their diet, that may not be sufficient since some studies find dietary vitamin D less effective than that produced by exposure to sunlight.<sup>14</sup>

## DISCUSSION AND CONCLUSIONS

The current study is the first to document a statistically significant correlation between a country's latitude and its COVID-19 mortality. The highly significant probability ( $P < .0001$ ) that countries proximal to the equator have lower COVID-19 fatalities than distal countries supports a probable connection between latitude, sunlight exposure, Vitamin D, and COVID-19 fatality. The most probable explanation for the correlation found between latitude and COVID-19 deaths is the mechanism of Vitamin D induced by sunlight exposure.<sup>5</sup> Further research is needed to see if endogenous vitamin D is protective against COVID-19, and if so, what the optimal amount of safe sunlight exposure is to produce a protective effect.

It is important to note that sunlight exposure does not bestow uniform benefits to all members of the population. The effectiveness by which UV radiation on the skin produces endogenous Vitamin D is modified by the age, skin color, and sex of the person.<sup>3,5</sup> The body's efficiency in producing Vitamin D from sunlight decreases with age, such that elderly women in Ecuador where sunlight is abundant have been found deficient in Vitamin D.<sup>5</sup> Darker skin color reduces the production of Vitamin D from UV exposure, and this may be one of the reasons that African Americans suffer twice the prevalence of Vitamin D insufficiency compared with the general population (82.1% vs 41.6%) and disproportionately high mortality rates from COVID-19.<sup>3</sup> In addition to skin color and aging, local customs may also impact the results of UV exposure in the population: Vitamin D deficiency has been found in girls and women in the Middle East despite plenty of sunlight.<sup>5</sup>

An important limitation in this study is the unknown duration of time between the identification of first cases in a country and the reported death rates. All other factors being equal, death rates in a country where cases began to appear recently will appear lower than those in countries fighting the virus for a longer time. Such variability could raise or lower the numbers used in a correlation study depending on the country's latitude. That does not appear to have changed the striking difference between the death rates in Ireland and

Singapore mentioned in the Introduction. On May 11, 2020, the “worldometer” reported 297 deaths per million in Ireland compared with 4 deaths per million in Singapore.<sup>1</sup> On June 20, 2020, the “worldometer” reported 347 deaths/million in Ireland and still only 4 deaths/million in Singapore.<sup>21</sup> Despite the fact that Singapore’s COVID-19 case rate rose 75% (from 4,072/M to 7,152/M) and Ireland’s only rose 10% (from 4,685/M to 5,141/M)<sup>21</sup> and over 5 weeks have elapsed, Singapore’s death rate has remained stable at 4 deaths/M. While Ireland appears to have slowed the rate of increased cases compared with Singapore, it now has a fatality rate that is 86 times higher than Singapore’s. This paired comparison is not only consistent with a positive correlation between equatorial proximity and low fatality rates, it also shows that the difference in the reported death rates for this pair of countries is not the result of different time durations from diagnosis to mortality.

The above comparison may be an anomaly, and the fact remains that the unknown duration of time in our 88 countries from first identified cases to reported deaths represents a potential confounder to these results. Statistical probability testing cannot eliminate this confounder, but may reduce the likelihood of falsely claiming a significant correlation. The more extreme the “P” value is, the lower the likelihood is of erroneously finding a correlation that is not there (ie, of making a “type 1 error” in statistical hypothesis testing.)

The results of this study support that of other research that points to the urgent need to correct Vitamin D deficiency to reduce COVID-19 fatalities.<sup>2-6,14</sup> Further research regarding the amounts of safe sunlight exposure and of vitamin D oral supplementation is indicated because, even if they are only partially effective, they are cheap, safe, and readily available. Finding such ways for the general public to fortify the immune system (while scientists continue searching for medical treatments and a vaccine) would be a welcome and overdue addition of “inner” strategies in fighting COVID-19 to the “outer” ones (social distance, masks, disinfecting surfaces) that have been receiving exclusive attention.

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