COVID-19 outcomes span a wide spectrum, from asymptomatic, to mild, severe, hospitalization, ICU, and death. Much research has been devoted to understanding risk factors associated with case severity. For example, CDC recognizes obesity, diabetes, chronic lung disease, coronary artery disease, physical inactivity, and smoking, among others.
https://www.cdc.gov/coronavirus/2019-ncov/hcp/clinical-care/underlyingconditions.html

Environmental risk factors may also contribute to COVID-19 severity. The Harvard TH Chan School of Public Health has noted "Emerging research, including a study from Harvard T.H. Chan School of Public Health, finds that breathing more polluted air over many years may itself worsen the effects of COVID-19."
https://www.hsph.harvard.edu/c-change/subtopics/coronavirus-and-pollution/

The attached peer-reviewed research examines associations between COVID-19 severity and radiofrequency exposure, suggesting that, like air pollution, radiofrequency exposure could be a risk factor contributing to COVID-19 severity and mortality.
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8580522/
https://doi.org/10.18103/mra.v9i4.2371

The Council should immediately halt all small cell deployments in residential zoning in the County until it has examined this research and can assure the public that these deployments are safe and are not increasing disease severity or mortality in the County.

RESEARCH ARTICLE

COVID-19 Attributed Cases and Deaths are Statistically Higher in States and Counties with 5th Generation Millimeter Wave Wireless Telecommunications in the United States.

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Accepted for Publication: Medical Research Archives, European Society of Medicine
doi: https://doi.org/10.18103/mra.v9i4.2371

Abstract
COVID-19-attributed case and death rates for the U.S.A. were analyzed through May 2020 in three ways – for all 50 states, the country's largest counties, and the largest counties in California – and found to be statistically significantly higher for states and counties *with* compared to those *without* 5G millimeter wave (mmW) technology. 5G mmW index was a statistically significant factor for the higher case and rates in all three analyses, while population density, air quality and latitude were significant for only one or two of the analyses. For *state averages*, cases per million were 79% higher (p = 0.012), deaths per million were 94% higher (p = 0.049), cases per test were 68% higher (p = 0.003) and deaths per test were 81% higher (p = 0.025) for states with vs. without mmW. For *county averages*, cases per million were 87% higher (p = 0.005) and deaths per million were 165% higher (p = 0.012) for counties with vs. without mmW. While higher population density contributed to the higher mean case and death rates in the mmW states and counties, exposure to mmW had about the same impact as higher density of mmW states on mean case and death rates and about three times as much impact as higher density for mmW counties on mean case and death rates. Based on multiple linear regression, if there was no mmW exposure, case and death rates would be 18-30% lower for 5G mmW states and 39-57% lower for 5G mmW counties. This assessment clearly shows exposure to 5G mmW technology is statistically significantly associated with higher COVID-19 case and death rates in the U.S.A. The mechanism–should this be a causal relationship–may relate to changes in blood chemistry, oxidative stress, an impaired immune response, an altered cardiovascular and/or neurological response.
Keywords: 5G; millimeter waves; radiofrequency; RF; microwave radiation; microwave sickness; wireless; electromagnetic fields; EMF; EMR; EMI; EHS; COVID-19; SARS-CoV-2

1. Introduction

The first documented case of COVID-19 was reported in Wuhan, China in December 2019. To prevent its spread, the U.S. blocked travel from China on January 31st and declared a National Emergency on March 13th, 2020. After the World Health Organization (WHO) declared it a pandemic on March 19, 2020, the U.S. began quarantine and stay-at-home orders to slow the virus' spread and to "flatten the curve". Despite these precautions, the virus spread quickly in the U.S. and around the globe.

The infectious agent was named *severe acute respiratory syndrome coronavirus 2* (SARS-CoV-2) due to genetic similarity to SARS-CoV that caused a pandemic in 2002-4. The disease associated with SARS-CoV-2 is COVID-19, which is an abbreviation for Coronavirus Disease 2019 associated with SARS-CoV-2.

According to the U.S. Centers for Disease Control the epidemiological triangle for infectious diseases consists of the agent, the host and the environment. While attention has focused on the agent (genetics, modes of infection, etc.) and the host (age and comorbidities), little attention has focused on key environmental factors. These include but are not limited to air quality since this was initially identified as a respiratory illness, population density for person to person transmission, and electromagnetic radiation since COVID-19 appeared after 5G was implemented and many of the COVID-19 symptoms resemble those of microwave sickness.

As of September 18, 2020, according to Johns Hopkins University, the cases are not uniformly distributed globally (Figure 1). Many factors may account for this: testing differences, per capita income, standard of health care, population demographics, and environmental factors among others. This paper focuses on four environmental factors that may relate to the spread and fatality of this disease: population density, air pollution, latitude (which determines potential endogenous vitamin D production) and presence of 5G mmW technology, which is present in combination with frequencies used in previous generations of wireless communications from 1G to 4G and does not replace them. These data, along with COVID-19 case and death data, were readily available for the United States.

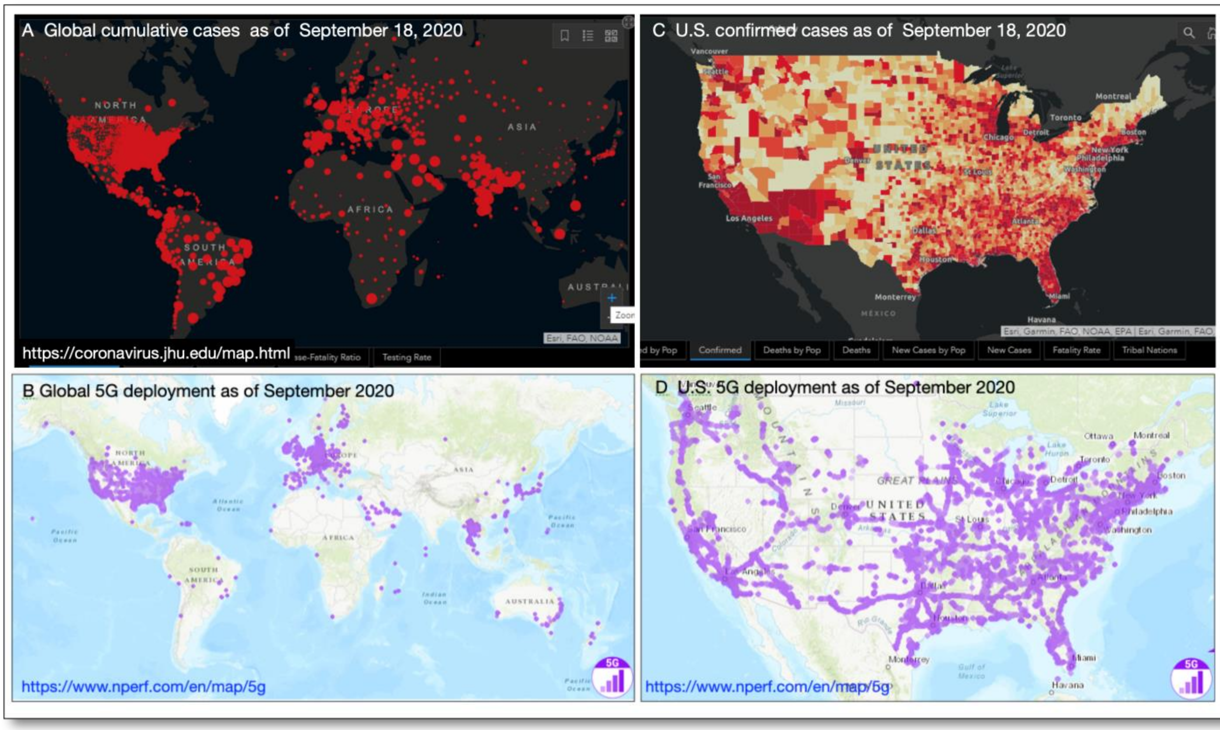

Figure 1. Data for COVID-19 (as of September 18, 2020) and rollout of 5G as of September 2020.

As of August 9, 2020, the U.S. was #1 out of 213 nations in the world for the highest number of total COVID-19 cases at 5.2 million, with 15,698 cases per million (9th highest) and 500 deaths per million (10th highest) [1].

The rollout of 5G technology is to support the Internet of things (IoT). As of January 2020, 31 countries had working 5G networks globally [2-5] In the top quartile of the highest ranking countries for COVID-19 deaths per million, 16 of them had working 5G networks; while only 7 countries had 5G in the 2nd highest quartile; 6 in the 3rd highest quartile and only 2 in the bottom quartile. In the top quartile, the 5G countries with higher deaths per million than the U.S. were San Marino (1238), Belgium (851), U.K. (686), Spain (610) and Italy (582). The other countries with 5G in the top quartile with fewer deaths per million than the U.S. were Ireland (358), Switzerland (229), South Africa (175), Romania (140), Germany (110), Denmark (106), Monaco (102), Oman (100), Bahrain (95), and Saudi Arabia (91).

Three radio frequency bands are used in 5th Generation (5G) wireless communications. The low band refers to frequencies below 1 GHz; the mid band to frequencies between 1 GHz and 6 GHz, and the high band to the millimeter waves (mmW), which are 24 GHz and above. The U.S. telecommunication companies began using mmW for 5G wireless communications in 2019 after their acquisition of the mmW spectrum, making the U.S. the first country in the world to use mmW for 5G. In June 2019, FCC's Auction 101 for 28 GHz sold for $700 million and Auction 102 for 24 GHz sold for $2 billion [6], and in March 2020, 37, 39 and 47 GHz bands in Auction 103 sold for $7.5 billion [7], generating a total of $10 billion for the U.S. government. As of February 2020, European countries were still not using mmW for 5G [8], and other countries have used only the low and mid band frequencies for 5G. To achieve higher speeds for 5G, densification of antennas has occurred worldwide. Also, because mmW have shorter wavelengths (higher frequencies) than that used for 1G to 4G, they are more susceptible to interference from obstructions, thus requiring more transmitters closer to users, which have been added to streetlamps and utility poles in some cities. The shorter distance and higher density of mmW antennas translates into higher radiation exposures, as acknowledged by the FCC's 2019 Notice of Proposed Rulemaking 19-126 [9] to increase the current RF exposure limits four-fold to accommodate 5G mmW devices and infrastructure.

If environmental exposure to 5G mmW increases the severity of COVID-19 or other viral infections, then the rapid rollout of 5G technology should be reconsidered.

2. Methods

2.1 COVID-19 Attributed Cases and Deaths

Data for number of cases, deaths, and tests for COVID-19 from Worldometer was assessed on April 22, 2020, May 15, 2020, and May 31, 2020 [1]. Data collection was stopped on May 31, 2020 because the nationwide quarantine effectively ended by that time as people in major cities all around the country broke quarantine when they gathered in crowds and some states began lifting their stay-at-home orders.

2.2 Variables: Air Quality Index, Latitude, Population Density and mmW Index

A mmW exposure index was calculated based on the sum of the total population of the cities serviced by mmW 5G by each provider in a county or state, divided by the total population of that county or state. This factor is not a calculation of the mmW exposure level but a differentiation between the different exposure levels in each state and county based on the number of mmW providers and the number of mmW cities and their population in those counties or states, which is necessary for statistical analysis.

Population density data were obtained from Wikipedia, which are calculated from population data from the U.S. Census divided by the area of the state or county. Air Quality Index (AQI) data from 2019 from the EPA were included in the analysis for states and counties. Latitude, which may relate to potential production of endogenous vitamin D associated with sun exposure, was also included in the analysis for counties.

2.3 States and Counties with and without 5G mmW Networks

Cities with 5G mmW networks were chosen for analysis because the most frequencies for wireless communications (5G mmW plus low and mid band 5G as well as frequencies from previous generations 1G to 4G) and the highest RF exposures due to the increased number of small cell antennas for 5G and their placement close to users would be present there. Even though urbanization and high density may be part of the criteria for choosing where to locate 5G mmW, and therefore it may seem appropriate to adjust the case and death rate data for urbanization and density, it is actually NOT appropriate to do so for this analysis. The higher the urbanization and density in an area, the higher the levels of RF radiation present because of the higher density of cell phone towers, Wi-Fi hot spots, cell phones and Wi-Fi routers present in highly urbanized or dense areas. To adjust the data for urbanization and density would therefore remove the effect of higher levels of RF radiation present in highly urbanized or dense areas. Therefore, case and death rate data and charts were not adjusted for density or urbanization. However, multi-variate analysis was done to determine if urbanization or density, along with AQI and latitude, were statistically significant factors in the case and death rates using multiple linear regression, and then their contributions relative to the contribution from 5G mmW to the case and death rates were calculated.

Counties and states with mmW 5G service were determined from the websites of the wireless providers AT&T [10], T-Mobile [11], and Verizon [12] which specified the cities that they service with mmW 5G (Table 1). There were no changes in the cities using mmW for 5G between April 22 and May 31, 2020.

The data were analyzed three ways to determine robustness: at the state level, at the county level, and for the largest counties in California.

In this analysis, 32 states were using mmW 5G and 18 states were not. All counties using mmW for 5G were included except for Hampton Roads, VA, because it spanned a combination of 16 counties and cities which made its analysis difficult; so, a total of 53 counties using mmW 5G were used.

The counties not using non-mmW were from the largest 120 cities in the U.S. according to the U.S. Census Bureau. After omitting the counties that contained cities with mmW 5G service, 49 counties were left that did not have mmW 5G technology. There are thousands of counties in the U.S., and because only the ones containing the 120 largest cities were included, some states were not represented in the county analysis. The states not represented in the county analysis (but included in the state analysis) are: VA, CT, DE, ME, MS, MT, NH, ND, RI, SC, VT, WY.

California, the most populated state in the U.S., has 60 counties in total and six counties with 5G mmW technology. The counties that did not use 5G mmW technology chosen for comparison included only those with a population of 500,000 or greater, of which there were 11.

Pearson's correlations were calculated for the case and death rates with the four variables population density, mmW index, AQI, and latitude. Two-sample t-test was used to compare case and death rates of 5G mmW states and counties to that of non-5G mmW states and counties, and statistical significance was defined to be $p < 0.05$ with $\alpha = 0.05$. Regression analyses were performed to find regression equations for the case and death rates and identify statistically significant variables at $p < 0.05$. The numbers of cases per test and deaths per test were analyzed at the state level but not at the county level due to missing data.

3. Results

3.1 U.S. Compared to European Countries

Whereas none of the European countries was using mmW for 5G as of February 2020 and mmW spectrum was not even assigned to any European country except Italy [8], the U.S. began using mmW for 5G in 2019. Of the 10 European countries (with populations greater than 2 million) with the highest numbers of COVID-19 deaths per million through August 9, 2020 [1], deaths per million were significantly higher for those countries with 5G compared to non-5G and this difference was statistically significant (617 vs. 383, $p = 0.026$) (Table 2).

Table 1. Cities with mmW 5G Coverage and Provider from April 22 to May 31, 2020. Source: AT&T [10], T-Mobile [11], Verizon [12].

City	State	AT&T	T-Mobile	Verizon
Atlanta	GA	X	X	
Austin	TX	X		
Baltimore	MD	X		
Charlotte	NC	X		
Chicago	IL			X
Cincinnati	OH			X
Cleveland	OH	X	X	X
Columbus	OH			X
Dallas	TX	X	X	X
Denver	CO			X
Des Moines	IA			X
Detroit	MI	X		X
Grand Rapids	MI			X
Greensboro	NC			X
Hampton Roads	VA			X
Hoboken	NJ			X
Houston	TX	X		X
Indianapolis	IN			X
Jacksonville	FL	X		
Kansas City	MO			X
King of Prussia	PA	X		
Las Vegas	NV	X	X	
Little Rock	AR			X
Los Angeles	CA	X	X	X
Louisville	KY	X		
Memphis	TN			X
Menlo Pk, Rdwd City, San Bruno	CA	X		
Miami	FL	X		X
Miami Gardens (AT&T only)	FL	X		
Minneapolis	MN			X
Nashville	TN	X		
New York City	NY	X	X	X
Oakland	CA	X		
Ocean City	MD	X		
Oklahoma City	OK	X		
Omaha	NE			X
Orlando	FL	X		
Panama City	FL			X
Philadelphia	PA	X		
Phoenix	AZ	X		X
Raleigh	NC	X		
Salt Lake City	UT			X
San Antonio	TX	X		
San Diego	CA	X		
San Francisco	CA	X		
San Jose	CA	X		
Sioux Falls	SD			X
Spokane	WA			X
St. Paul	MN			X
Waco	TX	X		
Washington	DC			X
West Hollywood	CA	X		

Table 2. Top 10 Ranking European Countries for COVID-19 Deaths/Million for 5G * vs. Without 5G through August 9, 2020. Source: Worldometer [1]

Rank # Deaths per Million out of 213 Countries Worldwide	Rank # Deaths per Million out of European Countries (pop. > 2 million)	Country	Population	Total Deaths per Million
2	1	Belgium *	11,595,151	851
3	2	U.K. *	67,924,946	686
6	3	Spain *	46,756,796	610
7	4	Italy *	60,451,842	582
17	8	Ireland *	4,943,652	358
8	5	Sweden	10,106,111	570
12	6	France	65,289,486	464
16	7	Netherlands	17,139,065	359
22	9	Armenia	2,963,856	267
23	10	N. Macedonia	2,083,364	253
U.S. For Comparison		U.S.*	331,214,010	500
	Mean 5G European Countries			617
	Mean non-5G European Countries			383
	p-value of T-test, with vs. without 5G			**0.0257***

The 500 deaths per million for the U.S. are within the range of the 5G European countries. Because of differences in testing and criteria for how cases are counted between U.S. and European countries, deaths per million is the most consistent number to use for comparison between countries. However, there are still other differences between the U.S. and European countries - per capita income, standard of health care, population demographics, quarantine measures, and environmental factors like air pollution - that complicate comparison between countries. Nevertheless, these data are provided to show how the U.S. compares to the top 10 European countries with the highest deaths per million, with and without 5G.

3.2 States with vs. without 5G mmW

There were 32 states with 5G mmW and 18 states without 5G mmW. Descriptive statistics for the cumulative data through April 22, which was just after the peak of daily deaths for COVID-19 had occurred on April 21 (Figure 2), can be found in Table 3. The average rate of cases and deaths was much higher for the mmW states compared to the non mmW states, and these differences were statistically significant with p-values between 0.005 to 0. 046 (Table 3 and Table 4A). There were almost twice as many cases per million (2,500 vs. 1,288, ratio 1.94) and more than twice as many deaths per million (126 vs. 55, ratio 2.29) for states with vs. without mmW technology. For mmW states compared to the non-mmW states, there were almost twice as many cases/test (15.5% vs. 8.82%, ratio 1.76) and twice as many deaths/test (0.721% vs. 0.364%, ratio 1.98). The fatality rate (deaths per case) was higher for the mmW states but was not statistically significant (4.13% vs. 3.50%, ratio 1.18, p = 0.081).

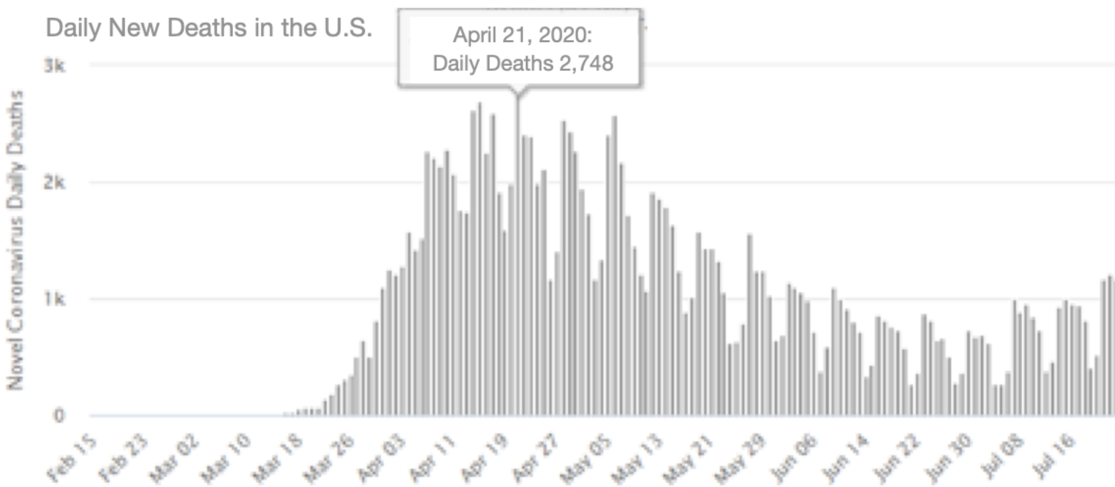

Figure 2. COVID-19 daily new deaths peaked at 2,748 on April 21, 2020 in the U.S. Source: Worldometer [1]

Table 3. Descriptive statistics through April 22, 2020 (after peak of daily deaths occurred) for states with and without 5G mmW for population, mmW index, COVID-19 tests, air quality index (AQI), and number of COVID-19 attributed cases and deaths. Statistical significance is indicated by * (p < 0.05) and ** (p < 0.01).

States	n		State Population	Population Density (people per sq. km)	mmW index	AQI	Tests per Million	Cases per Million	Deaths per Million	% Cases per Test	% Deaths per Test	% Deaths per Case
with 5G mmW		max	39,937,489	467	1.284	51.2	39,487	13,368	1037	51.60%	3.04%	8.30%
with 5G mmW	**32**	**mean**	**8,752,116**	**91.7**	**0.207**	**43.4**	**14,378**	**2500**	**126**	**15.50%**	**0.72%**	**4.13%**
with 5G mmW		min	903,027	4.29	0.006	33.5	7,224	492	10	4.50%	0.07%	0.47%
without 5G mmW		max	8,626,207	287	0	47.6	21,540	6274	431	32.10%	2.20%	6.90%
without 5G mmW	**18**	**mean**	**2,639,561**	**50.2**	**0**	**40.0**	**14,324**	**1288**	**55**	**8.80%**	**0.40%**	**3.50%**
without 5G mmW		min	567,025	0.502	0	21.2	6,567	412	8	2.30%	0.00%	1.30%
p-value of t-test			0.0002 **	0.062	7.3E-06 **	0.025 *	0.49	0.027 *	0.046 *	0.005 **	0.022 *	0.081
Ratio of means			3.32	1.83	N/A	1.09	1.00	1.99	2.33	1.77	1.81	1.18

Data from May 15 and May 31 show the same pattern as for April 22, with statistically significant higher cases/million, deaths/million, cases/test, and deaths/test for the mmW states compared to the non mmW states. For data cumulative through May 31, 2020, comparing mmW to non-mmW states, there were 5776 vs. 3220 cases per million (ratio 1.79, p = 0.012); 307 vs. 158 deaths per million (ratio 1.95, p = 0.049); 9.88% vs. 5.88% cases per test (ratio 1.68, p = 0.003); and 0.494% vs. 0.270% deaths per test (ratio 1.83, p = 0.025) (Table 4B & C; Figure 3A & B; Figure 4A & B).

Table 4. Case and death rates attributed to COVID-19 and Pearson's Correlations for population density, mmW index and their interaction for U.S. states for cumulative data through (A) April 22, 2020; (B) May 15, 2020; and (C) May 31, 2020. Statistical significance is indicated by * (p < 0.05) and ** (p < 0.01). NOTE: YTD is year to date.

A YTD through April 22, 2020	n	Total Tests per million	Total Cases per million	Total Deaths per million	% Cases per Test	% Deaths per Test	% Death per Case
Mean for States with mmW 5G	**32**	**14,378**	**2,500**	**126**	**15.5%**	**0.721%**	**4.13%**
Mean for States without mmW 5G	**18**	**14,324**	**1,288**	**55**	**8.82%**	**0.364%**	**3.50%**
mmW vs. non-mmW 5G		2%	99%	131%	77%	99%	18%
p-value for t-test mmW vs. non-mmW		0.49	**0.027 ***	**0.046 ***	**0.005 ****	**0.022 ***	**0.081**
Pearson Corr. to PopDensity (50 states)			**0.723**	**0.577**	**0.701**	**0.600**	**0.284**
Pearson Corr. to PopDensity*mmW (mmW states)			**0.700**	**0.783**	**0.434**	**0.559**	**0.360**
Pearson Corr. to mmW index (50 states)			**0.479**	**0.580**	**0.353**	**0.431**	**0.302**
Correlation between Population Density and mmW Factor 's 0.072, i.e. they are independent of each other, no relationship.							
Pearson Correlation to Air Quality Index			0.094	0.047	0.282	0.183	0.085

B YTD through May 15, 2020	n	Total Tests per million	Total Cases per million	Total Deaths per million	% Cases per Test	% Deaths per Test	% Death per Case
Mean for States with mmW 5G	**32**	**34,606**	**4,595**	**248**	**12.26%**	**0.622%**	**4.60%**
Mean for States without mmW 5G	**18**	**33,932**	**2,459**	**123**	**7.24%**	**0.340%**	**3.97%**
mmW vs. non-mmW 5G		2%	87%	102%	69%	83%	15.9%
p-value for t-test mmW vs. non-mmW		0.44	**0.016 ***	**0.052**	**0.005****	**0.031 ***	**0.12**
Pearson Corr. to PopDensity (50 states)			**0.788**	**0.733**	**0.654**	**0.687**	0.439
Pearson Corr. to PopDensity*mmW (mmW states)			**0.656**	**0.681**	**0.400**	**0.485**	0.306
Pearson Corr. to mmW index (50 states)			**0.422**	**0.442**	**0.321**	**0.329**	0.213
Correlation between Population Density and mmW Factor is 0.073, i.e. they are independent of each other, no relationship.							
Pearson Correlation to Air Quality Index			0.152	0.121	0.284	0.237	0.162

C YTD through May 31, 2020	n	Total Tests per million	Total Cases per million	Total Deaths per million	% Cases per Test	% Deaths per Test	% Death per Case
Mean for States with mmW 5G	**32**	**54,805**	**5,776**	**307**	**9.88%**	**0.494%**	**4.57%**
Mean for States without mmW 5G	**18**	**53,506**	**3,220**	**158**	**5.88%**	**0.270%**	**3.91%**
mmW vs. non-mmW 5G		2%	79%	94%	68%	83%	17%
p-value for t-test mmW vs. non-mmW		0.42	**0.012***	**0.049***	**0.003****	**0.025***	**0.116**
Pearson Corr. to PopDensity (50 states)			**0.793**	**0.774**	**0.623**	**0.695**	**0.495**
Pearson Corr. to PopDensity*mmW (mmW states)			**0.625**	**0.665**	**0.350**	**0.453**	**0.332**
Pearson Corr. to mmW index (50 states)			**0.396**	**0.410**	**0.293**	**0.295**	**0.203**
Correlation between Population Density and mmW Factor is 0.073, i.e. they are independent of each other, no relationship.							
Pearson Correlation to Air Quality Index			0.181	0.143	0.319	0.257	0.169

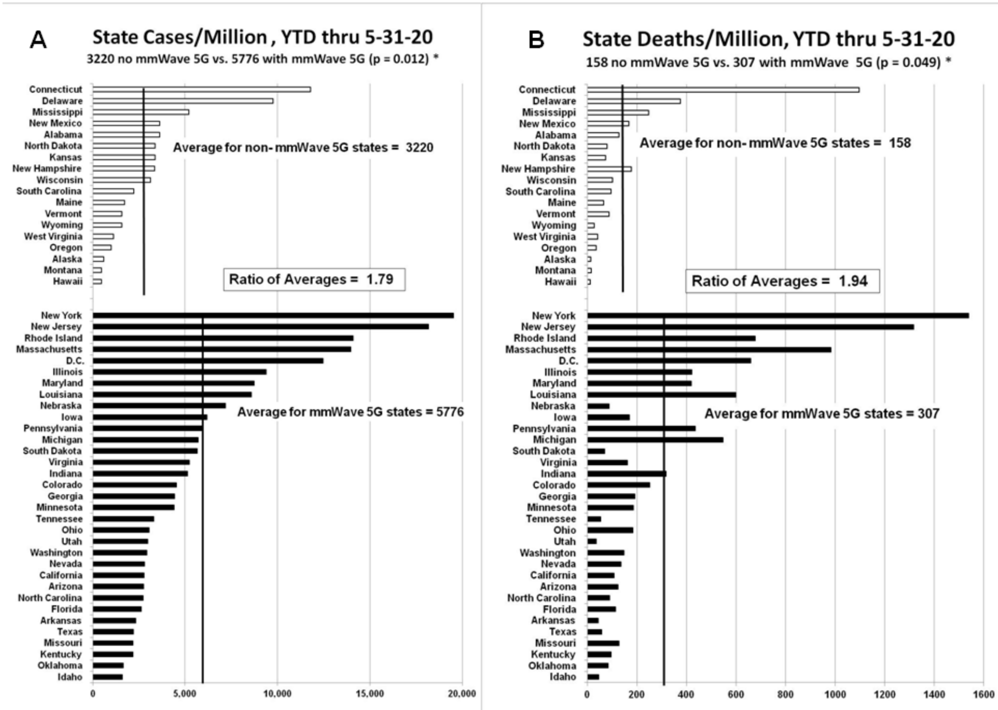

Figure 3. COVID-19 attributed case/million (A) and deaths/million (B) for states with and without 5G mmW for data through May 31, 2020.

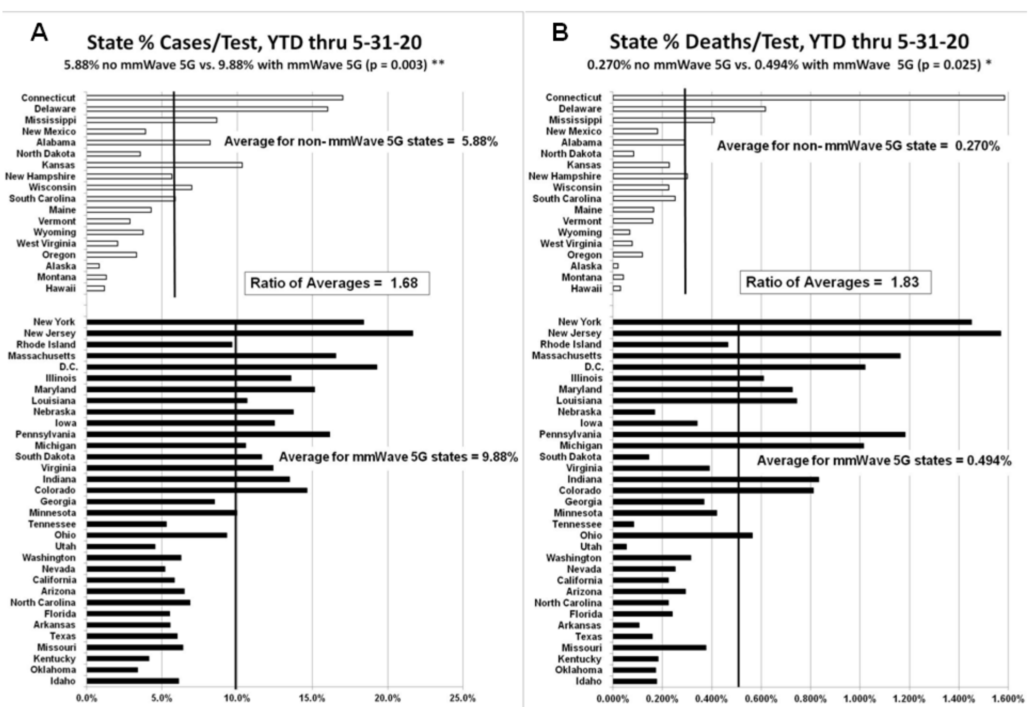

Figure 4. Percentage of COVID-19 attributed cases/test (A) and deaths/test (B) for states with and without 5G mmW technology for data through May 31, 2020. Note: different scale.

3.3 Counties with vs. without 5G mmW

Data for 53 counties with 5G mmW and 49 counties without 5G mmW were analyzed. Comparing mmW to non-mmW counties, there were 7100 vs. 3797 cases per million (ratio 1.87, p = 0.005) and 446 vs. 168 deaths per million (ratio 2.65, p = 0.012), and these differences were statistically significant. The fatality rate, which is deaths/cases, was higher for the mmW counties (4.70% vs. 4.07%, ratio 1.15), but this difference was not statistically significant (Table 5; Figures 5A and 5B).

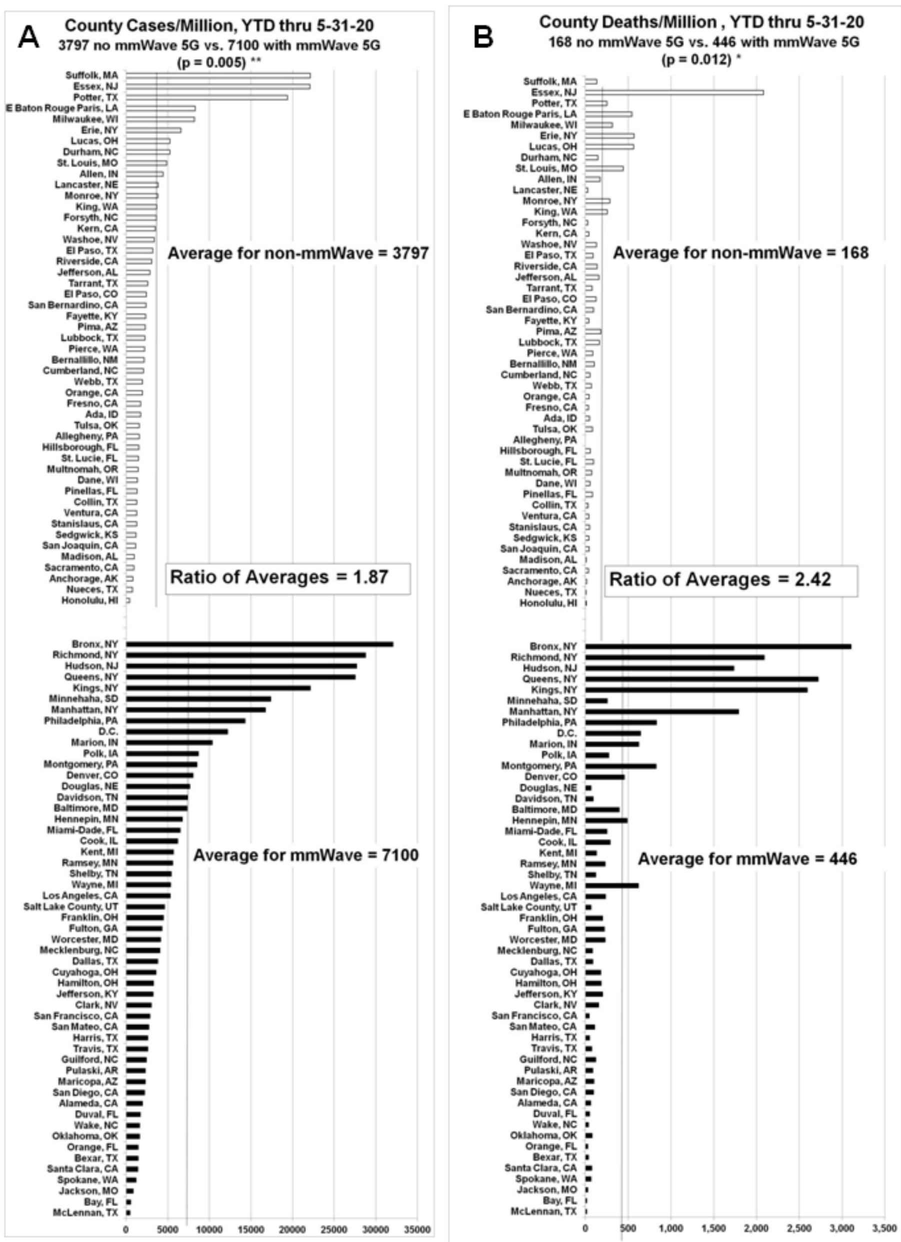

Figure 5. COVID-19 attributed cases/million (A) and deaths/million (B) for counties with and without 5G mmW technology through May 31, 2020. Note: different scale.

Table 5. Descriptive statistics and Pearson's Correlations for *U.S. counties* through May 31, 2020 with and without 5G mmW for population, population density, mmW index, air quality index (AQI), latitude and number of COVID-19 attributed case and death rates. Statistical significance is indicated by * (p < 0.05) and ** (p < 0.01).

Counties in U.S.	n		County Population	Population Density (people per sq. km)	mmW index	AQI	Latitude	Cases per Million	Deaths per Million	% Deaths per Case
with 5G mmW		max	10,105,518	26,822	3.00	71.0	47.7	32,064	3,105	11.7%
with 5G mmW	**53**	**mean**	**1,509,298**	**2,108**	**0.862**	**44.0**	**37.5**	**7,100**	**446**	**4.70%**
with 5G mmW		min	51,823	28.6	0.02	27.0	25.8	463	16	0.84%
without 5G mmW		max	3,185,968	5,360	0	80.0	61.2	22,141	2,081	10.7%
without 5G mmW	**49**	**mean**	**852,626**	**514**	**0**	**43.7**	**36.9**	**3,797**	**168**	**4.07%**
without 5G mmW		min	119,648	27	0	22.0	21.5	430	0	0.00%
p-value of t-test			0.005 **	0.007 **	3E-11 **	0.44	0.31	0.005 **	0.012 **	0.11
Ratio of means			1.77	4.11	N/A	1.01	1.02	1.87	2.66	1.15
Pearson's Correlation to Pop. Density								0.594	0.699	0.430
Pearson's Correlation to PopDensity*mmW								0.508	0.676	0.446
Pearson's Correlation to mmW								0.615	0.709	0.371
Pearson's Correlation to Air Quality Index								-0.212	-0.169	-0.072
Pearson's Correlation to Latitude								0.268	0.228	0.199

3.4 California Counties with vs. without 5G mmW

Data for six counties with 5G mmW and 11 counties with a population of 500,000 or greater without 5G mmW in California were analyzed. The six counties with 5G mmW technology were San Francisco, Los Angeles, San Diego, Alameda, Santa Clara, and San Mateo. The 11 counties that did not have 5G mmW technology were Orange, San Bernardino, Contra Costa, Sacramento, Riverside, Kern, Fresno, Ventura, San Joaquin, Stanslaus, and Sonoma. The mmW counties had higher average cases per million (2750 vs. 1679, ratio 1.64, p = 0.06) and significantly higher average deaths per million (102 vs. 52, ratio 1.96, p = 0.064 and higher fatality rate (3.75% vs. 3.01%, ratio 1.25, p = 0.131) than that of the non-mmW counties (Table 6).

3.5 Pearson's Correlations

A Pearson's correlation coefficient assesses the relationship between two variables. The correlation coefficient is considered very strong between ±0.7 and ±1; strong between ± 0.5 and ± 0.7, and moderate between ± 0.3 and ± 0.49.

Pearson's correlations of cases/million, deaths/million, cases/test, and deaths/test to air quality index, latitude population density, and mmW index were calculated. The results are in Table 4 for states, Table 5 for counties, and Table 6 for California.

Table 6. Descriptive statistics and Pearson's Correlations for *California counties* through May 31, 2020 with and without 5G mmW for population, population density, mmW index, air quality index (AQI), latitude and number of COVID-19 attributed case and death rates. Statistical significance is indicated by * (p < 0.05) and ** (p < 0.01).

Counties in California	n		County Population	Population Density (people per sq. km)	mmW index	AQI	Latitude	Cases per Million	Deaths per Million	% Deaths per Case
with 5G mmW		max	10,105,518	7,245	1.20	71	37.8	5,309	231	5.16%
with 5G mmW	**6**	**mean**	**3,117,676**	**1,653**	**0.61**	**48**	**36.2**	**2,750**	**102**	**3.75%**
with 5G mmW		min	769,545	262	0.22	35	32.8	1,409	46	1.62%
without 5G mmW		max	3,185,968	1,352	0	80	38.6	3,055	138	4.53%
without 5G mmW	**11**	**mean**	**1,367,642**	**400**	**0**	**54**	**36.2**	**1,679**	**52**	**3.01%**
without 5G mmW		min	499,942	38	0	34	33.9	909	8	0.73%
p-value of t-test, with vs. without 5G mmW			0.144	0.159	0.007 **	0.236	0.498	0.060	0.064	0.131
Ratio of means, with vs. without 5G mmW			2.28	4.13	N/A	0.89	1.00	1.64	1.98	1.25
Pearson's Correlation to Pop. Density								0.250	-0.046	-0.292
Pearson's Correlation to PopDensity*mmW								0.294	-0.006	-0.296
Pearson's Correlation to mmW								0.705	0.591	0.157
Pearson's Correlation to Air Quality Index								0.512	0.557	0.305
Pearson's Correlation to Latitude								-0.470	-0.481	-0.210

3.5.1 Correlations of Case and Death Rates with Population Density

Population density is strongly correlated with the rates of cases/million, cases/test and deaths/million, and deaths/test in the 50 states (r =0.60 to 0.79 for April through May) (Table 4). Population density is an indicator of person to person contact as well as the amount of wireless radiation exposure. For example, in New York City, many reside in multi-level apartment buildings where they are exposed to many Wi-Fi routers and other wireless devices from closeby neighbors. In addition, Wi-Fi routers from certain providers have public Wi-Fi hot spots that provide service to other customers. These hot spots give off enough radiation to wirelessly connect anyone within a 100 meter radius [13]. Those living in an apartment complex in the middle of a large urban city are likely to be exposed to more Wi-Fi hotspots than those living in single family homes in the suburbs. So even though population density is a major factor in transmission, higher population density also inherently means higher wireless radiation exposure from neighbors (Table 4 for state data and Table 5 for county data).

At the county level, population density was also found to be strongly correlated with the case and death rates. Pearson's correlations between cases/million and population density was 0.594, between deaths/million and population density was 0.699, and between deaths/cases and population density was moderate, at 0.43 (Table 5). These correlations for population density are comparable to those reported in other studies. A study [14] found a Pearson's correlation of ~0.6 for public transit to COVID-19 cases per million, and a ~0.5 correlation for population density to COVID-19 cases per million. A Brazilian study reported a negative correlation between COVID-19 cases and temperature (r = -0.38) and a positive relationship between COVID-19 cases and population density (r = 0.51) [15].

3.5.2 Correlations of Case and Death Rates with Millimeter Wave Exposure

The mmW index is moderately to strongly correlated with cases per million, cases per test, deaths per million, and deaths per test for the 50 states. For cumulative data through April 22, 2020, the Pearson's correlations with the mmW index for the cases/million (r = 0.479) and deaths/million (r = 0.580) were the highest of the correlations from the data from April and May. From April to May, the same correlations trended downward slightly, but multiple linear regression with cumulative data through May 31, 2020 determined that mmW index was a statistically significant factor in the case and death rates, which is discussed later. The correlation between population density and mmW index is very low at 0.072, meaning that population density and mmW index are not correlated to each other, and that a high mmW index area is not necessarily a high density area. This is important, because it means that the higher rates of cases and deaths in mmW states are not solely because of the higher population density that may be present in those states.

At the county level, mmW exposure was also found to be strongly correlated with the case and death rates. Pearson's correlation for the mmW index and for cases/million was 0.615, for deaths/million it was 0.709, and for deaths/cases it was a moderate 0.371 (Table 5).

For California counties, there were strong correlations between the mmW exposure index and cases per million (r = 0.705) and deaths per million (r = 0.591), There were strong correlations also for the air quality index (AQI) and the cases (r = 0.512) and deaths (r = 0.557) per million (Table 6). However, population density and latitude were not well correlated with the cases and deaths per million for California counties.

3.5.3 Synergy between Population Density with mmW Exposure

There was a positive interaction between population density and the mmW index acting together that was greater than the effect of population density or mmW acting singularly on the deaths per million in the cumulative data through April 22. This is because the interaction of population density with mmW index (PopDensity*mmW) had a higher correlation (0.783) to deaths/million (Table 4A) than either the correlation of population density (0.577) or mmW index (0.580) alone did with deaths/million, meaning that the combined action of population density with mmW index had a stronger effect on deaths/million than either population density or mmW index did singularly.

3.5.4 Correlations of Case and Death Rates with Latitude and Vitamin D

Latitude is an indicator of potential sun exposure and vitamin D production. As latitude increases, the intensity of the radiation from the sun decreases, which reduces endogenous vitamin D production. Higher latitudes have been found to be partially associated with increased COVID-19 mortality rates [16]. Low vitamin D levels have been found to be a risk factor for the COVID-19 complications, which will be discussed later. Latitude was found to have a weak correlation with the case and death rates (0.199 to 0.268 in Table 5), however, based on regression analysis, which will be discussed later, latitude was a statistically significant factor in the case and death rates.

3.5.5 Correlations of Case and Death Rates with Air Quality Index (AQI)

AQI was found to have very little to weak correlation with the case and death rates in the state and county analysis for the U.S. For the states, the correlations ranged from 0.047 to 0.319 (Tables 4A–C), and at the county level, the correlations ranged from -0.212 to -0.072 (Table 5). For California counties, air quality was strongly correlated with the cases per million and deaths per million ($r = 0.512$ and $r = 0.557$ respectively, Table 6), and air quality was a statistically significant factor for the cases per million and deaths per million ($p = 0.0016$ and $p = 0.0031$ respectively, Table 7)

Air quality does have an impact on respiratory diseases. AQI ranges from 0-500, and air is considered unhealthy above 100, very unhealthy from 201-300, and hazardous at 301-500. The average AQI data for all states was between 21.2 to 51.2, indicating relatively clean air, which may be why AQI did not show up as a significant factor at the state level. Furthermore, the AQI used was a yearly average and not live data, and during the lockdowns emissions from cars and industry were significantly reduced, which likely made the actual air quality that people were exposed to better than the AQI data used.

3.6 Multi-Variate Analysis shows Population Density, Latitude, mmW Index are Statistically Significant Factors in the Case and Death Rates

According to multiple linear regression, at the state level, population density and mmW index were statistically significant contributors to the rates of cases and deaths; urbanization was found to not be a statistically significant factor compared to population density and mmW index. At the county level, population density, mmW index, and latitude were statistically significant contributors to the rates of cases and deaths. For California counties, only the AQI and mmW index were statistically significant contributors ($p<0.01$) to the case and death rates.

For case and death rates, the p-values for population density were between 1.02E-13 to 0.0064 for mmW states and counties; the p-values for mmW index were between 5.00E-06 to 0.026 for mmW states, counties, and California counties; the p-values for latitude were 0.014 and 0.045 for mmW counties; the p-values for AQI were 0.0016 and 0.0031 for California counties (Table 7). All regression equations and the p-values for density, mmW index, AQI, latitude are given in Table 7.

Multi-variate analysis using multiple linear regression showed the higher mean population density in the mmW states and counties is not the main reason for their higher case and death rates, that mmW index has at least as great an impact as the higher density. At the state level, the contribution of the mmW index is about the same as that from the higher density, but at the county level, the contribution from mmW index is at least three times higher than that from density (Table 8).

The regression equation for state cases/million (Table 7) is: Cases/million = 1418 + 32.54 state density + 7100 mmW index, with an adjusted R^2 of 0.732 , which means that 73.2% of the variation in cases/million is explained by the state population density and the mmW index, and the adjusted R^2 measures how close the data are to the fitted regression line. Both the state population density and the mmW index are statistically significant contributors to the cases/million ($p < 0.01$ for both, Table 7), and the regression equation is statistically significant with p-value = 1.35E-14, which is much less than $p < 0.01$ (Table 7). The increase in state population density between average mmW state and average non-mmW state is 91.7-50.2 = 41.5 (Table 3). So, the contribution to the mean case/million for mmW states from its higher average population density = 32.54*41.5 = 1350 (Table 8). The increase in mmW index between average mmW state and average non-mmW state is = 0.207 – 0 = 0.207 (Table 3). So, the contribution to the mean cases/million for mmW states from its mmW exposure index = 7100 * 0.207 = 1470 (Table 8). Therefore, the contribution to the mean cases/million for mmW states from mmW exposure is almost the same, but slightly higher than it is from the higher population density (1470 vs. 1350 out of the 5776 actual cases/million (Table 8). Thus, the higher mean cases/million for the mmW states is due to the higher average population density AND the mmW exposure of those states, with the contribution from each being about the same.

The regression equations also predict what the case and death rates would be if there was no mmW exposure. For example, the mean cases/million of the mmW states is 5776 cases/million; however, if there was no mmW in these states, the same regression equation predicts that the mean cases/million would be 24% lower, at 4403 cases/million (Table 8).

For all of the case and death rates for states, counties, and California, the contributions from the higher population density and from the mmW exposure of the mmW states and counties are given in Table 8, as well as what the predicted case and death rates would be if there was no mmW exposure.

Table 7. Regression Equations for data cumulative through May 31, 2020. Statistical significance is indicated by * ($p < 0.05$) and ** ($p < 0.01$).

	Regression R^2 adj	p-value for Regression (Sig. F)	p-value for Pop. Density	p-value for mmW index	p-value for latitude	p-value for AQI
States:		**	**	**		
Case/Million = 1418 + 32.54 State Density + 7100 mmW index	0.732	1.35E-14	1.0E-13	3E-05	not sig.	not sig.
Death/Million = 12.2 + 2.46 State Density + 577 mmW index	0.713	6.83E-14	7.2E-13	3E-05	not sig.	not sig.
		**	**	*		
Case/Test = 0.0534 + 0.000299 State Density + 0.0606 mmW index	0.427	7.89E-07	1.2E-06	2.6E-02	not sig.	not sig.
Death/Test = 0.00144 + 2.68E-05 State Density + 0.00480 mmW index	0.525	9.73E-09	1.3E-08	1.6E-02	not sig.	not sig.
Counties in US:		**	**	**	*	
Case/Million = -5080 + 0.576 Density + 218 Latitude + 3770 mmW index	0.448	2.80E-13	6.4E-03	2.5E-04	1.4E-02	not sig.
Death/Million = -435 + 0.0652 Density + 13.4 Latitude + 361 mmW index	0.587	2.10E-19	6.4E-05	5.0E-06	4.5E-02	not sig.
Counties in CA:		**		**		**
Case/Million = -268+ 36.6 AQI + 2012 mmW index	0.725	4.71E-05	not sig.	9.9E-05	not sig.	1.6E-03
Death/Million = -49.7 + 1.96 AQI + 83.1 mmW index	0.610	5.37E-04	not sig.	2.0E-03	not sig.	3.1E-03

Table 8. Predicted Values and Contributions from mmW index and higher mean density for mmW state or county for data cumulative through May 31, 2020.

	Actual Value	Predicted by Regression if no mmW	Predicted Change if no mmW	Predicted Contribution from mmW	Predicted Contribution from Higher Mean Density of mmW state or county	Ratio of Contribution mmW:Higher Mean Density of mmW state or county
mmW States:						
Mean Case/Million	5776	4403	-23.8%	1470	1350	1.09
Mean Death/Million	307	214	-30.4%	119	102	1.17
Mean Case/Test	9.88%	8.09%	-18.1%	1.25%	1.24%	1.01
Mean Death/Test	0.494%	0.390%	-21.1%	0.099%	0.111%	0.89
mmW Counties in US:						
Mean Case/Million	7100	4320	-39.2%	3260	918	3.55
Mean Death/Million	446	204	-54.3%	312	104	3.00
mmW Counties in CA:						
Mean Case/Million	2750	1487	-45.9%	1227	N/A	N/A
Mean Death/Million	102	44.4	-56.5%	50.7	N/A	N/A

Figure 6 shows that the mmW exposure factor is better correlated than the population density with the case and death rates, and this is also seen in the higher R^2 for the mmW exposure factor. For the cases/million, the R^2 was 0.501 for the mmW exposure as a predictor compared to the R^2 of 0.363 for population density, and for the deaths/million, the R^2 was 0.632 for the mmW exposure as a predictor compared to the R^2 of 0.526 for population density.

These R^2 for COVID-19 case and death rate regressions as a function of mmW exposure, population density, and latitude are better than those found by others. In New York a positive correlation between COVID-19 cases per million and population density was $R^2 = 0.17$, $p < 0.01$, and between cases per million and public transportation commute ratios, $R^2 = 0.25$, $p < 0.01$ [17].

4. Discussion

The world changed in March 2020 after the WHO classified COVID-19 as a pandemic and as countries closed their borders and initiated social distancing. Admittance to hospital intensive care units (ICU) reached an all-time high in some places and elderly patients were moved to nursing homes, where residents and staff quickly developed fatal symptoms of COVID-19.

Ventilators, commonly used for respiratory ailments, were not as effective as expected and doctors around the world were sharing their concerns about treatment protocols that were not working. Atypical cardiovascular complications were also being reported, including blood clots, hypoxia, arrhythmia, lower hemoglobin levels and strokes even in younger patients [18-19].

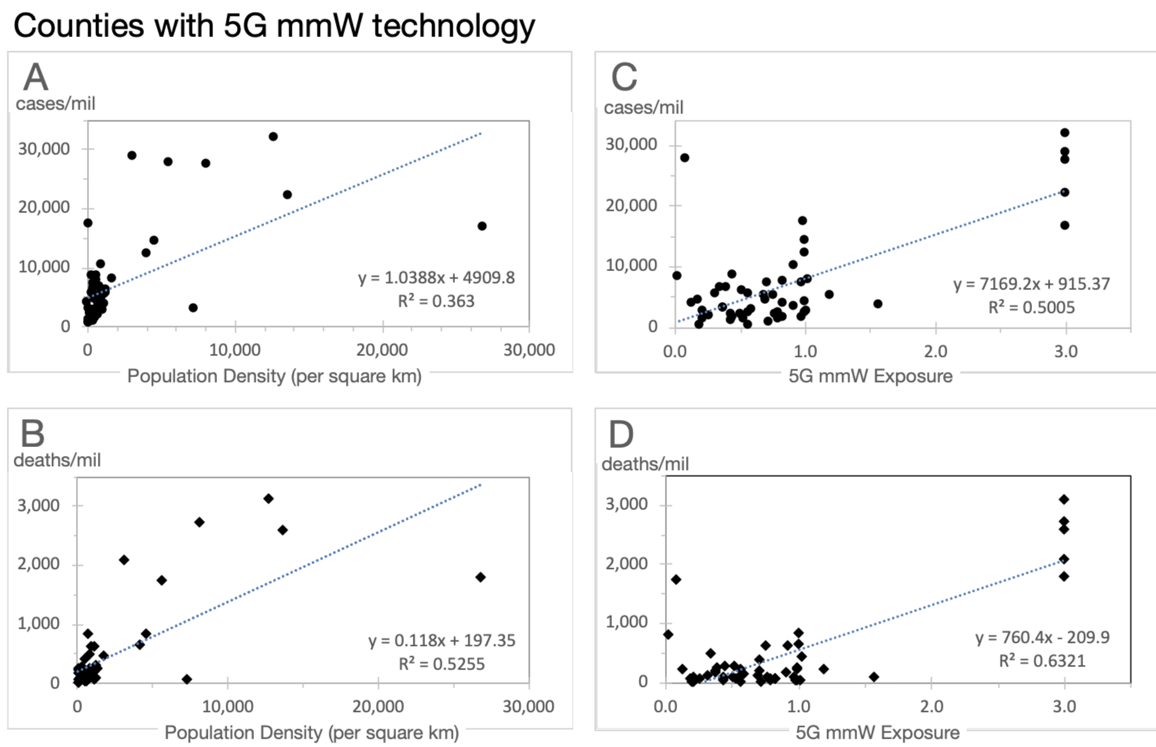

Figure 6. Regression plot for 53 counties with 5G mmW technology for COVID-19 attributed cases/million and deaths/million as a function of population density (A & B) and as a function of 5G mmW exposure (C & D) through May 31, 2020.

COVID-19 was clearly different than previous viral respiratory illnesses, and one theory was proffered that COVID-19 may be associated with the rollout of 5G mmW technology, which had occurred just prior to the first cases of COVID-19 in China [20].

Our results show a statistically significant increase between the COVID-19 attributed cases and deaths in states and counties in the U.S. with vs. without 5G mmW technology. States with 5G mmW technology had excess cases and excess deaths per million when compared to states without this technology, which was the case for three different dates: April 22, May 15 and May 30. When we examined U.S. counties, to determine how robust this relationship was, we got the same trend.

Multiple linear regression and Pearson's correlation coefficients have shown that the mmW index was statistically significant to the case and death rates in the analyses for states, counties, and California counties, i.e., in all three analyses, while population density was statistically significant for two of the analyses, and air quality index and latitude were statistically significant for only one of the analyses.

4.1 COVID-19 Anomalies and Wireless Radiation

There are some unique anomalies in COVID-19 that distinguish it from other viral infections. These anomalies are multiple blood clots that form in organs and blood vessels, severe inflammation, hypoxia and hypoxemia, and skin lesions even in those who test negative for SARS-CoV-2 (suggesting that their symptoms may be due to something other than SARS-CoV-2), and symptoms lingering for months after initial onset of the infection that resemble microwave sickness symptoms. The interesting thing about these anomalies are that RF exposure can exacerbate all of them.

Some COVID-19 patients report they have been sick for many months, despite testing negative for the SARS-CoV-2 virus, with numerous symptoms of microwave sickness. Microwave sickness, which the World Health Organization refers to as idiopathic environmental intolerance attributable to electromagnetic fields (IEI-EMF), is the medical term for the syndrome of symptoms that result from chronic exposure to non-ionizing radiation. It is also referred to as electromagnetic sensitivity per the Americans with Disabilities Act (ADA) or electrohypersensitivity (EHS) in some scientific studies. However, electromagnetic illness (EMI) is perhaps a more appropriate term since RFR exposure has the potential to affect all humans and not only those who are highly sensitive to this radiation. Most of the symptoms that these long COVID-19 patients have in common with microwave sickness are headaches, fatigue, difficulty concentrating, memory problems, insomnia, cardiovascular abnormalities like palpitations and tachycardia, tinnitus, anxiety, depression, and skin lesions according to a COVID-19 Survey Report by Indiana University School of Medicine [21]. At least 24 of the long COVID symptoms reported in the survey are also symptoms of microwave sickness, aka EHS [22] (Figure 7).

Wireless radiation is a toxic substance that degrades the immune system, and *"[e]xposure to myriad toxic substances degrades the immune system, whose dysfunction is then exploited by SARS-CoV-2 to result in COVID-19,"* [23]. A recent Russian study found a strong correlation between a country's exposure limits for RF radiation and COVID-19 deaths per million (r=0.577) and deaths per cases (r=0.551) [24].

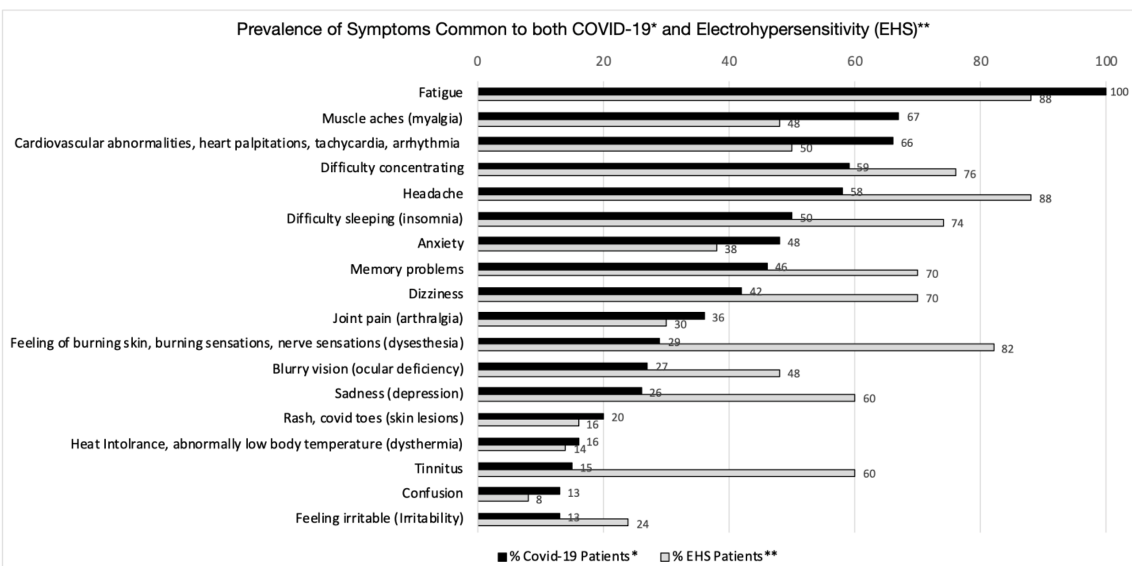

Figure 7. Prevalence of symptoms common to both COVID-19 and Electrohypersensitivity (EHS). Sources: *[21], **[22]

4.2 Common Mechanisms of Harm and Synergistic Effects between RF Radiation and COVID-19.

Radio frequency radiation (RFR) shares some mechanisms of harm with SARS-CoV-2 which could act synergistically with SARS-CoV-2 to promote and prolong infection. As explained below: (1) RFR impairs the immune system which would contribute to a greater number of people becoming infected and dying from disease [25-28]; (2) RFR is known to increase free-radicals and contribute to oxidative stress, leading to increased inflammation [29-33]; (3) RFR affects the blood, heart, and autonomic nervous system resulting in some combination of hypoxia, tachycardia, arrhythmia, rouleaux formation, and sympathetic up-regulation [34-36]; (4) RFR interferes with the body's repair mechanisms [37-39]; and (5) a growing population (between 1% – 10%) in developed countries is unable to tolerate current levels of RFR [40-41], developing symptoms of microwave sickness that are similar to those reported for long COVID-19 (Figure 7).

Microwave sickness is triggered by our increasing exposure to RFR emitted by mobile and cordless phones, cell phone base stations, radar, broadcast antennas, Wi-Fi, Bluetooth, smart meters, smart appliances, smart homes, smart light bulbs, wireless security systems, wireless personal assistants, wireless baby monitors, and wireless wearables, and now an increasing number of people are also exposed to 5G mmW.

Higher radiation exposures result from the shorter distance to people and higher density of antennas for 5G mmW. This is acknowledged by the FCC proposal in December 2019 to increase the current exposure limits four-fold to accommodate 5G mmW devices and infrastructure. The current exposure limit for the general population of 1000 μW/cm^2 averaged over a 30-minute period has been the guideline since 1996 per FCC 47 CFR Ch. I § 1.1310 and the FCC has proposed to increase that to 4000 μW/cm^2 indefinitely in its 2019 FCC Notice of Proposed Rulemaking 19-126 [9].

5G mmW have not been tested for their long-term biological effects and there is growing concern from the scientific and medical communities that this technology could have adverse biological consequences. Studies suggest that mmW can contribute to ocular damage, arrhythmias, antibiotic resistance among bacteria, teratogenic effects in drosophila, and impaired immunity in mice [42]. Even though mmW are absorbed mostly in the skin, systemic signaling in the skin from mmW can result in physiological effects on the nervous, cardiovascular and immune systems mediated through neuroendocrine mechanisms [42]. A compendium of 3800 studies showing a myriad of harmful biological effects from RFR at non-thermal levels (and below FCC's exposure limits) are contained in the 2012 BioInitiative Report [43].

4.3 Wireless Radiation affects the Immune System, increases Oxidative Stress and Inflammation

There is a common presumption that mmW are safer than the lower frequencies used in 4G and previous generations of wireless communications because mmW are mostly absorbed in the skin. However, biological responses to mmW irradiation can be initiated within the skin, and the subsequent systemic signaling in the skin can result in physiological effects on the nervous system, heart, and immune system [44]. The cities with 5G mmW would have the most varied and highest potential RF exposure levels because 5G mmW requires the use of multiple small cells in close proximity to users and all three bands of frequencies for 5G, in addition to radiation from previous generations of wireless communications..

Additionally, severe inflammation has been reported in COVID-19 cases, and oxidative stress is a cause of inflammation [45]. There are many studies showing that wireless radiation causes oxidative stress and generates free radicals [29-33, 46-48]. A review by an expert committee appointed by the Swiss government found that RF-EMF increased oxidative stress which can lead to changes in oxidative balance, and that those with pre-existing conditions (immune deficiencies or diseases such as diabetes and neurodegenerative diseases) that compromise the body's defense mechanisms (including antioxidative protection) can experience more severe health effects from EMF exposure; also, young and elderly individuals can react less efficiently to oxidative stress induced by EMF [49]. So chronic RF exposure creates oxidative stress and oxidative stress leads to inflammation. RF exposure has also been shown to directly increase inflammation by the production of pro-inflammatory cytokines that cause the immune system to overreact [50].

There are many studies showing the effect of wireless radiation on the immune system [27, 43]. A 2013 review found that wireless radiation has a stimulating effect on the immune system initially with short-term exposure, and an immunosuppressive effect with chronic exposure [26]. Cell phone radiation exposure for 1 hour per day for 30 days compromised the immune system of rats, resulting in a significant decrease in immunoglobulin levels, total leukocyte, lymphocyte, eosinophil and basophil counts; and a significant increase in neutrophil and monocyte counts [51]. Shielding from EMFs was found to significantly improve immune function and decrease inflammation in humans; lymphocyte NK (natural killer) cell activity increased by 30% after EMF exposure was reduced for two months [52]. In 2015, a significant discovery was made that the brain was directly connected to the immune system by lymphatic vessels [53], which would mean that the immune system can be affected directly by the brain and environmental influences that affect the brain, such as wireless radiation. A U.S. government study under the National Institute of Health found that cell phone radiation can affect the brain by increasing glucose metabolism in the brain [54] .

4.4 Wireless affects Vitamin D and Vitamin D Receptor

Vitamin D is essential to the proper functioning of the immune system. Low vitamin D levels have been associated with the most severe symptoms of COVID-19. Patients with low vitamin D are twice as likely to experience major complications from COVID-19 [55]. Another study found that 85% of severe COVID-19 patients had vitamin D insufficiency, and that 100% of ICU patients less than 75 years old had vitamin D insufficiency [56]. The case fatality rate of COVID-19 was highest in European countries with the highest incidence of severe vitamin D deficiency, and supplementation with vitamin D may reduce COVID-19 mortality [16].

Vitamin D deficiency can result from inflammation caused by chronic wireless radiation exposure [40]. Vitamin D supplementation was also found to reverse the negative effects of cell phone radiation on the immune system of rats [41]. Wireless radiation also lowers vitamin D receptor (VDR) activity by changing the shape of the VDR, thus impairing VDR activity and its ability to bind with vitamin D [28]. This is important because when a T-lymphocyte is exposed to a foreign pathogen, it extends a VDR to search for vitamin D, and if there is insufficient vitamin D, T-lymphocytes will not activate to destroy the invading pathogens [57].

4.5 Wireless Radiation depletes Glutathione which reduces Vitamin D and promotes Infection

There's evidence that low endogenous glutathione production has led to complications in COVID-19 and that low glutathione levels reduce vitamin D levels [58]. Vitamin D was also found to correlate positively with glutathione levels in type II diabetic patients [59], who have an increased risk for COVID-19 complications. Glutathione treatment of patients with COVID-19 pneumonia successfully prevented the cytokine storm in COVID-19 patients [60]. Several studies have shown reduced glutathione production from wireless radiation exposure. Glutathione was found to be at statistically significant lower levels in those living close to a cell tower (within 80 m) exposed to 100 times higher RF radiation compared to those living far from a cell tower (300 m or more) [37]. Another study found that radar workers in the military who had been working with radar for over 10 years had less than 50% of glutathione levels of non-radar workers, and this lower level was statistically significant [30].

4.6 Wireless Radiation lowers Oxygen Intake and damages Mitochondria

RF exposure also affects the structure of hemoglobin, reducing its ability to bind to oxygen. After just two hours of exposure to cell phone radiation, human hemoglobin structure changed, decreasing its affinity to bind to oxygen in the lungs between 11-12% [34] which reduces the amount of oxygen that would be carried from the lungs to the body's tissues, contributing to hypoxia. This is important because SARS CoV-2's ability to infect cells is enhanced when blood oxygen levels decline. The "furin cleavage" sequence in the virus activates increased ACE2 receptor attack and cellular invasion in low oxygen environments [61].

RF radiation also affects the electron transport chain in mitochondria. Mitochondria supply the energy in cells and consume the majority of oxygen in the cell. RF exposure leads to mitochondrial dysfunction, leading to lowered oxygen consumption in the cell and less energy production, which would cause fatigue. Wireless sources of EMF causing extensive electron leakage from the mitochondrial electron transport chain was attributed as the main cause of EMF damage in human reproductive cells, and wireless EMF exposure increased production of reactive oxygen species (ROS) by mitochondria [32].

4.7 Wireless Radiation promotes Blood Clotting

Vitamin D also has an anticoagulant effect, and low vitamin D levels have been shown to increase the chance of venous blood clots [62].

Formation of blood clots leading to strokes and other complications have been reported in COVID-19 cases in the young and middle-aged with no risk factors for clotting. In children, a condition associated with COVID-19 known as Multisystem Inflammatory Syndrome in Children (MIS-C) with symptoms including "COVID Toes" involves inflammation of the blood vessels and the formation of blood clots.

RF exposure can cause red blood cells to clump and stick together, known as rouleaux formation [35-36] (Figure 8). As early as 1978, effects of mmW on blood were found to cause a “tendency toward hypercoagulation” at an exposure of 1000 $\mu W/cm^2$ or less [63]; 1000 $\mu W/cm^2$ for 30 minutes is the current exposure limit for mmW for the public in the U.S.

Electromagnetic fields were found to increase the risk for blood clot formation [64]. Other studies have also shown changes in blood viscosity and rouleaux formation with frequencies of 2 kHz [65]. Frequencies in the 0-3 kHz range are found in wireless communications in the form of pulsation and modulation, and there is significant evidence that the biological effects from wireless communications is because of these electric fields; in addition, the application of pulsed electromagnetic fields (PEMF) for short periods of time have therapeutic effects [44] such as the stimulation of bone growth [66]. The right modulation in pulsating electrostatic field therapy can reduce rouleaux formation [67]. Electromagnetic fields have been used for over a hundred years therapeutically, and PEMF devices, approved by the FDA, have been used in animals and humans to reduce inflammation, increase circulation and reduce pain [68]. The fact that RF radiation at non-thermal levels is used in medical therapy means that there are biological effects of RF radiation at non-thermal levels. In addition, mmW are used in medical therapy, including cancer therapy. At power density levels far exceeding the FCC permissible levels for wireless communications of 1000 $\mu W/cm^2$, mmW have been used to stimulate immune cell activity suppressed by anti-cancer drugs [69-70]. Chronic RF radiation exposure within the FCC permissible levels disturbs immune function through stimulation of various allergic and inflammatory responses; for example, RFR increases mast cells in the skin, morphologically alters immune cells, and interferes with tissue repair processes [25]. Anti-inflammatory effects of mmW, achieved only with specific modulation frequencies for certain mmW carrier frequencies, have been used therapeutically also; but without the correct modulation frequency, certain carrier mmW frequencies were “ineffective” [71]. Therefore, it is not just the mmW carrier frequency, but also its combination with pulsation and modulation frequencies that determine biological effects. Medical therapy using RF and mmW radiation is achieved only under controlled conditions, with specific carrier and pulsation and modulation frequencies at specific power densities over a specific and relatively short period of time. The RF radiation that we are exposed to from wireless communications is constant and random, with varying power densities, layered with many frequencies from different sources that use pulsation and modulation frequencies needed to enable wireless communications without consideration of biological effects. Consequently, medical mmW and telecommunication mmW have very different biological impacts due to different exposure parameters.

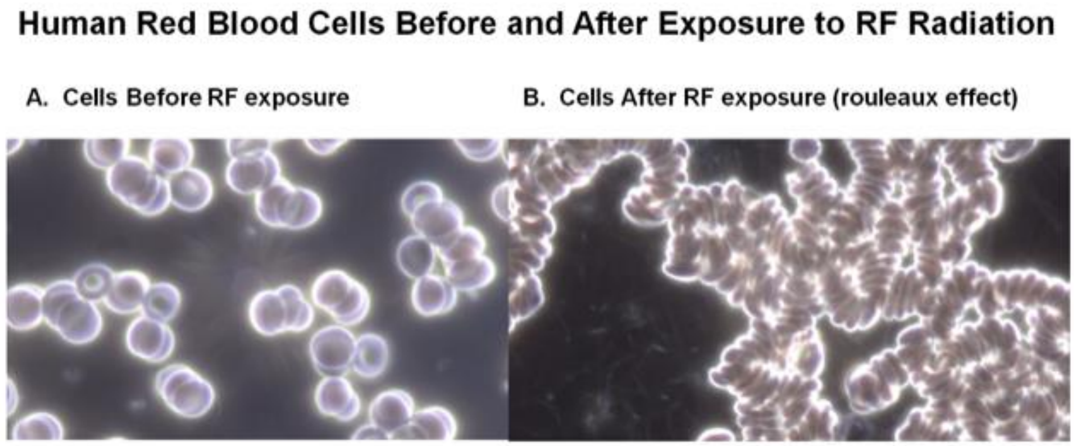

Figure 8. In A., red blood cells are not aggregated prior to RF radiation exposure. In B., blood cells from the same patient after 10 minutes of exposure to 2.45 GHz Wi-Fi aggregate and exhibit rouleaux effect.

4.8 Both Wireless Radiation and SARS-CoV-2 interfere with Calcium Channels in the Cell Membrane

Cell membranes are considered the major target for the interaction between mmW and biological systems, and the waves may alter structural and functional properties of membranes [72]. The cell membrane becomes more permeable from RF exposure from cell phones due to changes in the phospholipid composition at exposure levels well under the current FCC exposure limit. This increased cell membrane permeability altered the expression of 178 genes significantly ($p < 0.05$), affecting processes such as DNA replication and repair, cell signalling and calcium signalling, nervous system function, immune system response, lipid metabolism, and carcinogenesis [38]. Voltage gated calcium channels (VGCC's) located in cell membranes control intracellular calcium ion (Ca^{2+}) concentrations, and exposure to electromagnetic fields has been shown to increase intracellular Ca^{2+} concentration in human lymphocyte cells between approximately 25–50%, and this higher intracellular Ca^{2+} concentration in human lymphocyte cells increases allergic reactions [73]. Increasing intracellular Ca^{2+} concentrations have a myriad of health effects, from headaches to cancer in humans [66].

A related virus, porcine deltacoronavirus, attacks host cells by opening their voltage gated calcium channels (VGCCs) in the cell membrane, which increases the calcium ion (Ca^{2+}) concentration inside host cells which increases virus replication. Reducing the intracellular calcium by blocking VGCC's reduced the infection [74]. Anti-viral medications work by inhibiting VGCC activation to reduce intracellular Ca^{2+} to inhibit the viral replication [75].

4.9 Both Wireless Radiation and SARS-CoV-2 interfere with Cell Signalling via p38/MAPK and mTOR Pathways

SARS-CoV-2 takes over a human host cell by interfering with phosphorylation cell signalling and altering the phosphorylation of 40 human proteins and 49 kinase enzymes, involving the p38/MAPK and mTOR pathways among others. This takeover of the human host cells by the virus prevents the host cell from replicating and provides a stable environment for viral replication [76]. Signals from wireless communications have also been found to interfere with cell signalling and phosphorylation in the p38/MAPK and mTOR pathways, which were associated with an increased permeability in cell membranes due to changes in its phospholipid composition following exposure to radiofrequency radiation [38]. There have been many studies on the interaction of EMFs with cell signalling systems; interference with cell signalling and phosphorylation was reported in an earlier study that found that pulsed EMFs rapidly activates the mTOR signalling pathway [77].

For all the above reasons, environmental exposure to 5G mmW can increase cases and severity of COVID-19.

5. Conclusion

While 5G did not cause COVID-19, statistical analysis showed that exposure to 5G mmW (which is present in combination with 1G-4G and other RFR sources like Wi-Fi) is a statistically significant factor associated with higher COVID-19 case and death rates in the U.S. The higher population densities in the 5G mmW states or counties is another statistically significant factor but it does not entirely account for the higher case and death rates in those states and counties. Population density is an indicator not only of person to person contact, but also of wireless radiation exposure from neighbours. Latitude was also found to be a statistically significant factor that increases case and death rates for 5G mmW counties. Air quality was not found to be a statistically significant factor in the case and death rates except for California counties.

The higher case and death rates in the average mmW state or county compared to that of the average non-mmW state or county were statistically significant for multiple dates (April 22, May 15, May 31 2020) and for a variety of measurements (deaths/million, deaths/test, cases/million, cases/test).

Multiple linear regression found that at the state level, the mmW and the higher population density contributed almost equally to the increased case and death rates in the mmW states. Regression equations predicted that if the mmW states did not have mmW, the average cases per million for the mmW states would be reduced by 24%, and the deaths per million would be reduced by 30%.

At the county level, the mmW exposure contributed three times as much as the higher population density to the increased case and death rates in the mmW counties. Regression equations predicted that if the mmW counties did not have mmW exposure, the cases per million for the mmW counties would be reduced by 39%, and the deaths per million would be reduced by 54%.

For California counties, mmW and AQI were statistically significant contributors to the case and death rates while population density was not. Regression equations predicted that if the mmW counties did not have mmW, the cases per million would be reduced by 46%, and the deaths per million would be reduced by 57%.

It is not difficult to see how radiofrequency radiation could increase the case and death rates when wireless radiation and SARS-CoV-2 share common mechanisms of harm to human and animal cells and wireless radiation exposure produces conditions that enhance susceptibility to SARS-CoV-2. Both interfere with cell signalling via the phosphorylation pathways, increase intracellular calcium ion concentrations by activating VGCC's, and interfere with the actions of cell membranes. Radiofrequency radiation negatively impacts the immune system, reduces oxygen availability to blood cells and tissues, increases oxidative stress and inflammation, and reduces glutathione levels and vitamin D availability, all of which assist viral infection.

In this analysis, we compared 5G mmW areas with those that have RFR but do not yet have activated mmW technology. This is like comparing smokers to those exposed to second-hand smoke. Consequently, the difference between COVID-19 attributed case and death rates may be much higher had we compared areas with 5G mmW technology to areas with little or no RFR exposure, which is nearly impossible to do as few of these areas remain in the U.S.

The rollout of mmW 5G has been done without any testing to assess its safety, either singly or in combination with RF frequencies already present, such as 1G-4G and Wi-Fi. In fact, no long-term safety testing was done on any wireless technology before they were introduced to the market. Government presumption of safety on all wireless technology is that harmful effects can only happen at thermal levels and that effects at non-thermal levels do not exist, i.e. so as long as wireless devices and infrastructure do not emit enough energy to heat tissues, then there is nothing to be concerned about. However, thousands of studies have shown harmful biological effects at non-thermal levels, and medical devices using non-thermal levels of radiofrequency radiation have been used therapeutically for decades, which is concrete evidence of beneficial and adverse biological effects at non-thermal levels of non-ionizing radiation. Currently, mmW have been deployed for 5G in approximately 50 U.S. cities, but when 5G is fully rolled out, mmW will be everywhere. More than 400 scientists and doctors have signed the 5G Appeal [78] requesting a moratorium on the 5G rollout. Any economic benefits from 5G are likely to be outweighed by the risk of harm to the health of billions of people around the world.

Acknowledgments
We thank the anonymous reviewers and those dedicated scientists and doctors who have published their findings regarding either COVID-19 or RFR

Funding
No funding received for this research.

Competing Interests
None

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Journal of Clinical and Translational Research 2021; 7(5): 666-681

Journal of Clinical and Translational Research

Journal homepage: http://www.jctres.com/en/home

REVIEW ARTICLE

Evidence for a connection between coronavirus disease-19 and exposure to radiofrequency radiation from wireless communications including 5G

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ARTICLE INFO

Article history:
Received: March 10, 2021
Revised: June 11, 2021
Accepted: August 25, 2021
Published online: September 29, 2021

Keywords:
COVID-19
coronavirus
coronavirus disease-19
severe acute respiratory syndrome coronavirus 2
electromagnetic stress
electromagnetic fields
environmental factor
microwave
millimeter wave
pandemic
public health
radio frequency
radiofrequency
wireless

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ABSTRACT

Background and Aim: Coronavirus disease (COVID-19) public health policy has focused on the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus and its effects on human health while environmental factors have been largely ignored. In considering the epidemiological triad (agent-host-environment) applicable to all disease, we investigated a possible environmental factor in the COVID-19 pandemic: ambient radiofrequency radiation from wireless communication systems including microwaves and millimeter waves. SARS-CoV-2, the virus that caused the COVID-19 pandemic, surfaced in Wuhan, China shortly after the implementation of city-wide (fifth generation [5G] of wireless communications radiation [WCR]), and rapidly spread globally, initially demonstrating a statistical correlation to international communities with recently established 5G networks. In this study, we examined the peer-reviewed scientific literature on the detrimental bioeffects of WCR and identified several mechanisms by which WCR may have contributed to the COVID-19 pandemic as a toxic environmental cofactor. By crossing boundaries between the disciplines of biophysics and pathophysiology, we present evidence that WCR may: (1) cause morphologic changes in erythrocytes including echinocyte and rouleaux formation that can contribute to hypercoagulation; (2) impair microcirculation and reduce erythrocyte and hemoglobin levels exacerbating hypoxia; (3) amplify immune system dysfunction, including immunosuppression, autoimmunity, and hyperinflammation; (4) increase cellular oxidative stress and the production of free radicals resulting in vascular injury and organ damage; (5) increase intracellular Ca^{2+} essential for viral entry, replication, and release, in addition to promoting pro-inflammatory pathways; and (6) worsen heart arrhythmias and cardiac disorders.

Relevance for Patients: In short, WCR has become a ubiquitous environmental stressor that we propose may have contributed to adverse health outcomes of patients infected with SARS-CoV-2 and increased the severity of the COVID-19 pandemic. Therefore, we recommend that all people, particularly those suffering from SARS-CoV-2 infection, reduce their exposure to WCR as much as reasonably achievable until further research better clarifies the systemic health effects associated with chronic WCR exposure.

1. Introduction

1.1. Background

Coronavirus disease 2019 (COVID-19) has been the focus of international public health policy since 2020. Despite unprecedented public health protocols to quell the pandemic, the number of COVID-19 cases continues to rise. We propose a reassessment of our public health strategies.

DOI: http://dx.doi.org/10.18053/jctres.07.202105.007

According to the Center for Disease Control and Prevention (CDC), the simplest model of disease causation is the epidemiological triad consisting of three interactive factors: the agent (pathogen), the environment, and the health status of the host [1]. Extensive research is being done on the agent, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Risk factors that make a host more likely to succumb to the disease have been elucidated. However, environmental factors have not been sufficiently explored. In this paper, we investigated the role of wireless communication radiation (WCR), a widespread environmental stressor.

We explore the scientific evidence suggesting a possible relationship between COVID-19 and radiofrequency radiation related to wireless communications technology including fifth generation (5G) of wireless communications technology, henceforth referred to as WCR. WCR has already been recognized as a form of environmental pollution and physiological stressor [2]. Assessing the potentially detrimental health effects of WCR may be crucial to develop an effective, rational public health policy that may help expedite eradication of the COVID-19 pandemic. In addition, because we are on the verge of worldwide 5G deployment, it is critical to consider the possible damaging health effects of WCR before the public is potentially harmed.

5G is a protocol that will use high frequency bands and extensive bandwidths of the electromagnetic spectrum in the vast radiofrequency range from 600 MHz to nearly 100 GHz, which includes millimeter waves (>20 GHz), in addition to the currently used third generation (3G) and fourth generation (4G) long-term evolution (LTE) microwave bands. 5G frequency spectrum allocations differ from country to country. Focused pulsed beams of radiation will emit from new base stations and phased array antennas placed close to buildings whenever persons access the 5G network. Because these high frequencies are strongly absorbed by the atmosphere and especially during rain, a transmitter's range is limited to 300 meters. Therefore, 5G requires base stations and antennas to be much more closely spaced than previous generations. Plus, satellites in space will emit 5G bands globally to create a wireless worldwide web. The new system therefore requires significant densification of 4G infrastructure as well as new 5G antennas that may dramatically increase the population's WCR exposure both inside structures and outdoors. Approximately 100,000 emitting satellites are planned to be launched into orbit. This infrastructure will significantly alter the world's electromagnetic environment to unprecedented levels and may cause unknown consequences to the entire biosphere, including humans. The new infrastructure will service the new 5G devices, including 5G mobile phones, routers, computers, tablets, self-driving vehicles, machine-to-machine communications, and the Internet of Things.

The global industry standard for 5G is set by the 3G Partnership Project (3GPP), which is an umbrella term for several organizations developing standard protocols for mobile telecommunications. The 5G standard specifies all key aspects of the technology, including frequency spectrum allocation, beam-forming, beam steering, multiplexing multiple in, multiple out schemes, as well as modulation schemes, among others. 5G will utilize from 64 to 256 antennas at short distances to serve virtually simultaneously a large number of devices within a cell. The latest finalized 5G standard, Release 16, is codified in the 3GPP published Technical Report TR 21.916 and may be downloaded from the 3GPP server at https://www.3gpp.org/specifications. Engineers claim that 5G will offer performance up to 10 times that of current 4G networks [3].

COVID-19 began in Wuhan, China in December 2019, shortly after city-wide 5G had "gone live," that is, become an operational system, on October 31, 2019. COVID-19 outbreaks soon followed in other areas where 5G had also been at least partially implemented, including South Korea, Northern Italy, New York City, Seattle, and Southern California. In May 2020, Mordachev [4] reported a statistically significant correlation between the intensity of radiofrequency radiation and the mortality from SARS-CoV-2 in 31 countries throughout the world. During the first pandemic wave in the United States, COVID-19 attributed cases and deaths were statistically higher in states and major cities with 5G infrastructure as compared with states and cities that did not yet have this technology [5].

There is a large body of peer reviewed literature, since before World War II, on the biological effects of WCR that impact many aspects of our health. In examining this literature, we found intersections between the pathophysiology of SARS-CoV-2 and detrimental bioeffects of WCR exposure. Here, we present the evidence suggesting that WCR has been a possible contributing factor exacerbating COVID-19.

1.2. Overview on COVID-19

The clinical presentation of COVID-19 has proven to be highly variable, with a wide range of symptoms and variability from case to case. According to the CDC, early disease symptoms may include sore throat, headache, fever, cough, chills, among others. More severe symptoms including shortness of breath, high fever, and severe fatigue may occur in a later stage. The neurological sequela of taste and smell loss has also been described.

Ing *et al.* [6] determined 80% of those affected have mild symptoms or none, but older populations and those with comorbidities, such as hypertension, diabetes, and obesity, have a greater risk for severe disease [7]. Acute respiratory distress syndrome (ARDS) can rapidly occur [8] and cause severe shortness of breath as endothelial cells lining blood vessels and epithelial cells lining airways lose their integrity, and protein rich fluid leaks into adjacent air sacs. COVID-19 can cause insufficient oxygen levels (hypoxia) that have been seen in up to 80% of intensive care unit (ICU) patients [9] exhibiting respiratory distress. Decreased oxygenation and elevated carbon dioxide levels in patients' blood have been observed, although the etiology for these findings remains unclear.

Massive oxidative damage to the lungs has been observed in areas of airspace opacification documented on chest radiographs and computed tomography (CT) scans in patients with SARS-CoV-2 pneumonia [10]. This cellular stress may indicate a biochemical rather than a viral etiology [11].

DOI: http://dx.doi.org/10.18053/jctres.07.202105.007

Because disseminated virus can attach itself to cells containing an angiotensin-converting enzyme 2 (ACE2) receptor; it can spread and damage organs and soft tissues throughout the body, including the lungs, heart, intestines, kidneys, blood vessels, fat, testes, and ovaries, among others. The disease can increase systemic inflammation and induce a hypercoagulable state. Without anticoagulation, intravascular blood clots can be devastating [12].

In COVID-19 patients referred to as "long-haulers," symptoms can wax and wane for months [13]. Shortness of breath, fatigue, joint pain, and chest pain can become persistent symptoms. Post-infectious brain fog, cardiac arrhythmia, and new onset hypertension have also been described. Long-term chronic complications of COVID-19 are being defined as epidemiological data are collected over time.

As our understanding of COVID-19 continues to evolve, environmental factors, particularly those of wireless communication electromagnetic fields, remain unexplored variables that may be contributing to the disease including its severity in some patients. Next, we summarize the bioeffects of WCR exposure from the peer reviewed scientific literature published over decades.

1.3. Overview on bioeffects of WCR exposure

Organisms are electrochemical beings. Low-level WCR from devices, including mobile telephony base antennas, wireless network protocols utilized for the local networking of devices and internet access, trademarked as Wi-Fi (officially IEEE 802.11b Direct Sequence protocol; IEEE, Institute of Electrical and Electronic Engineers) by the Wi-Fi alliance, and mobile phones, among others, may disrupt regulation of numerous physiological functions. Non-thermal bioeffects (below the power density that causes tissue heating) from very low-level WCR exposure have been reported in numerous peer-reviewed scientific publications at power densities below the International Commission on Non-Ionizing Radiation Protection (ICNIRP) exposure guidelines [14]. Low-level WCR has been found to impact the organism at all levels of organization, from the molecular to the cellular, physiological, behavioral, and psychological levels. Moreover, it has been shown to cause systemic detrimental health effects including increased cancer risk [15], endocrine changes [16], increased free radical production [17], deoxyribonucleic acid (DNA) damage [18], changes to the reproductive system [19], learning and memory defects [20], and neurological disorders [21]. Having evolved within Earth's extremely low-level natural radiofrequency background, organisms lack the ability to adapt to heightened levels of unnatural radiation of wireless communications technology with digital modulation that includes short intense pulses (bursts).

The peer-reviewed world scientific literature has documented evidence for detrimental bioeffects from WCR exposure including 5G frequencies over several decades. The Soviet and Eastern European literature from 1960 to 1970s demonstrates significant biological effects, even at exposure levels more than 1000 times below 1 mW/cm^2, the current guideline for maximum public exposure in the US. Eastern studies on animal and human subjects were performed at low exposure levels (<1 mW/cm^2) for long durations (typically months). Adverse bioeffects from WCR exposure levels below 0.001 mW/cm^2 have also been documented in the Western literature. Damage to human sperm viability including DNA fragmentation by internet-connected laptop computers at power densities from 0.0005 to 0.001 mW/cm^2 has been reported [22]. Chronic human exposure to 0.000006 – 0.00001 mW/cm^2 produced significant changes in human stress hormones following a mobile phone base station installation [23]. Human exposures to cell phone radiation at 0.00001 – 0.00005 mW/cm^2 resulted in complaints of headache, neurological problems, sleep problems, and concentration problems, corresponding to "microwave sickness" [24,25]. The effects of WCR on prenatal development in mice placed near an "antenna park" exposed to power densities from 0.000168 to 0.001053 mW/cm^2 showed a progressive decrease in the number of newborns and ended in irreversible infertility [26]. Most US research has been performed over short durations of weeks or less. In recent years, there have been few long-term studies on animals or humans.

Illness from WCR exposure has been documented since the early use of radar. Prolonged exposure to microwaves and millimeter waves from radar was associated with various disorders termed "radio-wave sickness" decades ago by Russian scientists. A wide variety of bioeffects from nonthermal power densities of WCR were reported by Soviet research groups since the 1960s. A bibliography of over 3700 references on the reported biological effects in the world scientific literature was published in 1972 (revised 1976) by the US Naval Medical Research Institute [27,28]. Several relevant Russian studies are summarized as follows. Research on *Escherichia coli* bacteria cultures show power density windows for microwave resonance effects for 51.755 GHz stimulation of bacterial growth, observed at extremely low power densities of 10^{-13} mW/cm^2 [29], illustrating an extremely low level bioeffect. More recently Russian studies confirmed earlier results of Soviet research groups on the effects of 2.45 GHz at 0.5 mW/cm^2 on rats (30 days exposure for 7 h/day), demonstrating the formation of antibodies to the brain (autoimmune response) and stress reactions [30]. In a long-term (1 – 4 year) study comparing children who use mobile phones to a control group, functional changes, including greater fatigue, decreased voluntary attention, and weakening of semantic memory, among other adverse psychophysiological changes, were reported [31]. Key Russian research reports that underlie the scientific basis for Soviet and Russian WCR exposure guidelines to protect the public, which are much lower than the US guidelines, have been summarized [32].

By comparison to the exposure levels employed in these studies, we measured the ambient level of WCR from 100 MHz to 8 GHz in downtown San Francisco, California in December, 2020, and found an average power density of 0.0002 mW/cm^2. This level is from the superposition of multiple WCR devices. It is approximately 2×10^{10} times above the natural background.

DOI: http://dx.doi.org/10.18053/jctres.07.202105.007

Pulsed radio-frequency radiation such as WCR exhibits substantially different bioeffects, both qualitatively and quantitatively (generally more pronounced) compared to continuous waves at similar time-averaged power densities [33-36]. The specific interaction mechanisms are not well understood. All types of wireless communications employ extremely low frequency (ELFs) in the modulation of the radiofrequency carrier signals, typically pulses to increase the capacity of information transmitted. This combination of radiofrequency radiation with ELF modulation(s) is generally more bioactive, as it is surmised that organisms cannot readily adapt to such rapidly changing wave forms [37-40]. Therefore, the presence of ELF components of radiofrequency waves from pulsing or other modulations must be considered in studies on the bioeffects of WCR. Unfortunately, the reporting of such modulations has been unreliable, especially in older studies [41].

The BioInitiative Report [42], authored by 29 experts from ten countries, and updated in 2020, provides a scholarly contemporary summary of the literature on the bioeffects and health consequences from WCR exposure, including a compendium of supporting research. Recent reviews have been published [43-46]. Two comprehensive reviews on the bioeffects of millimeter waves report that even short-term exposures produce marked bioeffects [47,48].

2. Methods

An ongoing literature study of the unfolding pathophysiology of SARS-CoV-2 was performed. To investigate a possible connection to bioeffects from WCR exposure, we examined over 250 peer-reviewed research reports from 1969 to 2021, including reviews and studies on cells, animals, and humans. We included the world literature in English and Russian reports translated to English, on radio frequencies from 600 MHz to 90 GHz, the carrier wave spectrum of WCR (2G to 5G inclusive), with particular emphasis on nonthermal, low power densities (<1 mW/cm^2), and long-term exposures. The following search terms were used in queries in MEDLINE® and the Defense Technical Information Center (https://discover.dtic.mil) to find relevant study reports: radiofrequency radiation, microwave, millimeter wave, radar, MHz, GHz, blood, red blood cell, erythrocyte, hemoglobin, hemodynamic, oxygen, hypoxia, vascular, inflammation, pro-inflammatory, immune, lymphocyte, T cell, cytokine, intracellular calcium, sympathetic function, arrhythmia, heart, cardiovascular, oxidative stress, glutathione, reactive oxygen species (ROS), COVID-19, virus, and SARS-CoV-2. Occupational studies on WCR exposed workers were included in the study. Our approach is akin to Literature-Related Discovery, in which two concepts that have heretofore not been linked are explored in the literature searches to look for linkage(s) to produce novel, interesting, plausible, and intelligible knowledge, that is, potential discovery [49]. From analysis of these studies in comparison with new information unfolding on the pathophysiology of SARS-CoV-2, we identified several ways in which adverse bioeffects of WCR exposure intersect with COVID-19 manifestations and organized our findings into five categories.

Table 1. Bioeffects of Wireless Communication Radiation (WCR) exposure in relation to COVID-19 manifestations and their progression

Wireless communications radiation (WCR) exposure bioeffects	COVID-19 manifestations
Blood changes	**Blood changes**
Short-term: rouleaux, echinocytes Long-term: reduced blood clotting time, reduced hemoglobin, hemodynamic disorders	Rouleaux, echinocytes Hemoglobin effects; vascular effects → Reduced hemoglobin in severe disease; autoimmune hemolytic anemia; hypoxemia and hypoxia → Endothelial injury; impaired microcirculation; hypercoagulation; disseminated intravascular coagulopathy (DIC); pulmonary embolism; stroke
Oxidative stress	**Oxidative stress**
Glutathione level decrease; free radicals and lipid peroxide increase; superoxide dismutase activity decrease; oxidative injury in tissues and organs	Glutathione level decrease; free radical increase and damage; apoptosis → Oxidative injury; organ damage in severe disease
Immune system disruption and activation	**Immune system disruption and activation**
Immune suppression in some studies; immune hyperactivation in other studies Long-term: suppression of T-lymphocytes; inflammatory biomarkers increased; autoimmunity; organ injury	Decreased production of T-lymphocytes; elevated inflammatory biomarkers. → Immune hyperactivation and inflammation; cytokine storm in severe disease; cytokine-induced hypo-perfusion with resulting hypoxia; organ injury; organ failure
Increased intracellular calcium	**Increased intracellular calcium**
From activation of voltage-gated calcium channels on cell membranes, with numerous secondary effects	→ Increased virus entry, replication, and release → Increased NF-κB, pro-inflammatory processes, coagulation, and thrombosis
Cardiac effects	**Cardiac effects**
Up-regulation of sympathetic nervous system; palpitations and arrhythmias	Arrhythmias → Myocarditis; myocardial ischemia; cardiac injury; cardiac failure

Supportive evidence including study details and citations are provided in the text under each subject heading, i.e., blood changes, oxidative stress, etc.

DOI: http://dx.doi.org/10.18053/jctres.07.202105.007

3. Results

Table 1 lists the manifestations common to COVID-19 including disease progression and the corresponding adverse bioeffects from WCR exposure. Although these effects are delineated into categories — blood changes, oxidative stress, immune system disruption and activation, increased intracellular calcium (Ca^{2+}), and cardiac effects — it must be emphasized that these effects are not independent of each other. For example, blood clotting and inflammation have overlapping mechanisms, and oxidative stress is implicated in erythrocyte morphological changes as well as in hypercoagulation, inflammation, and organ damage.

3.1. Blood changes

WCR exposure can cause morphologic changes in blood readily seen through phase contrast or dark-field microscopy of live peripheral blood samples. In 2013, Havas observed erythrocyte aggregation including rouleaux (rolls of stacked red blood cells) in live peripheral blood samples following 10 min human exposure to a 2.4 GHz cordless phone [50]. Although not peer reviewed, one of us (Rubik) investigated the effect of 4G LTE mobile phone radiation on the peripheral blood of ten human subjects, each of whom had been exposed to cell phone radiation for two consecutive 45-min intervals [51]. Two types of effects were observed: increased stickiness and clumping of red blood cells with rouleaux formation, and subsequent formation of echinocytes (spiky red blood cells). Red blood cell clumping and aggregation are known to be actively involved in blood clotting [52]. The prevalence of this phenomenon on exposure to WCR in the human population has not yet been determined. Larger controlled studies should be performed to further investigate this phenomenon.

Similar red blood cell changes have been described in peripheral blood of COVID-19 patients [53]. Rouleaux formation has been observed in 1/3 of COVID-19 patients, whereas spherocytes and echinocyte formation is more variable. Spike protein engagement with ACE2 receptors on cells lining the blood vessels can lead to endothelial damage, even when isolated [54]. Rouleaux formation, particularly in the setting of underlying endothelial damage, can clog the microcirculation, impeding oxygen transport, contributing to hypoxia, and increasing the risk of thrombosis [52]. Thrombogenesis associated with SARS-CoV-2 infection may also be caused by direct viral binding to ACE2 receptors on platelets [55].

Additional blood effects have been observed in both humans and animals exposed to WCR. In 1977, a Russian study reported that rodents irradiated with 5 – 8 mm waves (60 – 37 GHz) at 1 mW/cm^2 for 15 min/day over 60 days developed hemodynamic disorders, suppressed red blood cell formation, reduced hemoglobin, and an inhibition of oxygen utilization (oxidative phosphorylation by the mitochondria) [56]. In 1978, a 3-year Russian study on 72 engineers exposed to millimeter wave generators emitting at 1 mW/cm^2 or less showed a decrease in their hemoglobin levels and red blood cell counts, and a tendency toward hypercoagulation, whereas a control group showed no changes [57]. Such deleterious hematologic effects from WCR exposure may also contribute to the development of hypoxia and blood clotting observed in COVID-19 patients.

It has been proposed that the SARS-CoV-2 virus attacks erythrocytes and causes degradation of hemoglobin [11]. Viral proteins may attack the 1-beta chain of hemoglobin and capture the porphyrin, along with other proteins from the virus catalyzing the dissociation of iron from heme [58]. In principle this would reduce the number of functional erythrocytes and cause the release of free iron ions that could cause oxidative stress, tissue damage, and hypoxia. With hemoglobin partially destroyed and lung tissue damaged by inflammation, patients would be less able to exchange carbon dioxide (CO_2) and oxygen (O_2), and would become oxygen depleted. In fact, some COVID-19 patients show reduced hemoglobin levels, measuring 7.1 g/L and even as low as 5.9 g/L in severe cases [59]. Clinical studies of almost 100 patients from Wuhan revealed that the hemoglobin levels in the blood of most patients infected with SARS-CoV-2 are significantly lowered resulting in compromised delivery of oxygen to tissues and organs [60]. In a meta-analysis of four studies with a total of 1210 patients and 224 with severe disease, hemoglobin values were reduced in COVID-19 patients with severe disease compared to those with milder forms [59]. In another study on 601 COVID-19 patients, 14.7% of anemic COVID-19 ICU patients and 9% of non-ICU COVID-19 patients had autoimmune hemolytic anemia [61]. In patients with severe COVID-19 disease, decreased hemoglobin along with elevated erythrocyte sedimentation rate (ESR), C-reactive protein, lactate dehydrogenase, albumin [62], serum ferritin [63], and low oxygen saturation [64] provide additional support for this hypothesis. In addition, packed red blood cell transfusion may promote recovery of COVID-19 patients with acute respiratory failure [65].

In short, both WCR exposure and COVID-19 may cause deleterious effects on red blood cells and reduced hemoglobin levels contributing to hypoxia in COVID-19. Endothelial injury may further contribute to hypoxia and many of the vascular complications seen in COVID-19 [66] that are discussed in the next section.

3.2. Oxidative stress

Oxidative stress is a non-specific pathological condition reflecting an imbalance between an increased production of ROS and an inability of the organism to detoxify the ROS or to repair the damage they cause to biomolecules and tissues [67]. Oxidative stress can disrupt cell signaling, cause the formation of stress proteins, and generate highly reactive free radicals, which can cause DNA and cell membrane damage.

SARS-CoV-2 inhibits intrinsic pathways designed to reduce ROS levels, thereby increasing morbidity. Immune dysregulation, that is, the upregulation of interleukin (IL)-6 and tumor necrosis factor α (TNF-α) [68] and suppression of interferon (IFN) α and IFN β [69] have been identified in the cytokine storm accompanying severe COVID-19 infections and generates oxidative stress [10]. Oxidative stress and mitochondrial dysfunction may further perpetuate the cytokine storm, worsening tissue damage, and increasing the risk of severe illness and death.

Similarly low-level WCR generates ROS in cells that cause oxidative damage. In fact, oxidative stress is considered to be one of the primary mechanisms in which WCR exposure causes cellular damage. Among 100 currently available peer-reviewed studies investigating oxidative effects of low-intensity WCR, 93 of these studies confirmed that WCR induces oxidative effects in biological systems [17]. WCR is an oxidative agent with a high pathogenic potential especially when exposure is continuous [70].

Oxidative stress is also an accepted mechanism causing endothelial damage [71]. This may manifest in patients with severe COVID-19 in addition to increasing the risk for blood clot formation and worsening hypoxemia [10]. Low levels of glutathione, the master antioxidant, have been observed in a small group of COVID-19 patients, with the lowest level found in the most severe cases [72]. The finding of low glutathione levels in these patients further supports oxidative stress as a component of this disease [72]. In fact, glutathione, the major source of sulfhydryl-based antioxidant activity in the human body, may be pivotal in COVID-19 [73]. Glutathione deficiency has been proposed as the most likely cause of serious manifestations in COVID-19 [72]. The most common co-morbidities, hypertension [74]; obesity [75]; diabetes [76]; and chronic obstructive pulmonary disease [74] support the concept that pre-existing conditions causing low levels of glutathione may work synergistically to create the "perfect storm" for both the respiratory and vascular complications of severe infection. Another paper citing two cases of COVID-19 pneumonia treated successfully with intravenous glutathione also supports this hypothesis [77].

Many studies report oxidative stress in humans exposed to WCR. Peraica *et al.* [78] found diminished blood levels of glutathione in workers exposed to WCR from radar equipment (0.01 mW/cm^2 – 10 mW/cm^2; 1.5 – 10.9 GHz). Garaj-Vrhovac *et al.* [79] studied bioeffects following exposure to non-thermal pulsed microwaves from marine radar (3 GHz, 5.5 GHz, and 9.4 GHz) and reported reduced glutathione levels and increased malondialdehyde (marker for oxidative stress) in an occupationally exposed group [79]. Blood plasma of individuals residing near mobile phone base stations showed significantly reduced glutathione, catalase, and superoxide dismutase levels over unexposed controls [80]. In a study on human exposure to WCR from mobile phones, increased blood levels of lipid peroxide were reported, while enzymatic activities of superoxide dismutase and glutathione peroxidase in the red blood cells decreased, indicating oxidative stress [81].

In a study on rats exposed to 2450 MHz (wireless router frequency), oxidative stress was implicated in causing red blood cell lysis (hemolysis) [82]. In another study, rats exposed to 945 MHz (base station frequency) at 0.367 mW/cm^2 for 7 h/day, over 8 days, demonstrated low glutathione levels and increased malondialdehyde and superoxide dismutase enzyme activity, hallmarks for oxidative stress [83]. In a long-term controlled study on rats exposed to 900 MHz (mobile phone frequency) at 0.0782 mW/cm^2 for 2 h/day for 10 months, there was a significant increase in malondialdehyde and total oxidant status over controls [84]. In another long-term controlled study on rats exposed to two mobile phone frequencies, 1800 MHz and 2100 MHz, at power densities 0.04 – 0.127 mW/cm^2 for 2 h/day over 7 months, significant alterations in oxidant-antioxidant parameters, DNA strand breaks, and oxidative DNA damage were found [85].

There is a correlation between oxidative stress and thrombogenesis [86]. ROS can cause endothelial dysfunction and cellular damage. The endothelial lining of the vascular system contains ACE2 receptors that are targeted by SARS-CoV-2. The resulting endotheliitis can cause luminal narrowing and result in diminished blood flow to downstream structures. Thrombi in arterial structures can further obstruct blood flow causing ischemia and/or infarcts in involved organs, including pulmonary emboli and strokes. Abnormal blood coagulation leading to micro-emboli was a recognized complication early in the history of COVID-19 [87]. Out of 184 ICU COVID-19 patients, 31% showed thrombotic complications [88]. Cardiovascular clotting events are a common cause of COVID-19 deaths [12]. Pulmonary embolism, disseminated intravascular coagulation (DIC), liver, cardiac, and renal failure have all been observed in COVID-19 patients [89].

Patients with the highest cardiovascular risk factors in COVID-19 includ males, the elderly, diabetics, and obese and hypertensive patients. However, increased incidence of strokes in younger patients with COVID-19 has also been described [90].

Oxidative stress is caused by WCR exposure and is known to be implicated in cardiovascular disease. Ubiquitous environmental exposure to WCR may contribute to cardiovascular disease by creating a chronic state of oxidative stress [91]. This would lead to oxidative damage to cellular constituents and alter signal transduction pathways. In addition, pulse-modulated WCR can cause oxidative injury in liver, lung, testis, and heart tissues mediated by lipid peroxidation, increased levels of nitric oxides, and suppression of the antioxidant defense mechanism [92].

In summary, oxidative stress is a major component in the pathophysiology of COVID-19 as well as in cellular damage caused by WCR exposure.

3.3. Immune system disruption and activation

When SARS-CoV-2 first infects the human body, it attacks cells lining the nose, throat, and upper airway harboring ACE2 receptors. Once the virus gains access to a host cell through one of its spike proteins, which are the multiple protuberances projecting from the viral envelope that bind to ACE2 receptors, it converts the cell into a virus self-replicating entity.

In response to COVID-19 infection, both an immediate systemic innate immune response as well as a delayed adaptive response has been shown to occur [93]. The virus can also cause a dysregulation of the immune response, particularly in the decreased production of T-lymphocytes. [94]. Severe cases tend to have lower lymphocyte counts, higher leukocyte counts and neutrophil-lymphocyte ratios, as well as lower percentages of monocytes, eosinophils, and basophils [94]. Severe cases of COVID-19 show the greatest impairment in T-lymphocytes.

In comparison, low-level WCR studies on laboratory animals also show impaired immune function [95]. Findings

DOI: http://dx.doi.org/10.18053/jctres.07.202105.007

include physical alterations in immune cells, a degradation of immunological responses, inflammation, and tissue damage. Baranski [96] exposed guinea pigs and rabbits to continuous or pulse-modulated 3000 MHz microwaves at an average power density of 3.5 mW/cm^2 for 3 h/day over 3 months and found nonthermal changes in lymphocyte counts, abnormalities in nuclear structure, and mitosis in the erythroblastic cell series in the bone marrow and in lymphoid cells in lymph nodes and spleen. Other investigators have shown diminished T-lymphocytes or suppressed immune function in animals exposed to WCR. Rabbits exposed to 2.1 GHz at 5mW/cm^2 for 3 h/day, 6 days/week, for 3 months, showed suppression of T-lymphocytes [97]. Rats exposed to 2.45 GHz and 9.7 GHz for 2 h/day, 7 days/week, for 21 months showed a significant decrease in the levels of lymphocytes and an increase in mortality at 25 months in the irradiated group [98]. Lymphocytes harvested from rabbits irradiated with 2.45 GHz for 23 h/day for 6 months show a significant suppression in immune response to a mitogen [99].

In 2009, Johansson conducted a literature review, which included the 2007 Bioinitiative Report. He concluded that electromagnetic fields (EMF) exposure, including WCR, can disturb the immune system and cause allergic and inflammatory responses at exposure levels significantly less than current national and international safety limits and raise the risk for systemic disease [100]. A review conducted by Szmigielski in 2013 concluded that weak RF/microwave fields, such as those emitted by mobile phones, can affect various immune functions both *in vitro* and *in vivo* [101]. Although the effects are historically somewhat inconsistent, most research studies document alterations in the number and activity of immune cells from RF exposure. In general, short-term exposure to weak microwave radiation may temporarily stimulate an innate or adaptive immune response, but prolonged irradiation inhibits those same functions.

In the acute phase of COVID-19 infection, blood tests demonstrate elevated ESR, C-reactive protein, and other elevated inflammatory markers [102], typical of an innate immune response. Rapid viral replication can cause death of epithelial and endothelial cells and result in leaky blood vessels and pro-inflammatory cytokine release [103]. Cytokines, proteins, peptides, and proteoglycans that modulate the body's immune response, are modestly elevated in patients with mild-to-moderate disease severity [104]. In those with severe disease, an uncontrolled release of pro-inflammatory cytokines--a cytokine storm--can occur. Cytokine storms originate from an imbalance in T-cell activation with dysregulated release of IL-6, IL-17, and other cytokines. Programmed cell death (apoptosis), ARDS, DIC, and multi-organ system failure can all result from a cytokine storm and increase the risk of mortality.

By comparison, Soviet researchers found in the 1970s that radiofrequency radiation can damage the immune system of animals. Shandala [105] exposed rats to 0.5 mW/cm^2 microwaves for 1 month, 7 h/day, and found impaired immune competence and induction of autoimmune disease. Rats irradiated with 2.45 GHz at 0.5 mW/cm^2 for 7 h daily for 30 days produced autoimmune reactions, and 0.1 – 0.5 mW/cm^2 produced persistent pathological immune reactions [106]. Exposure to microwave radiation, even at low levels (0.1 – 0.5 mW/cm^2), can impair immune function, causing physical alterations in the essential cells of the immune system and a degradation of immunologic responses [107]. Szabo *et al.* [108] examined the effects of 61.2 GHz exposure on epidermal keratinocytes and found an increase in IL-1b, a pro-inflammatory cytokine. Makar *et al.* [109] found that immunosuppressed mice irradiated 30 min/day for 3 days by 42.2 GHz showed increased levels of TNF-α, a cytokine produced by macrophages.

In short, COVID-19 can lead to immune dysregulation as well as cytokine storms. By comparison, exposure to low-level WCR as observed in animal studies can also compromise the immune system, with chronic daily exposure producing immunosuppression or immune dysregulation including hyperactivation.

3.4. Increased intracellular calcium

In 1992, Walleczek first suggested that ELF electromagnetic fields (<3000 Hz) may be affecting membrane-mediated Ca^{2+} signaling and lead to increased intracellular Ca^{2+} [110]. The mechanism of irregular gating of voltage-gated ion channels in cell membranes by polarized and coherent, oscillating electric or magnetic fields was first presented in 2000 and 2002 [40,111]. Pall [112] in his review of WCR-induced bioeffects combined with use of calcium channel blockers (CCB) noted that voltage-gated calcium channels play a major role in WCR bioeffects. Increased intracellular Ca^{+2} results from the activation of voltage-gated calcium channels, and this may be one of the primary mechanisms of action of WCR on organisms.

Intracellular Ca^{2+} is essential for virus entry, replication, and release. It has been reported that some viruses can manipulate voltage-gated calcium channels to increase intracellular Ca^{2+} thereby facilitating viral entry and replication [113]. Research has shown that the interaction between a virus and voltage-gated calcium channels promote virus entry at the virus-host cell fusion step [113]. Thus, after the virus binds to its receptor on a host cell and enters the cell through endocytosis, the virus takes over the host cell to manufacture its components. Certain viral proteins then manipulate calcium channels, thereby increasing intracellular Ca^{2+}, which facilitates further viral replication.

Even though direct evidence has not been reported, there is indirect evidence that increased intracellular Ca^{2+} may be involved in COVID-19. In a recent study, elderly hospitalized COVID-19 patients treated with CCBs, amlodipine or nifedipine, were more likely to survive and less likely to require intubation or mechanical ventilation than controls [114]. Furthermore, CCBs strongly limit SARS-CoV-2 entry and infection in cultured epithelial lung cells [115]. CCBs also block the increase of intracellular Ca^{2+} caused by WCR exposure as well as exposure to other electromagnetic fields [112].

Intracellular Ca^{2+} is a ubiquitous second messenger relaying signals received by cell surface receptors to effector proteins involved in numerous biochemical processes. Increased intracellular Ca^{2+} is a significant factor in upregulation of transcription nuclear factor KB (NF-κB) [116], an important regulator of pro-inflammatory cytokine production as well as coagulation and thrombotic cascades. NF-κB is hypothesized to be a key factor underlying severe clinical manifestations of COVID-19 [117].

In short, WCR exposure, therefore, may enhance the infectivity of the virus by increasing intracellular Ca^{2+} that may also indirectly contribute to inflammatory processes and thrombosis.

3.5. Cardiac effects

Cardiac arrhythmias are more commonly encountered in critically ill patients with COVID-19 [118]. The cause for arrhythmia in COVID-19 patients is multifactorial and includes cardiac and extra-cardiac processes [119]. Direct infection of the heart muscle by SARS-CoV-19 causing myocarditis, myocardial ischemia caused by a variety of etiologies, and heart strain secondary to pulmonary or systemic hypertension can result in cardiac arrhythmia. Hypoxemia caused by diffuse pneumonia, ARDS, or extensive pulmonary emboli represent extra-cardiac causes of arrhythmia. Electrolyte imbalances, intravascular fluid imbalance, and side effects from pharmacologic regimens can also result in arrhythmias in COVID-19 patients. Patients admitted to ICUs have been shown to have a higher increase in cardiac arrhythmias, 16.5% in one study [120]. Although no correlation between EMFs and arrhythmia in COVID-19 patients has been described in the literature, many ICUs are equipped with wireless patient monitoring equipment and communication devices producing a wide range of EMF pollution [121].

COVID-19 patients commonly show increased levels of cardiac troponin, indicating damage to the heart muscle [122]. Cardiac damage has been associated with arrhythmias and increased mortality. Cardiac injury is thought to be more often secondary to pulmonary emboli and viral sepsis, but direct infection of the heart, that is, myocarditis, can occur through direct viral binding to ACE2 receptors on cardiac pericytes, affecting local, and regional cardiac blood flow [60].

Immune system activation along with alterations in the immune system may result in atherosclerotic plaque instability and vulnerability, that is, presenting an increased risk for thrombus formation, and contributing to development of acute coronary events and cardiovascular disease in COVID-19.

Regarding WCR exposure bioeffects, in 1969 Christopher Dodge of the Biosciences Division, U.S. Naval Observatory in Washington DC, reviewed 54 papers and reported that radiofrequency radiation can adversely affect all major systems of the body, including impeding blood circulation; altering blood pressure and heart rate; affecting electrocardiograph readings; and causing chest pain and heart palpitations [123]. In the 1970s Glaser reviewed more than 2000 publications on radiofrequency radiation exposure bioeffects and concluded that microwave radiation can alter the electrocardiogram, cause chest pain, hypercoagulation, thrombosis, and hypertension in addition to myocardial infarction [27,28]. Seizures, convulsions, and alteration of the autonomic nervous system response (increased sympathetic stress response) have also been observed.

Since then, many other researchers have concluded that WCR exposure can affect the cardiovascular system. Although the nature of the primary response to millimeter waves and consequent events are poorly understood, a possible role for receptor structures and neural pathways in the development of continuous millimeter wave-induced arrhythmia has been proposed [47]. In 1997, a review reported that some investigators discovered cardiovascular changes including arrhythmias in humans from long-term low-level exposure to WCR including microwaves [124]. However, the literature also shows some unconfirmed findings as well as some contradictory findings [125]. Havas *et al.* [126] reported that human subjects in a controlled, double-blinded study were hyper-reactive when exposed to 2.45 GHz, digitally pulsed (100 Hz) microwave radiation, developing either an arrhythmia or tachycardia and upregulation of the sympathetic nervous system, which is associated with the stress response. Saili *et al.* [127] found that exposure to Wi-Fi (2.45 GHz pulsed at 10 Hz) affects heart rhythm, blood pressure, and the efficacy of catecholamines on the cardiovascular system, indicating that WCR can act directly and/or indirectly on the cardiovascular system. Most recently, Bandara and Weller [91] present evidence that people who live near radar installations (millimeter waves: 5G frequencies) have a greater risk of developing cancer and experiencing heart attacks. Similarly, those occupationally exposed have a greater risk of coronary heart disease. Microwave radiation affects the heart, and some people are more vulnerable if they have an underlying heart abnormality [128]. More recent research suggests that millimeter waves may act directly on the pacemaker cells of the sinoatrial node of the heart to change the beat frequency, which may underlie arrhythmias and other cardiac issues [47].

In short, both COVID-19 and WCR exposure can affect the heart and cardiovascular system, directly and/or indirectly.

4. Discussion

Epidemiologists, including those at the CDC, consider multiple causal factors when evaluating the virulence of an agent and understanding its ability to spread and cause disease. Most importantly, these variables include environmental cofactors and the health status of the host. Evidence from the literature summarized here suggests a possible connection between several adverse health effects of WCR exposure and the clinical course of COVID-19 in that WCR may have worsened the COVID-19 pandemic by weakening the host and exacerbating COVID-19 disease. However, none of the observations discussed here prove this linkage. Specifically, the evidence does not confirm causation. Clearly COVID-19 occurs in regions with little wireless communication. Furthermore, the relative morbidity caused by WCR exposure in COVID-19 is unknown.

We recognize that many factors have influenced the pandemic's course. Before restrictions were imposed, travel patterns facilitated the seeding of the virus, causing early rapid global spread. Population density, higher mean population age, and socioeconomic factors certainly influenced early viral spread. Air pollution, especially particulate matter $PM_{2.5}$ (2.5

DOI: http://dx.doi.org/10.18053/jctres.07.202105.007

micro-particulates), likely increased symptoms in patients with COVID-19 lung disease [129].

We postulate that WCR possibly contributed to the early spread and severity of COVID-19. Once an agent becomes established in a community, its virulence increases [130]. This premise can be applied to the COVID-19 pandemic. We surmise that "hot spots" of the disease that initially spread around the world were perhaps seeded by air travel, which in some areas were associated with 5G implementation. However, once the disease became established in those communities, it was able to spread more easily to neighboring regions where populations were less exposed to WCR. Second and third waves of the pandemic disseminated widely throughout communities with and without WCR, as might be expected.

The COVID-19 pandemic has offered us an opportunity to delve further into the potential adverse effects of WCR exposure on human health. Human exposure to ambient WCR significantly increased in 2020 as a "side effect" to the pandemic. Stay-at-home measures designed to reduce the spread of COVID-19 inadvertently resulted in greater public exposure to WCR, as people conducted more business and school related activities through wireless communications. Telemedicine created another source of WCR exposure. Even hospital inpatients, particular ICU patients, experienced increased WCR exposure as new monitoring devices utilized wireless communication systems that may exacerbate health disorders. It would potentially provide valuable information to measure ambient WCR power densities in home and work environments when comparing disease severity in patient populations with similar risk factors.

The question of causation could be investigated in future studies. For example, a clinical study could be conducted in COVID-19 patient populations with similar risk factors, to measure the WCR daily dose in COVID-19 patients and look for a correlation with disease severity and progression over time. As wireless device carrier frequencies and modulations may differ, and the power densities of WCR fluctuate constantly at a given location, this study would require patients to wear personal microwave dosimeters (monitoring badges). In addition, controlled laboratory studies could be conducted on animals, for example, humanized mice infected with SARS-CoV-2, in which groups of animals exposed to minimal WCR (control group) as well as medium and high power densities of WCR could be compared for disease severity and progression.

A major strength of this paper is that the evidence rests on a large body of scientific literature reported by many scientists worldwide and over several decades--experimental evidence of adverse bioeffects of WCR exposure at nonthermal levels on humans, animals, and cells. The Bioinitiative Report [42], updated in 2020, summarizes hundreds of peer-reviewed scientific papers documenting evidence of nonthermal effects from exposures ≤1 mW/cm^2. Even so, some laboratory studies on the adverse health effects of WCR have sometimes utilized power densities exceeding 1mW/cm^2. In this paper, almost all of the studies that we reviewed included experimental data at power densities ≤1 mW/cm^2.

A potential criticism of this paper is that adverse bioeffects from nonthermal exposures are not yet universally accepted in science. Moreover, they are not yet considered in establishing public health policy in many nations. Decades ago, Russians and Eastern Europeans compiled considerable data on nonthermal bioeffects, and subsequently set guidelines at lower radiofrequency radiation exposure limits than the US and Canada, that is, below levels where nonthermal effects are observed. However, the Federal Communications Commission (FCC, a US government entity) and ICNIRP guidelines operate on thermal limits based on outdated data from decades ago, allowing the public to be exposed to considerably higher radiofrequency radiation power densities. Regarding 5G, the telecommunication industry claims that it is safe because it complies with current radiofrequency radiation exposure guidelines of the FCC and ICNIRP. These guidelines were established in 1996 [131], are antiquated, and are not safety standards. Thus, there are no universally accepted safety standards for wireless communication radiation exposure. Recently international bodies, such as the EMF Working Group of the European Academy of Environmental Medicine, have proposed much lower guidelines, taking into account nonthermal bioeffects from WCR exposure in multiple sources [132].

Another weakness of this paper is that some of the bioeffects from WCR exposure are inconsistently reported in the literature. Replicated studies are often not true replications. Small differences in method, including unreported details, such as prior history of exposure of the organisms, non-uniform body exposure, and other variables can lead to inadvertent inconsistency. Moreover, not surprisingly, industry-sponsored studies tend to show less adverse bioeffects than studies conducted by independent researchers, suggesting industry bias [133]. Some experimental studies that are not industry-sponsored have also shown no evidence of harmful effects of WCR exposure. It is noteworthy, however, that studies employing real-life WCR exposures from commercially available devices have shown high consistency in revealing adverse effects [134].

WCR bioeffects depend on specific values of wave parameters including frequency, power density, polarization, exposure duration, modulation characteristics, as well as the cumulative history of exposure and background levels of electromagnetic, electric and magnetic fields. In laboratory studies, bioeffects observed also depend on genetic parameters and physiological parameters such as oxygen concentration [135]. The reproducibility of bioeffects of WCR exposure has sometimes been difficult due to failure to report and/or control all of these parameters. Similar to ionizing radiation, the bioeffects of WCR exposure can be subdivided into deterministic, that is, dose-dependent effects and stochastic effects that are seemingly random. Importantly, WCR bioeffects can also involve "response windows" of specific parameters whereby extremely low-level fields can have disproportionally detrimental effects [136]. This nonlinearity of WCR bioeffects can result in biphasic responses such as immune suppression from one range of parameters, and immune hyperactivation from another range of parameters, leading to variations that may appear inconsistent.

In gathering reports and examining existing data for this paper, we looked for outcomes providing evidence to support a proposed connection between the bioeffects of WCR exposure and

DOI: http://dx.doi.org/10.18053/jctres.07.202105.007

COVID-19. We did not make an attempt to weigh the evidence. The radiofrequency radiation exposure literature is extensive and currently contains over 30,000 research reports dating back several decades. Inconsistencies in nomenclature, reporting of details, and cataloging of keywords make it difficult to navigate this enormous literature.

Another shortcoming of this paper is that we do not have access to experimental data on 5G exposures. In fact, little is known about population exposure from real-world WCR, which includes exposure to WCR infrastructure and the plethora of WCR emitting devices. In relation to this, it is difficult to accurately quantify the average power density at a given location, which varies greatly, depending on the time, specific location, time-averaging interval, frequency, and modulation scheme. For a specific municipality it depends on the antenna density, which network protocols are used, as, for example, 2G, 3G, 4G, 5G, Wi-Fi, WiMAX (Worldwide Interoperability for Microwave Access), DECT (Digitally Enhanced Cordless Telecommunications), and RADAR (Radio Detection and Ranging). There is also WCR from ubiquitous radio wave transmitters, including antennas, base stations, smart meters, mobile phones, routers, satellites, and other wireless devices currently in use. All of these signals superimpose to yield the total average power density at a given location that typically fluctuates greatly over time. No experimental studies on adverse health effects or safety issues of 5G have been reported, and none are currently planned by the industry, although this is sorely needed.

Finally, there is an inherent complexity to WCR that makes it very difficult to fully characterize wireless signals in the real world that may be associated with adverse bioeffects. Real world digital communication signals, even from single wireless devices, have highly variable signals: variable power density, frequency, modulation, phase, and other parameters changing constantly and unpredictably each moment, as associated with the short, rapid pulsations used in digital wireless communication [137]. For example, in using a mobile phone during a typical phone conversation, the intensity of emitted radiation varies significantly each moment depending on signal reception, number of subscribers sharing the frequency band, location within the wireless infrastructure, presence of objects and metallic surfaces, and "speaking" versus "non-speaking" mode, among others. Such variations may reach 100% of the average signal intensity. The carrier radiofrequency constantly changes between different values within the available frequency band. The greater the amount of information (text, speech, internet, video, etc.), the more complex the communication signals become. Therefore, we cannot estimate accurately the values of these signal parameters including ELF components or predict their variability over time. Thus, studies on the bioeffects of WCR in the laboratory can only be representative of real-world exposures [137].

This paper points to the need for further research on nonthermal WCR exposure and its potential role in COVID-19. Moreover, some of the WCR exposure bioeffects that we discuss here — oxidative stress, inflammation, and immune system disruption — are common to many chronic diseases, including autoimmune disease and diabetes. Thus, we hypothesize that WCR exposure may also be a potential contributing factor in many chronic diseases.

When a course of action raises threats of harm to human health, precautionary measures should be taken, even if clear causal relationships are not yet fully established. Therefore, we must apply the Precautionary Principle [138] regarding wireless 5G. The authors urge policymakers to execute an immediate worldwide moratorium on wireless 5G infrastructure until its safety can be assured.

Several unresolved safety issues should be addressed before wireless 5G is further implemented. Questions have been raised about 60 GHz, a key 5G frequency planned for extensive use, which is a resonant frequency of the oxygen molecule [139]. It is possible that adverse bioeffects might ensue from oxygen absorption of 60 GHz. In addition, water shows broad absorption in the GHz spectral region along with resonance peaks, for example, strong absorption at 2.45 GHz that is used in 4G Wi-Fi routers. This raises safety issues about GHz exposure of the biosphere, since organisms are comprised of mostly water, and changes in the structure of water due to GHz absorption have been reported that affect organisms [140]. Bioeffects from prolonged WCR exposure of the whole body need to be investigated in animal and human studies, and long-term exposure guidelines need to be considered. Independent scientists in particular should conduct concerted research to determine the biological effects of real-world exposure to WCR frequencies with digital modulation from the multiplicity of wireless communication devices. Testing could also include real-life exposures to multiple toxins (chemical and biological) [141], because multiple toxins may lead to synergistic effects. Environmental impact assessments are also needed. Once the long-term biological effects of wireless 5G are understood, we can set clear safety standards of public exposure limits and design an appropriate strategy for safe deployment.

5. Conclusion

There is a substantial overlap in pathobiology between COVID-19 and WCR exposure. The evidence presented here indicates that mechanisms involved in the clinical progression of COVID-19 could also be generated, according to experimental data, by WCR exposure. Therefore, we propose a link between adverse bioeffects of WCR exposure from wireless devices and COVID-19.

Specifically, evidence presented here supports a premise that WCR and, in particular, 5G, which involves densification of 4G, may have exacerbated the COVID-19 pandemic by weakening host immunity and increasing SARS-CoV-2 virulence by (1) causing morphologic changes in erythrocytes including echinocyte and rouleaux formation that may be contributing to hypercoagulation; (2) impairing microcirculation and reducing erythrocyte and hemoglobin levels exacerbating hypoxia; (3) amplifying immune dysfunction, including immunosuppression, autoimmunity, and hyperinflammation; (4) increasing cellular oxidative stress and the production of free radicals exacerbating vascular injury and organ damage; (5) increasing intracellular Ca^{2+} essential for viral entry, replication, and release, in addition to promoting pro-inflammatory pathways; and (6) worsening heart arrhythmias and cardiac disorders.

WCR exposure is a widespread, yet often neglected, environmental stressor that can produce a wide range of adverse bioeffects. For decades, independent research scientists worldwide have emphasized the health risks and cumulative damage caused by WCR [42,45]. The evidence presented here is consistent with a large body of established research. Healthcare workers and policymakers should consider WCR a potentially toxic environmental stressor. Methods for reducing WCR exposure should be provided to all patients and the general population.

Acknowledgments

The authors acknowledge small contributions to early versions of this paper by Magda Havas and Lyn Patrick. We are grateful to Susan Clarke for helpful discussions and suggested edits of early drafts of the manuscript.

Conflict of Interest

The authors declare that they have no conflicts of interest in preparing and publishing this manuscript. No competing financial interests exist.

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