

Review article

Locked on salt? Excessive consumption of high-sodium foods during COVID-19 presents an underappreciated public health risk

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Abstract

Abrupt changes in food preferences and eating habits pose an overlooked public health risk during the coronavirus disease (COVID-19) pandemic. Emerging evidence suggests an ongoing, population-level shift to consumption of high-sodium foods, during COVID-19 and lockdowns, in the general population surveyed in different countries and cultures. High-sodium foods are defined as those with sodium contents exceeding 500 mg per 100 g, and many processed and preserved foods fall into this particular category. Excessive dietary sodium intake is associated with chronic diseases including hypertension, cardiovascular diseases, and kidney diseases, and poses confounding risks during COVID-19. Here, we review food categories in consumers' shopping lists and food parcels delivered to those who need assistance during the current pandemic, when frozen meals, canned foods, instant foods, snacks, and other high-sodium foods gained substantial popularity. Such emerging trends in consumers' behavior are driven by a multitude of factors. Specifically, the perceived risk of COVID-19 infection in grocery shopping trips, limited supplies and inflated prices of fresh produce, preference on foods with long shelf lives, emotional eating, and the general low awareness of sodium contents in food have all contributed to the increased consumption of high-sodium foods during COVID-19. We also discuss the possible effects on COVID-19 infection and severity caused by excessive sodium intake, by reviewing current reports and hypotheses examining their relations. In light of the evidence, it is advisable to educate the public to maintain a healthy sodium intake during the current pandemic, and measures could be adopted by governments and private donors in procuring food parcels with more balanced sodium contents to lower the risks of prolonged and excessive sodium intakes in vulnerable population groups.

Keywords: Coronavirus; SARS-CoV-2; lockdown; confinement; diet; sodium intake

1. Introduction

The Coronavirus Disease 2019 (COVID-19) emerged in December 2019 has swept the world. Thirteen months after the World Health Organization (WHO) declared it a pandemic, nearly 150 million infections have been reported, including more than three million deaths worldwide (WHO 2021). Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the infectious agent of COVID-19, is believed to spread easily between people via droplets and droplets nuclei (aerosols) from human respiratory activities such as sneezing, coughing, talking, or breathing (CDC 2020; Sun et al. 2021; WHO 2020). As a common response to the situation, governments and public health authorities enforced containment measures (Han and Zhang 2020), including social distancing, travel restrictions, and lockdowns. These have had positive effects on curbing the spread of SARS-CoV-2 but also led to uncertain and potentially adverse effects on human behavior and health. Specifically, lockdown-related dietary changes, such as preferences to processed and preserved foods, have been noted in the general population (Han et al. 2020). Recent surveys on local populations confirmed such trends that during COVID-19 lockdowns, food purchases increased significantly in certain categories, including snacks, biscuits, cold meats, and other processed foods (Bracale and Vaccaro 2020; Laguna et al., 2020; Marty et al. 2020).

A widely overlooked risk associated with changes in people's dietary choices and eating habits during COVID-19 is that a vast range of processed and preserved foods contain excessive sodium contents (**Figure 1**). Numerous studies provided ample evidence that excessive dietary sodium intake is strongly linked to an array of human diseases, such as hypertension, cardiovascular diseases, and kidney diseases (de Wardener and MacGregor 2002; He and MacGregor 2007). As an integral part of public health management in COVID-19 (Chen et al. 2021; Han and He 2021; Han et al. 2020), advising the public to maintain a healthy diet during confinements is equally important as infection control and prevention measures to reduce health risks in the population. As the world is still struggling to tackle the COVID-19 pandemic (Dai et al. 2020; He et al. 2021), and lockdowns are expected to continue in many countries and regions, it is important to evaluate the key driving factors of people's dietary changes and the underlying health risks associated with such behavior.

In this article, we focus our discussions on increased sodium intakes in the general public, including vulnerable population groups, by discussing the most pertinent and up-to-date evidence on such behavior, including: 1) sources of sodium in foods, especially on the contribution of food processing to sodium contents in foods, and common high-sodium foods in typical western diets; 2) notable trends of dietary changes in the population including their preferences on certain types of foods and observable changes in their eating habits during the current pandemic, especially during lockdowns; 3) motivations and key driving factors of these changes, and mitigation strategies; 4) health risks associated with high sodium intake and their confounding effects in COVID-19 infection and symptom aggravation.

2. Sodium contents in common foods and high-sodium foods

Surprisingly, the sodium contents inherent to the food itself or added during food preparation or consumption (e.g., cooking, table salts) typically constitute only a small portion of the dietary sodium intake (Mattes and Donnelly 1991). Most sodium contents in modern human diets come from food processing procedures that consumers cannot directly observe or participate in. Common fresh produce and meat such as beef (*ca.* 48.3 mg per 100 g), potatoes (*ca.* 9.2 mg per 100 g), peanuts (*ca.* 2.3 mg per 100g), peas, and sweet corns (trace contents) generally contain low sodium contents (Brown et al. 2009). After processing, however, their sodium contents undergo multi-fold increases. For instance, the sodium content of raw bran or wheat is about 27.2 mg per 100 g, while the equivalent sodium content increases to over 1,000 mg in processed bran

flakes, a nearly 40-fold increase (Brown et al. 2009). Similar trends are observed in salmon. The sodium contents in 100 grams of raw, canned, and smoked salmon were 110.4 mg, 570.4 mg, and 1879.1 mg, respectively (Brown et al. 2009). It is noteworthy that eating 100 g of smoked salmon alone would approach the recommended maximum limit of daily sodium intake for adults (2,000 mg/d) (WHO 2012).

For those on a typical western diet, approximately two-thirds of their daily sodium intake comes from processed foods, of which nearly half are from ten product categories, namely, bread and rolls, cold cuts/cured meats, pizza, poultry, soups, sandwiches, cheese, pasta mixed dishes, meat mixed dishes, and savory snacks (Moshfegh et al. 2012). Webster et al. (2010) surveyed the sodium contents of common processed foods purchased from grocery stores. Based on a typical western diet, their data covered 7,221 food products sold in Australia (**Figure 2**). Although differences exist, surveys in other countries on mean sodium contents are in general consistent with these data across a similar range of food products (Mhurchu et al. 2011; Moshfegh et al. 2012; Webster et al. 2010). Webster et al. (2010) categorized those with sodium contents higher than 500 mg per 100 g as high-sodium foods. Food products such as sauces, pickles, processed meat, chilled and canned dishes, which are often put on dinner tables during COVID-19 and lockdown periods, are high-sodium foods (Han et al. 2020; Romeo-Arroyo et al. 2020). Pizza, a highly popular processed food, also contains high sodium contents exceeding 400 mg per 100 g. It is noteworthy that, although pasta contains less than 200 mg sodium per 100 g and thus is not considered a high-sodium food itself, it is often served with sauces, which can dramatically increase its sodium contents upon its consumption. Although canned vegetables do not meet the high-sodium criterion, they contain much higher sodium contents than equivalent fresh varieties (Webster et al. 2010).

3. Increased consumption of high-sodium foods in the population during COVID-19

Recent surveys have indicated the unintended effects of COVID-19 and lockdowns on people's eating habits. Due to the confinement, people increased their intake of processed foods, such as canned foods, snacks, and instant foods, most of which are high in sodium contents (**Table 1**). In a retrospective study, Marty et al. (2020) investigated the diets of 938 French adults both before (17 February to 16 March 2020) and during a COVID-19 lockdown (17 March to 16 April 2020). On average, participants ingested 3.2 g salts per day during the lockdown, compared with 2.9 g salts per day before the lockdown, and such increases were found to be statistically significant ($p < 0.001$). Bracale and Vaccaro (2020) presented data on food sales in 10,769 Italian grocery stores from 23 February to 29 March 2020. Their data showed large increases (42%–99%) in sales of pizza and pizza mix, canned beans, canned meat, canned peas, tomato sauce, canned tomato pulp, and diced cold cuts compared with those during the same period in the previous year. The Spanish population, who generally had preferences for eating outside in their working life or leisure activities, was also impacted by the pandemic and many people preferred preparing meals and eating at home (Batlle-Bayer et al. 2020; Diaz-Mendez and Garcia-Espejo 2017). Laguna et al. (2020) observed that after two weeks of strict confinement (i.e., after exhausting the initial stocks of food), pasta, preserves, snacks, biscuits, and cold meats became more common in Spanish consumers' grocery shopping lists ($n = 362$). Rolland et al. (2020) also reported increases in addiction-related eating habits during an early COVID-19 lockdown in France (5 March to 11 March 2020), where 36.2% of participants ($n = 11,391$) reported increased consumption of caloric or salty foods and only 9.7% reported decreases. In Italy, Scarmozzino and Visioli (2020) found that 46.1% of respondents ($n = 1,932$) ate more during an earlier lockdown (3 April to 15 April 2020), and 19.5% of the survey respondents had gained weight in this period. Particularly, the participants consumed more 'comfort foods', such as chocolates, ice creams, desserts and salty snacks. As a diverse category of high-sodium foods, snacks have gained immense popularity in the general population during COVID-19. One study

reported that the perception of snacking more were observed in 56% of the survey respondents ($n = 2,002$) in the UK (Robinson et al. 2021). A cross-sectional online survey in Poland reported similar lockdown-related changes in eating habits among 1,097 adults, where increased consumption of snacks was seen in half of those (50.1%) with a normal body mass index, with a higher prevalence rate (61.7%) observed in obese individuals (Sidor and Rzymiski 2020). According to an online survey conducted after COVID-19 confinement in Belgium (2 April to 28 May 2020), nearly one-third (31.5%) of the survey respondents ($n = 8,640$) reported increasing consumption of sweet and salty snacks during this period (Vandevijvere et al. 2020).

As an affordable and long-storage-life variety, frozen foods also enjoyed tremendous growth of consumption by consumers during the COVID-19 pandemic (Han et al., 2020). A survey conducted in the four weeks ending on 5 April 2020 by American Frozen Food Institute (AFFI) indicated that frozen food products experienced massive upsurges in sales, including frozen meals-dinners/entrees (47.6%), frozen snacks (82.8%), and frozen pizza (94.2%) (AFFI 2020). When asked about the particular types of frozen food products bought during the pandemic and how those compared with their normal purchases before the COVID-19 pandemic, 35% of the consumers reported an increase in pizza consumption, 31% reported an increase in appetizers/snacks consumption, 26% reported an increase in single-serve entrée consumption (e.g., lasagna, pot pie, meat with sides), and 88% indicated their intention to keep on buying more frozen foods in the upcoming months (AFFI 2020). In conclusion, lockdowns and confinement measures implemented during the COVID-19 pandemic resulted in observable changes in people's dietary preferences, where a significant portion of the general population increased their consumption of high-sodium foods.

4. Driving factors and motivations for increased consumption of high-sodium foods

4.1 Reduced grocery shopping trips

Multiple driving factors contributed to the general preference on processed and preserved foods during the current pandemic. While grocery stores are one of the few public places remaining open during the COVID-19 lockdown, the enclosed and often crowded environment, contact surfaces, and large numbers of visitors in grocery stores may pose elevated risks of COVID-19 transmission (Han et al. 2020; Sidor and Rzymiski 2020). Customers are inclined to reduce their shopping trips to limit their exposure to those perceived 'high-risk' environments. Meanwhile, control measures such as reduced business hours, symptom screening of customers, requirement on social distancing imposed at stores during COVID-19 limit consumers' ability to shop in a normal and largely free manner. Under such circumstances, consumers are inclined to stock up foods with long shelf lives, such as processed and preserved foods, many of which have high sodium contents (Laguna et al. 2020; Sridhar et al. 2020).

4.2 Limited supplies and inflated prices of fresh produce

An important factor contributing to the increased consumption of high-sodium foods is the inadequate supplies and often inflated price of fresh produce during the current pandemic. Picking, fishing, slaughtering, or processing of fresh produce such as fruits and vegetables, meat, fish, and seafood often require labor-intensive work. The enclosed and crowded space in food processing facilities created ideal environments for virus spread, which resulted in clusters of infections in some facilities that were forced to suspend operations during COVID-19 (Gallagher and Kirkland 2020). Under the impact of COVID-19, many seasonal and migrant workers were unable to return to work due to prolonged travel restrictions and potential risks of COVID-19 infections working in labor-intensive environments, causing a shortage of laborers and limited

supplies of fresh produce to consumers (Butler 2019; KAYAK 2021). In the meantime, additional safety requirements and food quarantine extend the time required for food transportation, which increased the risks of food decay (Cullen 2020). These factors have induced an overall increase in food prices in 25 European Union (EU) countries and six non-EU countries, where a positive relation was found between food price inflation and stay-at-home restrictions (Akter 2020). Among the various food categories, meat, fish and seafood, and fresh vegetables showed the most marked increases in their prices. Under such circumstances, processed and preserved foods become the preferred choices for general consumers due to their cost-effectiveness and long shelf lives.

4.3 Psychological and physical changes and emotional eating

There are other important contributors, most notably the psychological and physical factors, to the overall increase of dietary sodium intake during COVID-19. The perceived risks of virus infection, unemployment, financial loss, and disruption of normal social activities affected people's emotional well-being which may subsequently lead to depression, anxiety, fatigue, hypochondria, and insomnia (Di Renzo et al. 2020). Specifically, psychological impact exerted by confinement and quarantine include frustration, boredom, and stress due to inadequate information or supplies (Brooks et al. 2020). Ahmed (2020) reported that over two-thirds (68.1%) of the patients ($n = 765$) visiting bariatric clinics were emotionally unstable after social distancing and self-isolations. Their negative emotional states were mainly expressed by stress ($n = 231$), boredom ($n = 145$), and loneliness ($n = 131$). Rossinot et al. (2020) conducted a web-based survey to assess the behavioral changes and mental state of people in France during COVID-19 confinements, where a total of 1,454 participants provided their responses. The result showed that about half (50.6%) of the participants experienced more depression, stress, or irritation than before since the lockdowns were implemented. Notably, those emotional states were found to be associated with their eating behaviors (**Figure 3**). Di Renzo et al. (2020) conducted an online survey to investigate the linkage between emotional state and eating habits in the Italian population ($n = 602$) during the COVID-19 confinement. Their study found high percentages of respondents reporting negative emotional states, including breathing difficulties (83.1%), tachycardia and feeling faint (81.2%), tension and fatigability (77.1%), anxious feelings (70.4%), and depressed mood (61.3%), and about half of the survey respondents (48.7%–57.8%) reported various types of emotional eating behaviors. Similar findings were reported by Flaudias et al. (2020) who identified a strong correlation between the stress caused by COVID-19 confinement and problematic eating behaviors among undergraduate students ($n = 5,738$) in France, including binge eating and dietary restrictions. Results from an online survey ($n = 365$) conducted by Cecchetto et al. (2021) during COVID-19 lockdown in Italy confirmed that increased emotional eating was strongly associated with high levels of negative emotions (e.g., anxiety, depression), while increased binge eating was associated with higher stress. These emotional issues can have direct consequences on eating habits and dietary preferences, such as mood-driven food consumption characterized by eating palatable foods (e.g., snacks) to cope with the disquiet emotional state (Dallman 2010; Parylak et al. 2011). Consumption of high-sodium food has also been used as a means of relieving mental stress during the pandemic. In certain metropolitan areas in France, people living in large apartment complexes created social media groups named 'pretexte apéro', meaning 'any excuse to get together', which are used for organizing social gatherings to eat sausages and snacks, along with alcoholic drinks (Lichtfouse, 2021).

Prolonged confinements during COVID-19 substantially reduced the levels of daily physical activities, which are also linked with unhealthy food consumption. Excessive sedentary behavior became even more of a problem during COVID-19 lockdowns. Before the current pandemic, sedentary habits such as staying indoor and using electronic devices for extended periods of time, driving to work, using elevators and escalators, sitting in offices for hours had created a virtual 'moving lockdown'. The confinements during COVID-19 aggravated this problem by drastically reducing the activities of people out of their homes (Lichtfouse, 2021).

Castaneda-Babarro et al. (2020) conducted a questionnaire survey on 3,800 Spanish adults aged 18–64 during an early COVID-19 confinement from March 23 to April 1, 2020. The study found that 58.2% ($p < 0.001$) and 16.8% ($p < 0.001$) of the survey respondents reduced walk and vigorous physical activities, respectively, while overall sedentary time increased by 23.8% ($p < 0.001$). Their findings were in line with another recent study in Spain, where authors identified decreased physical activity levels, increased sedentary time, and weight gains during the three months of confinement in the country (Lopez-Moreno et al. 2020). Similar findings on reduced physical activities and increased sedentary time were also widely reported in other countries during COVID-19 confinements (Cheval et al. 2020; Pietrobelli et al. 2020; Qin et al. 2020; Wang et al. 2020b). Excessive sedentary behaviors often lead to low appetite, and are related to unhealthy diets such as less consumption of fresh vegetables and fruits, and increased intake of high-calory or high-sodium foods (e.g., snacks and fast foods) (Pearson and Biddle 2011). Overall, emotional eating behaviors caused by boredom, anxiety, mental stress, and low appetite due to the lack of physical activities during COVID-19 confinements are key driving factors for people to eat unhealthy foods, including processed foods containing high sodium contents.

4.4 Low awareness of sodium contents in foods

A known cause of excessive sodium uptake in the general population is the general low awareness of sodium contents in foods. Particularly, there is a lack of understanding of the difference between salt and sodium, which often leads to the misconception that the main source of sodium is the salts added during cooking or upon serving of food (Marakis et al. 2014). This popular belief contradicts with the actual fact that a much larger amount of sodium is generally added during food processing which consumers cannot directly observe or participate in, and more than half of the sodium intake by the human body comes from processed foods (Mattes and Donnelly 1991). When purchasing foods, some people may not pay enough attention to the sodium contents listed on the nutrition labels attached on food packaging, and thus cannot correctly identify food products with inherently high sodium contents (Marakis et al. 2014; Papadakis et al. 2010). It is noteworthy that the low awareness of sodium contents in food exists widely in both developing and developed countries (**Figure 4**). Using survey data between 1990 and 2010, one study estimated that people aged 20 or above in 187 countries had a mean sodium consumption of 3,950 mg per day, an amount that is nearly twice as high as the maximum daily sodium intake (2,000 mg per day) recommended by the WHO (Powles et al. 2013; WHO 2012). The study further showed that, in most countries ($n = 181$), the average salt intake was also well above the recommended daily intake. Such a prevalent trend may be exacerbated by the limited choices of food supplies and changes in food preference during the COVID-19 pandemic. Overall, the low awareness of sodium contents in food is a long-term contributor to the excessive consumption of high-sodium foods observed in the general population.

5. Food assistance parcels during COVID-19 and their inadvertent effect on promoting high-sodium diets

The disruptions caused by COVID-19 on normal social and economic activities caused more than 110 million people to lose their jobs over 2020, with a large population suddenly plunged into poverty (Richeter, 2021). The risks of COVID-19 infection, mandates on social distancing, and lockdown policies in place have further limited their opportunities to find employment, leaving many people struggling to feed themselves and their families. People turned to food banks and other sources for food assistance. In the UK, people identified as clinically vulnerable to COVID-19 were asked to stay home and to receive their food parcels by delivery.

Over one million food parcels – with items such as canned meat, canned tuna, canned vegetables, multi-packs of soup, and cooking sauce – were delivered to those who needed to self-quarantine at home or without family members or friends to assist with their food supplies (Hamilton 2020; Jenrick 2020). In South Africa, about 58,000 households and 250,000 people received food parcels distributed by the government, which contained cans of baked beans, macaroni, and sachets of instant soup (Clifford 2020; Kahla 2020). In the Philippines, food parcels were distributed to indigent communities across the country, which contained instant noodles, plain biscuits, white bread, canned corned beef, canned sardines, canned tuna, and canned beef loaf (Ong et al. 2020). People in other countries and regions also received food assistance parcels (Niall 2020). In addition, a large number of food parcels were distributed by charity organizations during the COVID-19 pandemic. In the UK, about 1.2 million food parcels were handed out by the ‘Trussell Trust foodbanks’ in the six months to September 2020, and more than 470,000 parcels were sent to children (Anonymous 2020). Another British charity organization named ‘Today Food Alliance’ distributed half a million food parcels in the UK between March 2020 to March 2021, to meet the demand by those facing food shortages or being in self-isolation due to the pandemic (Henderson 2021). The distribution of food parcels, conducted by governments and charities during the lockdown, aimed to provide relief to families and individuals in need of assistance with food supplies. However, it should be noted that a majority of the items in those food parcels are high-sodium foods, such as canned foods and instant foods. While these food parcels provide the much-needed relief for those families and individuals, prolonged consumption of foods with excessive sodium contents can result in health issues, particularly for vulnerable population groups. On the other hand, such risks can be easily alleviated by governments or donors during food procurement by paying more attention to the selection of food items and to balance the need of shelf life, affordability, and risks of promoting a high-sodium diet in these population groups.

6. The need for maintaining a healthy diet with moderate sodium intake during COVID-19

Excessive sodium intake is linked to a plethora of human health issues and disorders, including hypertension, cardiovascular disease, and kidney diseases (de Wardener and MacGregor 2002; Ritz et al. 2009). It was estimated that nearly 100 million adults around the globe had hypertension, and 9–17% of those were attributed to excessive sodium intake from dietary sources (Geleijnse et al. 2004; Kearney et al. 2005). A recent study showed that an increase of 100 mmol in 24-h urinary sodium excretion was correlated with a 1.55 hazard ratio (95% C.I.) of coronary heart disease mortality, 1.38 (95% C.I.) of cardiovascular mortality, and 1.30 (95% C.I.) of all-cause mortality in the adult male Finnish population (Tuomilehto et al. 2001), which can have adverse effects on COVID-19 infection. Sommerstein and Gräni (2020) hypothesized that patients suffered from hypertension and cardiovascular diseases could be at higher risks of COVID-19 infection, as the SARS-CoV-2 virus uses angiotensin-converting enzyme 2 (ACE2) for cell entry. Specifically, angiotensin-converting enzyme inhibitors or angiotensin receptor antagonists, which are used in therapies for patients diagnosed with hypertensive cardiovascular diseases, upregulate the mRNA expression of ACE2 at cell surfaces and therefore, provide more binding targets and viral reservoirs for SARS-CoV-2 (Sommerstein and Gräni 2020).

Epidemiologic and clinical characteristics of COVID-19 patients have demonstrated that there is indeed a positive correlation between certain chronic diseases (e.g., hypertension, cardiovascular diseases, kidney diseases) and clinical symptoms as well as higher fatality rate of COVID-19 (Flythe et al. 2021; Wu and McGoogan 2020). Evidence reported by the Chinese Center for Disease Control and Prevention on 72,314 patients including 44,672 confirmed cases of COVID-19 showed that the overall case-fatality rate was 2.3%, which increased to 6.0% for those with hypertension and further to 10.5% for those with cardiovascular

diseases (Wu and McGoogan 2020). According to a pooled analysis by Lippi et al. (2020b), hypertension was associated with a 2.5-fold increase in risks of severity as well as a similar increase in risks of mortality after COVID-19 infection.

Recent studies have also reported the confounding effects of low serum sodium levels in COVID-19 patients. Sarvazad et al. (2020) detected serum sodium levels in patients diagnosed with COVID-19 with no underlying conditions. In a total of 134 patients, 38% ($n = 51$) showed hyponatremia. Indeed, hyponatremia has been reported in COVID-19 patients, and may be associated with a more severe or fatal course of the disease. Zhang et al. (2020) reported lower serum sodium concentrations in COVID-19 patients with abnormal imaging findings, who typically had a more severe clinical course of the disease. Lippi et al. (2020a) demonstrated that hyponatremia is positively associated with COVID-19 severity. By performing a pooled analysis on early published data on electrolytes in COVID-19 patients with and without severe disease, the study showed a significantly lower serum sodium concentration in patients with severe COVID-19. Further, it has been reported that low dietary sodium intake or low serum sodium level was responsible for kidney involvement in COVID-19 infection via upregulated expression of ACE2 in kidneys (**Figure 5**). Particularly, the human kidney is a strong target for SARS-CoV-2 with a 100-fold higher tissue ACE2 expression than lungs (Fagerberg et al. 2014), and kidney involvement presents a high risk factor correlated with in-hospital death of COVID-19 patients (Cheng et al. 2020). Animal studies showed that increased dietary sodium intake could down-regulate the tissue expression of ACE2. Cao et al. (2017) reported that after three weeks of feeding with different diets (8% vs. 0.4% salt), the ACE2 expression in renal tissues of 0.4%-salt fed rats was about twice of the 8%-salt fed ones. Overall, these findings highlight the importance of maintaining a healthy diet and a balanced sodium intake during COVID-19, as abnormal sodium intakes can affect blood pressure, kidney ACE2 expressions, along with a plethora of other health issues which can have confounding effects on COVID-19 infection and symptom aggravation. To summarize, for those diagnosed with hypertension, cardiovascular, and kidney diseases, it may be necessary to limit their intake of high-sodium foods, given the compelling evidence on their negative health effects and demonstrated effects on COVID-19 aggravation. For those who have acquired COVID-19 infection, it is beneficial to maintain an adequate sodium intake and resuscitate their serum sodium levels to reduce kidney involvement in COVID-19 infections. Given the limited evidence published to date, the underlying effects of dietary sodium intake on COVID-19 infections warrant further investigations.

7. Conclusion

Excessive dietary sodium intake presents a global public health risk that may have been exacerbated during the COVID-19 pandemic. Surveys in different geographical regions and population groups indicated that during the lockdowns, factors such as the perceived risks of infection during shopping trips, limited supplies and inflated prices of fresh produce, consumers' preference for long shelf-life foods, emotional eating, and a general low awareness of sodium contents in food, have tilted the balance towards higher consumption of sodium-rich foods such as canned foods, instant foods, frozen meals, snacks, and other processed foods. Prolonged intake of high-sodium foods significantly increases the risks of hypertension, cardiovascular diseases, and kidney diseases, which in turn increases the susceptibility of human body to SARS-CoV-2 infection and leads to a severe clinical course of COVID-19 disease. Confounding effects were also observed in COVID-19 patients losing body fluids and electrolytes and experiencing hyponatremia. For those individuals, maintaining an adequate sodium intake could down-regulate the tissue expression of ACE2, yielding fewer receptors for SARS-CoV-2 binding and alleviating kidney impairment. For the general public, however, maintaining a healthy diet with a balanced sodium intake and limiting the consumption of high-

sodium foods during COVID-19 confinements can alleviate the risks of developing chronic diseases and help reduce the susceptibility to COVID-19 infection. We therefore appeal to public health authorities, organizations, and the scientific community to take notice of these emerging trends in dietary choices and eating habits, and take actions to advise the general public on the risks as part of the public health management during and after COVID-19.

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Conflict of Interest

The authors declare that they have no conflict of interest in this work.

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Table 1. A list of surveys reporting increased consumption of high-sodium foods during COVID-19 and confinements

Location	Surveyed period	Number of participants	Key findings	Reference
Belgium	2 April to 28 May, 2020	8,640	31.5% of participants reported increased consumption of salty and sweet snacks during the confinement period	Vandevijvere et al. (2020)
France	17 February to 16 March, 2020 (before COVID-19) and 17 March to 16 April, 2020 (during a lockdown)	938	Average salt intake increased from 2.9 g per day (before COVID-19) to 3.2 g per day during the lockdown	Marty et al. (2020)
France	5 March to 11 March, 2020	11,391	36.2% of participants reported more consumption of caloric or salty foods	Rolland et al. (2020)
Italy	23 February to 29 March, 2020	10,769 (stores)	Increases (42%–99%) in sales of pizza and pizza mix, canned beans, canned meat, canned peas, tomato sauce, canned tomato pulp, and diced cold cuts compared with those during the same period in the previous year	Bracale and Vaccaro (2020)
Italy	3 April to 15 April, 2020	1,932	Participants consumed more “comfort foods” such as salty snacks (23.5%) and chocolates, ice creams, desserts (42.5%)	Scarmozzino and Visioli (2020)
Poland	17 April to 1 May, 2020	1,097	Increased consumption of snacks in half of the participants (50.1%) with a normal body mass index, with a higher prevalence rate (61.7%) in obese individuals	Sidor and Rzymiski (2020)
UK	28 April to 22 May, 2020	2,002	56% of participants reported the perception of eating more snacks	Robinson et al. (2021)
USA	9 March to 5 April, 2020	n.a.	Large increases in frozen food purchases including baked goods (+56.2%), beverages (+94.6%), desserts (+33.6%), meals (+60.3%), and snacks (+82.2%)	AFFI (2020)

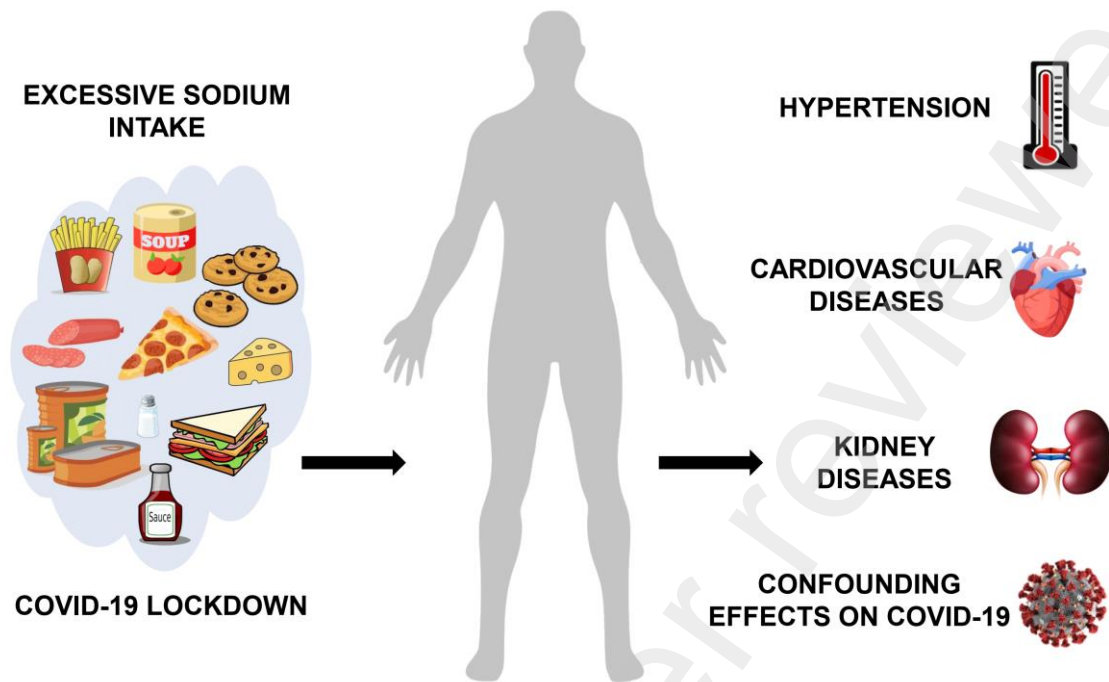


Figure 1. Prolonged excessive consumption of high-sodium foods, such as canned foods, instant foods, snacks, and other processed foods can lead to adverse health effects and chronic diseases (hypertension, cardiovascular diseases, and kidney diseases) in the population during COVID-19 confinements. Excessive sodium intake may have unintended consequences on COVID-19 infection and severity. Chronic diseases associated with high sodium intake is positively correlated with higher severity and mortality of COVID-19 infection, while maintaining an adequate sodium intake can help resuscitate serum sodium levels in patients and reduce kidney involvement in COVID-19 infection.

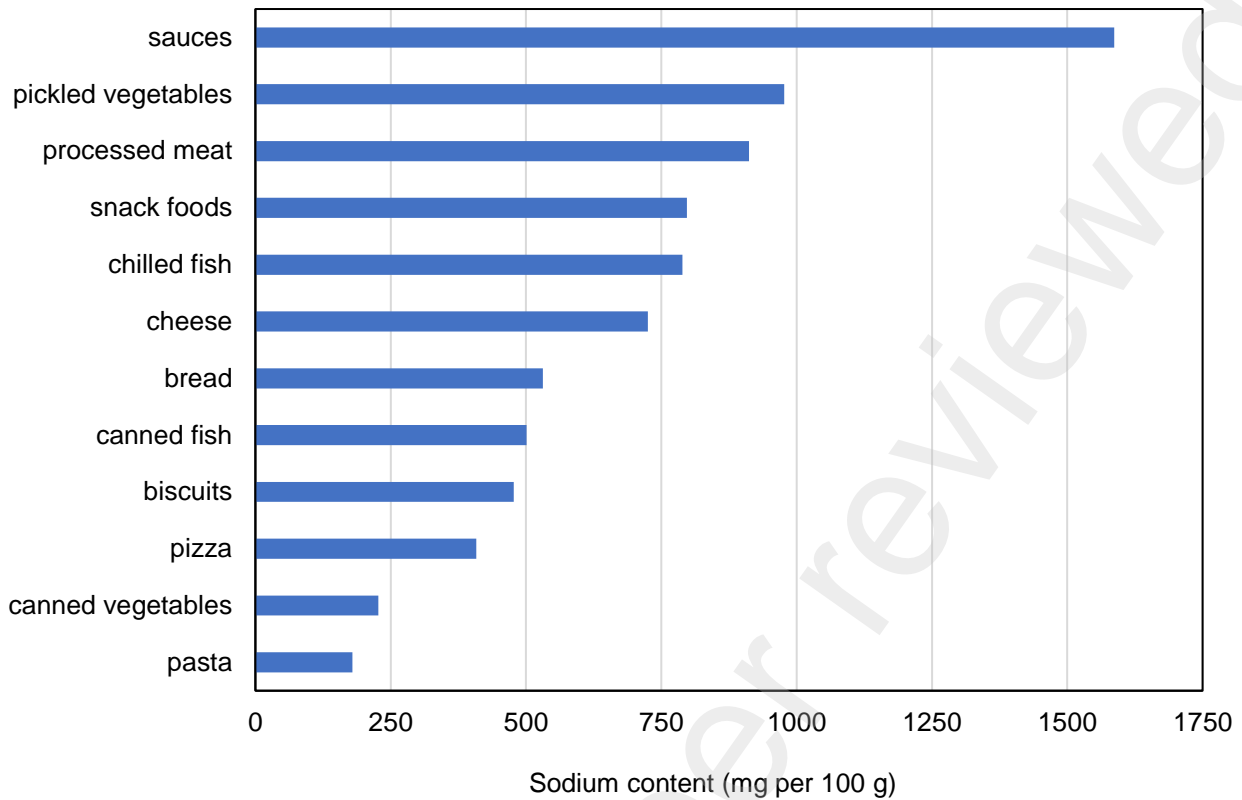


Figure 2. Sodium contents of common processed foods consumed in Australia, based on a typical western diet. The category “sauces” includes table sauces (tomato sauce, chili sauce, barbecue sauce, steak/worcestershire), Asian sauces (mustard, marinade, meat accompaniment, tomato paste, meal-based sauces, powdered, ambient, liquid), pasta sauces (gravy, stock), mayonnaise and dressings; “processed meat” includes bacon, sausages and hot dogs, sliced meat, salami, meat burgers, canned meat, meat with pastry; “snack food” includes potato crisps, salt and vinegar, extruded snacks, corn chips, snack packs. Adapted from Webster et al. (2010).

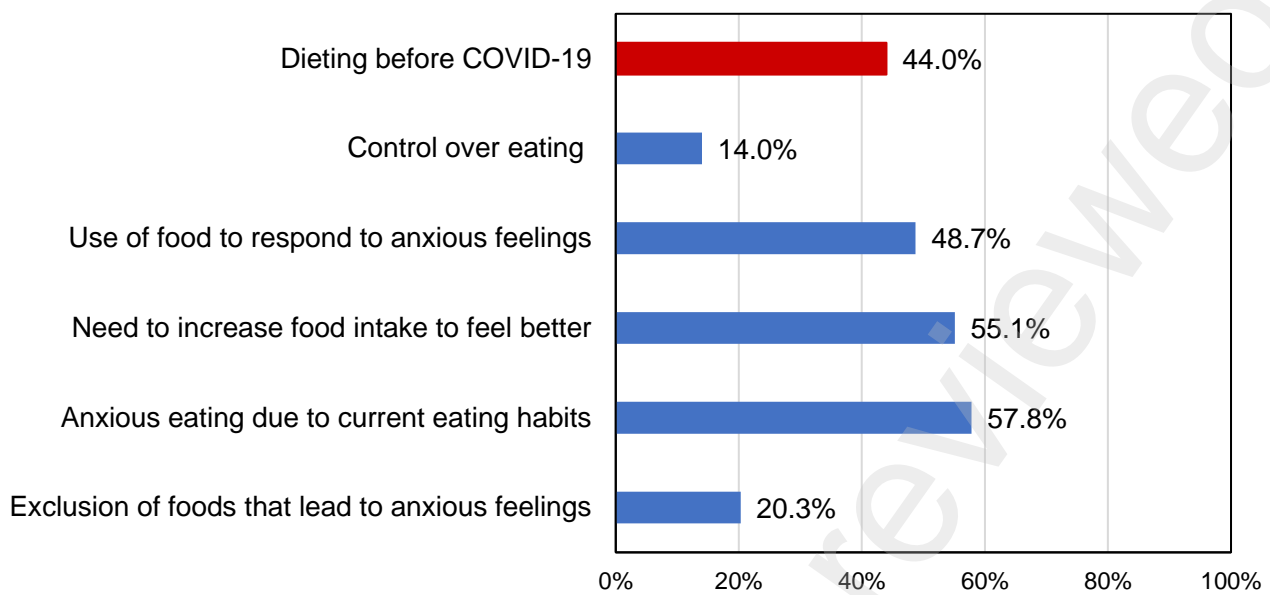


Figure 3. Emotional eating behavior during COVID-19. Percentages of emotional eating in survey respondents during COVID-19 confinement. Data are based on an online survey in Italy ($n = 602$). Among those, 44% reported dieting before COVID-19, while only 14% of the survey respondents reported ‘control over eating’ during COVID-19. Notably, about half of the survey respondents (48.7%–57.8%) reported emotional eating behaviors during COVID-19 confinement. Reprinted from the open-access article by Di Renzo et al. (2020).

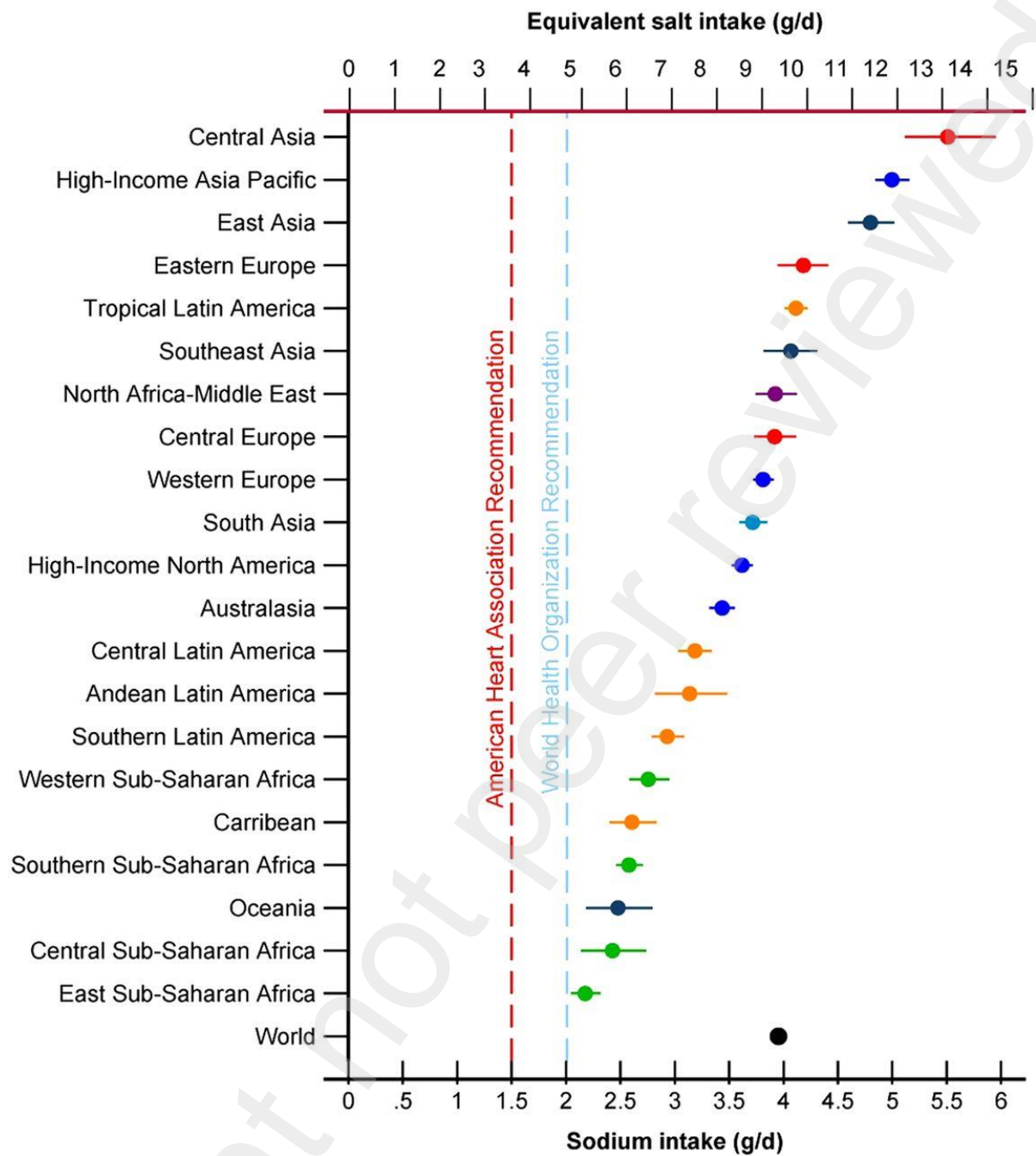


Figure 4. Mean (95% uncertainty interval) age-standardized sodium intakes (g/day) in 2010 in 21 Global Burden of Diseases regions. Regions are ranked by levels in both sexes combined, ages 20 and above. Intakes are not age-standardized. Reprinted from the open-access article by Powles et al. (2013).

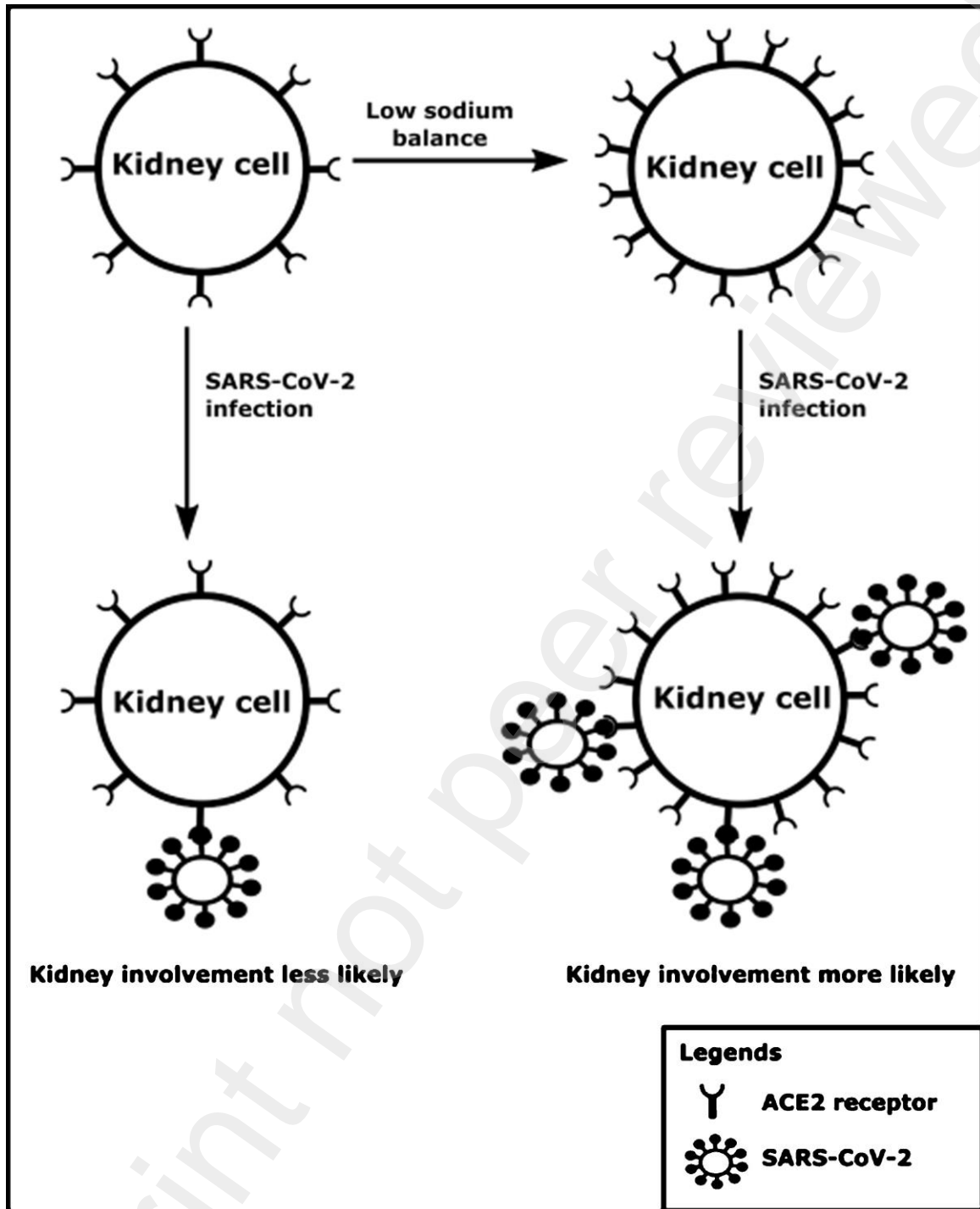


Figure 5. A schematic diagram of the hypothesized interactions between sodium balance, the angiotensin-converting enzyme 2 (ACE2) receptor expression, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), and kidney cell. Reprinted from the open-access article by Post et al. (2020).