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Interwoven challenges of covid-19, poor diet, and cardiometabolic health

Carmen Piernas and **Jordi Merino** argue that suboptimal diet and poor metabolic health aggravated the covid-19 pandemic and require greater attention to increase population resilience and reduce health inequalities

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The covid-19 pandemic emerged at a time when many countries were already grappling with unprecedented levels of obesity and cardiometabolic disease.[1] Underlying poor metabolic health, unhealthy diets, and increased health inequalities compounded the pandemic's economic, public health, and social burdens.

The initial policy responses reasonably aimed at containing the spread of the virus through restricting movement (lockdowns). However, in the context of suboptimal diets and poor metabolic health, these measures unintentionally imposed additional challenges on people's lifestyles, with observed trends towards overeating, unhealthy snacking, and increased alcohol consumption across many countries.[2] In addition, the pandemic restrictions amplified food insecurity, which further compromised dietary quality, especially among people already living in difficult conditions.[3]

Even though effective vaccines and treatment advances have significantly reduced covid-19 severity and death rates, a compromised health system during the pandemic has delayed adequate medical care, increasing morbidity and mortality among those with underlying, preventable, and treatable medical conditions.[4] We argue that suboptimal nutrition, obesity, and cardiometabolic diseases aggravated the burden of covid-19 and propose preventive strategies that can help mitigate future pandemics.

People with obesity and diabetes were disproportionately affected

Early in the pandemic, numerous observational studies reported a high prevalence of obesity and related morbidities among patients admitted to hospital with covid-19.[5] Subsequent evidence has confirmed that obesity and impaired metabolic health are strong independent predictors of covid-19 severity (box 1). A systematic review of studies across the world reported with high certainty that a body mass index (BMI) ≥40 is an independent prognostic risk factor for covid-19 severity and mortality.[6] Body fat distribution, specifically a higher proportion of adipose tissue around the visceral area, has also been associated with worst covid-19 outcomes, though the number of studies is limited.[9]

Box 1: Evidence from systematic reviews and primary studies investigating associations between obesity, diabetes, and covid-19 severity*

Body mass index and body composition

- A Cochrane review and meta-analysis of 149 observational studies including >12 million participants reported with high certainty (based on GRADE system) that severe obesity (BMI>40) is an independent prognostic risk factor for covid-19 mortality. In people with a milder grade of obesity, there is lower certainty evidence for covid-19 death but higher certainty for the risk of intensive care admission or mechanical ventilation[6]
- Other evidence comes from two large community based studies using primary care medical records in the UK. One study in 17 million adults reported increased risk of covid-19 death for BMI 35-39.9 (hazard ratio 1.40; 95% CI 1.30 to 1.52) and ≥40 (1.92; 1.72 to 2.13) compared with a BMI<30.[7] Another study of 6.9 million adults reported a J shaped association for the risk of covid-19 hospital admission, need for intensive care, and death across the whole range of BMI values, with the lowest risk at BMI of 23 and significant linear increases above this point. This study found significant heterogeneity in the reported risks, with younger people and those of black ethnicity showing increased risks of severe covid-19 associated with BMI[8]
- A systematic review of 62 studies investigated the role of body composition on covid-19 severity,[9] reporting that visceral adipose tissue was associated with intensive care admission (6 out of 7 studies) and that intramuscular adipose tissue was associated with covid-19 severity (2 out of 2 studies) and mortality (4 out of 5 studies).
- Mendelian randomisation studies using data from large biorepositories and genetically proxied BMI have consistently reported a causal role of BMI in covid-19 severity, independently, or through its effect on obesity related cardiometabolic disease. However, there is weaker evidence supporting an independent effect of central fat distribution, over and above the observed effects of overall adiposity[10 -12]

Diabetes

- Systematic reviews have consistently reported increased risk of severe covid-19 among people with type 1 and 2 diabetes (odds ratios for in-hospital covid-19 related death 2.86 (95% CI 2.58 to 3.18) for type 1 diabetes and 1.80 (1.75 to 1.86) for type 2 diabetes), with a clear association between glucose control and covid-19 severity and mortality.[13 14] There is also evidence of increased risks in people with

diabetes for haemoglobin A1c levels below and above 58 mmol/mol (7.5%) as well as in people with diabetes and other pre-existing comorbidities[15]

- Mendelian randomisation studies have generally not supported causal associations between genetically proxied type 2 diabetes traits (referring to a genetic predisposition to develop type 2 diabetes, not a clinical diagnosis) and severe covid-19 outcomes, independently of the BMI effect[10 -12]

* Studies have been selected based on their methodological rigour as well as the impact and implications of their results.

Impaired metabolic health, particularly diabetes, has been linked with a worse prognosis after SARS-CoV-2 infection (box 1). Evidence shows that people with type 1 or type 2 diabetes have increased risk of severe covid-19.[13 -15] Particularly, the acute effects of raised blood glucose levels have been shown to affect disease severity after SARS-CoV-2 infection.[16] These findings are in contrast to studies using Mendelian randomisation—a statistical method that uses genetic variants associated with an exposure (ie, diabetes) to examine causal associations with an outcome (ie, covid-19). These studies have not found that type 2 diabetes and glycaemic traits are causally related to severe covid-19 outcomes, suggesting that the increased risk of severe covid-19 attributed to type 2 diabetes may be largely mediated by adiposity.[10 -12] These contrasting findings warrant further investigation as, given the molecular heterogeneity of type 2 diabetes, covid-19 severity might be associated with specific phenotypes related to insulin resistance and systemic inflammation.

The rates of severe illness and death from covid-19 have been drastically reduced since the introduction of vaccines. Early reports hypothesised that covid-19 vaccines might be less effective in people with obesity because of poorer innate and adaptive immune responses, as seen with vaccines for other respiratory viruses.[17] However, a community based study using primary care medical records from 9 million adults in the UK comparing vaccinated and unvaccinated people showed a high level of protection against severe covid-19 regardless of weight.[18] A J shaped association was reported among fully vaccinated individuals, with increased risk of severe covid-19 outcomes found at both extremes of the BMI spectrum. Consistent results were subsequently observed after the administration of boosters.[19] Similarly, poor glycaemic control in people with type 2 diabetes has been associated with a worse immunological response after vaccination and increased risk of SARS-CoV-2 infection.[20 -22] Although debate continues about the need for boosters against new SARS-CoV-2 variants across the population, experts agree that the most vulnerable people will benefit from them, and this includes those with poor metabolic health and risk factors such as obesity.[23]

Prolonged symptoms after SARS-CoV-2 infection—long covid—are an increasing public health concern. Long covid is a debilitating illness comprising over 200 symptoms affecting multiple organ systems.[24] Population based studies of large cohorts from England, including a cohort of 17 million adults, have reported an increased risk of clinically coded long covid in people with obesity compared with those without obesity.[25 26] In absolute terms, the increased risk of developing long covid was marginal among people with obesity who had received at least two doses of the vaccine, and overall null effects were reported for diabetes and cardiovascular risk factors before and after vaccination.[26]

Suboptimal diets underlie disease

Our understanding of the relation between nutrition and immunity has evolved since the 18th century, when observations first linked nutritional deficiencies to increased mortality rates from infectious diseases. We now have extensive knowledge about the crucial role that nutrition plays in supporting immune system function,[27] and global health organisations and medical societies endorse healthy dietary patterns to help tackle the complex public health challenges arising from the intersection of communicable and non-communicable diseases.

The evidence around dietary patterns, consumption of specific foods, and supplement use in relation to covid-19 outcomes has increased, though most comes from observational studies that recruited health conscious participants from higher income countries (table 1). A study of 3000 healthcare workers from six countries showed that people following plant based or pescatarian dietary patterns had lower odds of moderate-to-severe covid-19, independent of other potential confounders such as comorbidities and demographic or lifestyle factors, including BMI.[28] Data from the covid-19 Symptom Study, a smartphone based survey of nearly 600 000 people in the UK and US before vaccines were available, showed that a dietary pattern consisting of healthy plant based foods was associated with a lower risk of infection and a lower risk of hospital admission related to covid-19.[30] Another study showed that adherence to a Mediterranean diet is related to a lower risk of covid-19,[29] while consumption of ultra-processed foods or sugar sweetened beverages has been linked with increased covid-19 infection and mortality, respectively.[31 32]These studies underscore the potential benefits of adopting a healthy diet, independently of other risk factors, in lowering covid-19 risk and severity, over and above the known beneficial effects on non-communicable diseases.

Table 1 | Overview of selected studies investigating links between diet and covid-19 risk and severity*

Study characteristics	Summary of findings
Dietary patterns	
Case-control study including 3000 healthcare workers from six countries[28]	Plant based diets or pescatarian diets were associated with lower odds of moderate-to-severe covid-19 (ORs 0.28, 95% CI 0.10 to 0.82 and 0.41, 0.16 to 0.99, respectively, compared with those that didn't follow those diets)
Prospective study including 5194 health professionals from Spain[29]	High adherence to Mediterranean diet was associated with lower odds of covid-19 (OR 0.36, 0.16 to 0.84) compared with low adherence
Prospective study including 592 571 participants from the UK and US[30]	Diet characterised by healthy plant based foods was associated with lower risk (HR 0.91, 95% CI 0.88 to 0.94) and severity (0.59, 0.47 to 0.74) of covid-19 compared with lower dietary quality
Food groups	
Prospective study in 41 012 UK Biobank participants[31]	Higher consumption of ultra-processed foods was associated with higher odds (OR 1.22, 95%CI 1.12 to 1.34) of covid-19 infection compared with lower consumption
Ecological study including data from 158 countries[32]	Covid-19 mortality was higher for higher sugar sweetened beverages intakes and lower for higher fruits, beans, and legumes intake
Prospective study in 37 988 UK Biobank participants [33]	Higher *v* lower consumption of coffee (OR 0.90, 0.83 to 0.96) and vegetables (0.88, 0.80 to 0.98) was associated with lower odds of covid-19 infection; but higher odds for those consuming processed meat 1.14, 1.01 to 1.29)
Supplements	
Randomised trial of 34 601 adults from Norway[34]	Supplementation with cod liver oil did not reduce the incidence of SARS-CoV-2 infection (RR 1.00, 99.9% CI 0.82 to 1.22) or serious covid-19 (1.20, 0.87 to 1.65)
Systematic review and meta-analysis of nutrient supplementation[35]	Vitamins C, D, and zinc supplementation were not associated with reduced covid-19 mortality (RR 1.00, 95% CI 0.62 to 1.62; 0.75, 0.49 to 1.17; and 0.79, 0.60 to 1.03, respectively)
Prospective study including 372 720 UK participants[36]	Modest association between use of probiotics, omega-3 fatty acid, multivitamin, or vitamin D supplements and lower risk of testing positive for SARS-CoV-2 (14%, 95% CI 8% to 19%; 12%, 8% to 16%; 13%, 10% to 16%; and 9%, 6% to 12%, respectively). Associations were significant only in women after sex stratification

* Studies have been selected based on their methodological rigour as well as the impact and implications of their results.

Despite evidence of benefit for dietary patterns, there is no evidence that using dietary supplements reduces the risk of covid-19 infection and complications.[34 -36] The strongest evidence comes from randomised clinical trials of vitamin D supplementation, one of which found no effect on the incidence of covid-19.[37] One reason for this difference could be that a healthy diet improves immunity and protects against infectious disease outcomes through the effect of multiple nutritional components that interact with many cellular mechanisms and metabolic processes.

Importance of nutritional status in lower socioeconomic groups

Overstretched health systems and socioeconomic inequalities have increased vulnerability in certain communities and contributed to disparities in mortality during the covid-19 pandemic. Before covid-19, people living in areas of higher deprivation were already disproportionally affected by obesity and cardiometabolic disease.[38] During covid-19, these communities were particularly affected by food insecurity, experiencing more problems in maintaining healthy food habits and meeting nutrient recommendations,[3] including families with children relying on school meal programmes. The Covid-19 Eating and Activity Over Time Study surveyed people experiencing food insecurity in the US, who reported increases in irregular eating patterns and hunger as well as lower consumption of fruits and vegetables and higher intakes of fast food or takeaways during the lockdown.[39] Evidence indicates that an adequate nutritional status is particularly important for people living in disadvantaged communities in the context of covid-19. For instance, results from the Covid-19 Symptom Study suggest that nearly one third of covid-19 cases in people living in areas of high economic deprivation could have been prevented if poor diet quality or socioeconomic deprivation were absent.[30] These observed patterns during covid-19 may have implications for people's nutritional status and susceptibility to infections,[40] reinforcing the need for effective public policies tackling food insecurity.

Can we be ready for the future?

The evidence supporting the intricate connections between diet, cardiometabolic health, and covid-19 emerged as a focal point in public health research during the pandemic. People with underlying cardiometabolic diseases, often influenced by poor dietary habits and complex social determinants of health, are widely recognised as having a higher risk of severe covid-19 outcomes. While the world navigates the current "post-pandemic phase," it is imperative to shift our attention to dietary adequacy and metabolic health.

We need to empower people to adopt healthier dietary patterns and promote nutrition in order to strengthen immune function and resilience against infections (fig 1). In the context of a pandemic such as covid-19, public health policies must ensure equitable access to healthy foods, particularly in vulnerable communities. Specifically, policies that help improve food security and reduce food deserts, as well as strategies to make healthier options more accessible and affordable while making unhealthier options less ubiquitous, convenient, and cheap can be transformative. Adequate nutrition is even more essential for deprived communities and in low and middle income countries where food insecurity is common.[41] Nutrient deficiencies and sarcopenia are prevalent in older people and have been documented in patients admitted to hospital with covid-19.[42] Deficiencies in key nutrients may expose these groups to greater morbidity and mortality after infection.[43] Effective coordination between public health agencies, healthcare providers, food authorities, and community organisations is crucial

to ensure a comprehensive and responsive public health approach to mitigate the consequences of a pandemic.

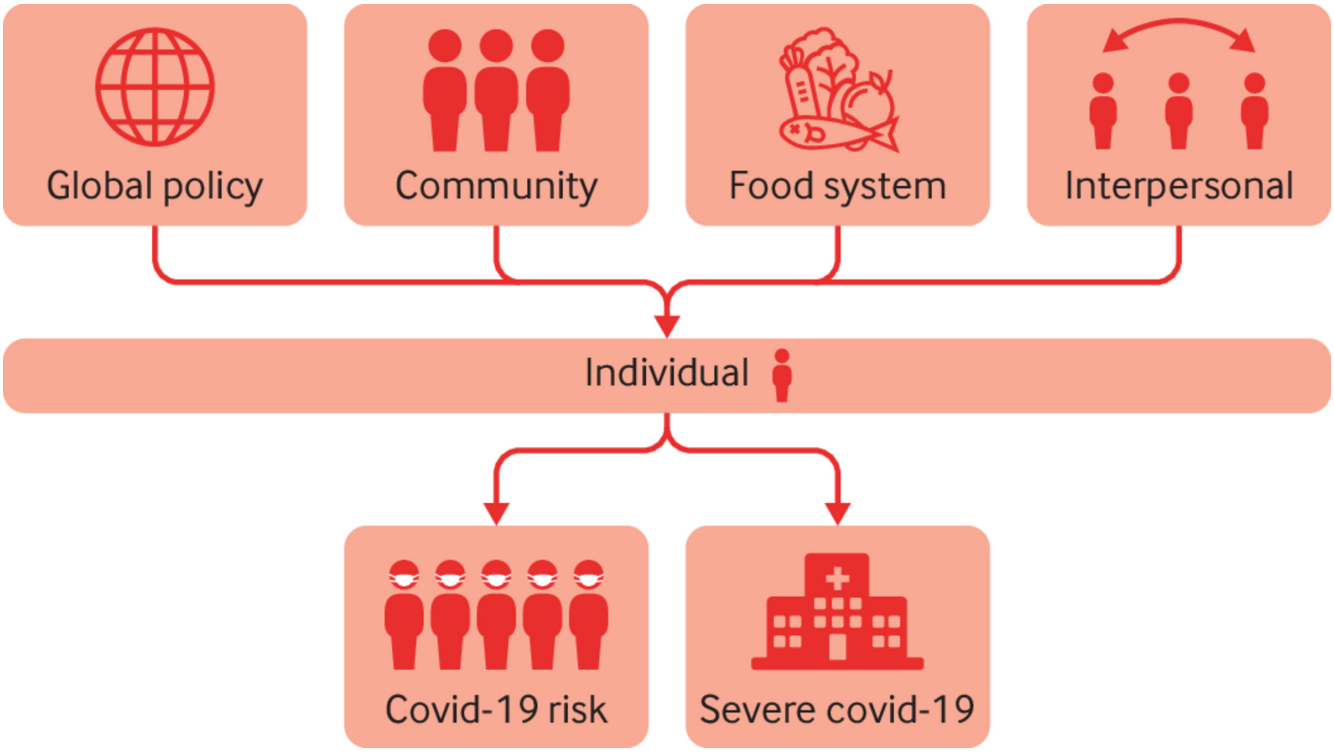

Fig 1 | Factors influencing diet and consequently risk of cardiometabolic disease and covid-19

Recognition of the relevance of diet related diseases such as obesity and type 2 diabetes as risk factors for infectious disease severity can guide targeted public health efforts to protect the most vulnerable people. For instance, as scientific data on covid-19 risk factors became rapidly available, some countries prioritised vaccinating people with diabetes and severe obesity.[44] However, the success of these targeted vaccination programmes can vary as people may underestimate the seriousness of their disease or may not consider themselves at risk of infection. Hence, communication strategies must ensure that programmes reach those at risk, especially in disadvantaged communities where obesity and cardiometabolic diseases are still underdiagnosed and undertreated. In addition, given the high prevalence of obesity and cardiometabolic disease globally, efforts must continue to support people to achieve and maintain a healthy weight. Evidence suggests that even modest weight loss can rapidly improve insulin resistance and cardiometabolic risk factors, which can help reduce infectious disease severity. A comparative risk assessment study suggested that a 10% reduction in the prevalence of obesity and type 2 diabetes would have prevented around 11% of covid-19 hospital admissions among US adults from March 2020 to November 2020.[45]

The covid-19 crisis has been a stark reminder of the vulnerabilities in our healthcare systems. The prioritisation of emergency clinics and the transformation of routine hospital rooms into intensive care units negatively affected cardiometabolic risk management,[46] which may have contributed to longer term health consequences that we are just starting to observe.[47] Populations with the highest burden of covid-19, including people affected by chronic disease or multimorbidity and those with a poor nutritional status, should therefore be prioritised for healthcare and specialised nutritional support (eg, older adults at risk of malnutrition) to reduce disease severity.

Overall, the covid-19 pandemic has amplified existing inequalities and undermined the already fragile progress towards achieving the United Nations sustainable development goals by 2030, particularly those concerning good health and wellbeing for all. Amid this challenge, lies a real opportunity to raise the profile of optimal nutrition within the intricate social determinants of health. By recognising the importance of nutrition as a critical component, health systems can be reoriented towards a proactive approach that emphasises health promotion rather than focusing solely on treatment. Emphasising nutrition as a core pillar of public health efforts will be instrumental not only to combating the immediate effects of covid-19 and other prevalent chronic diseases but also to paving the way for reducing health inequalities while building healthier and more resilient populations.

Key messages

- Poor metabolic health together with unhealthy diets and health inequalities have compounded the covid-19 pandemic's economic, social, and public health burdens
- Studies have consistently reported that obesity and diabetes are independent predictors of covid-19 severity
- Evidence from dietary studies suggests that adopting a healthy dietary pattern lowers covid-19 risk and severity, especially in disadvantaged communities
- Health policy needs to recognise obesity and metabolic health as important risk factors for infectious disease severity and prioritise higher risk groups for healthcare and nutritional support
- Reorienting health systems towards health promotion, including targeted efforts to reduce existing inequalities, will increase resilience

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to the first draft of the manuscript, provided critical revisions and gave intellectual input to improve the manuscript and have read and approved the final version. CP is the guarantor.

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1 NCD Risk Factor Collaboration (NCD-RisC). Trends in adult body-mass index in 200 countries from 1975 to 2014: a pooled analysis of 1698 population-based measurement studies with 19·2 million participants. *Lancet* 2016;387:-96. doi: 10.1016/S0140-6736(16)30054-X pmid: 27115820

2 Mignogna C, Costanzo S, Ghulam A, etal. Impact of nationwide lockdowns resulting from the first wave of the COVID-19 pandemic on food intake, eating behaviors, and diet quality: a systematic review. *Adv Nutr* 2022;13:-423. doi: 10.1093/advances/nmab130 pmid: 34967842

3 Crowder SL, Beckie T, Stern M. A review of food insecurity and chronic cardiovascular disease: implications during the COVID-19 pandemic. *Ecol Food Nutr* 2021;60:-611. doi: 10.1080/03670244.2021.1956485 pmid: 34617867

4 CDC. Excess deaths associated with covid-19. 2022. https://www.cdc.gov/nchs/nvss/vs-rr/covid19/excess_deaths.htm.

5 Richardson S, Hirsch JS, Narasimhan M, etalthe Northwell COVID-19 Research Consortium. Presenting characteristics, comorbidities, and outcomes among 5700 patients hospitalized with covid-19 in the New York City area. *JAMA* 2020;323:-9. doi: 10.1001/jama.2020.6775 pmid: 32320003

6 Tadayon Najafabadi B, Rayner DG, Shokraee K, etal. Obesity as an independent risk factor for COVID-19 severity and mortality. *Cochrane Database Syst Rev* 2023;5:CD015201.pmid: 37222292

7 Williamson EJ, Walker AJ, Bhaskaran K, etal. Factors associated with COVID-19-related death using OpenSAFELY. *Nature* 2020;584:-6. doi: 10.1038/s41586-020-2521-4 pmid: 32640463

8 Gao M, Piernas C, Astbury NM, etal. Associations between body-mass index and COVID-19 severity in 6·9 million people in England: a prospective, community-based, cohort study. *Lancet Diabetes Endocrinol* 2021;9:-9. doi: 10.1016/S2213-8587(21)00089-9 pmid: 33932335

9 Montes-Ibarra M, Orsso CE, Limon-Miro AT, etal. Prevalence and clinical implications of abnormal body composition phenotypes in patients with covid-19: a systematic review. *Am J Clin Nutr* 2023;117:-305. doi: 10.1016/j.ajcnut.2023.04.003 pmid: 37037395

10 Gao M, Wang Q, Piernas C, etal. Associations between body composition, fat distribution and metabolic consequences of excess adiposity with severe COVID-19 outcomes: observational study and Mendelian randomisation analysis. *Int J Obes (Lond)* 2022;46:-50. doi: 10.1038/s41366-021-01054-3 pmid: 35031696

11 Leong A, Cole JB, Brenner LN, Meigs JB, Florez JC, Mercader JM. Cardiometabolic risk factors for COVID-19 susceptibility and severity: a mendelian randomization analysis. *PLoS Med* 2021;18:e1003553. doi: 10.1371/journal.pmed.1003553 pmid: 33661905

12 Ponsford MJ, Gkatzionis A, Walker VM, etal. cardiometabolic traits, sepsis, and severe covid-19: a mendelian randomization investigation. *Circulation* 2020;142:-3. doi: 10.1161/CIRCULATIONAHA.120.050753 pmid: 32966752

13 Hartmann-Boyce J, Rees K, Perring JC, etal. Risks of and from SARS-CoV-2 infection and COVID-19 in people with diabetes: a systematic review of reviews. *Diabetes Care* 2021;44:-811. doi: 10.2337/dc21-0930 pmid: 34711637

14 Barron E, Bakhai C, Kar P, etal. Associations of type 1 and type 2 diabetes with covid-19-related mortality in England: a whole-population study. *Lancet Diabetes Endocrinol* 2020;8:-22. doi: 10.1016/S2213-8587(20)30272-2 pmid: 32798472

15 Schlesinger S, Lang A, Christodoulou N, etal. Risk phenotypes of diabetes and association with COVID-19 severity and death: an update of a living systematic review and meta-analysis. *Diabetologia* 2023;66:-412. doi: 10.1007/s00125-023-05928-1 pmid: 37204441

16 Codo AC, Davanzo GG, Monteiro LB, etal. Elevated glucose levels favor SARS-CoV-2 infection and monocyte response through a HIF-1α/glycolysis-dependent axis. *Cell Metab* 2020;32:-9. doi: 10.1016/j.cmet.2020.07.015 pmid: 32877692

17 Honce R, Schultz-Cherry S. Influenza in obese travellers: increased risk and complications, decreased vaccine effectiveness. *J Travel Med* 2019;26:taz020. doi: 10.1093/jtm/taz020 pmid: 30924873

18 Piernas C, Patone M, Astbury NM, etal. Associations of BMI with COVID-19 vaccine uptake, vaccine effectiveness, and risk of severe COVID-19 outcomes after vaccination in England: a population-based cohort study. *Lancet Diabetes Endocrinol* 2022;10:-80. doi: 10.1016/S2213-8587(22)00158-9 pmid: 35780805

19 Agrawal U, Bedston S, McCowan C, etal. Severe COVID-19 outcomes after full vaccination of primary schedule and initial boosters: pooled analysis of national prospective cohort studies of 30 million individuals in England, Northern Ireland, Scotland, and Wales. *Lancet* 2022;400:-20. doi: 10.1016/S0140-6736(22)01656-7 pmid: 36244382

20 Khunti K, Valabhji J, Misra S. Diabetes and the COVID-19 pandemic. *Diabetologia* 2023;66:-66. doi: 10.1007/s00125-022-05833-z pmid: 36418578

21 Marfella R, Sardu C, D'Onofrio N, etal. Glycaemic control is associated with SARS-CoV-2 breakthrough infections in vaccinated patients with type 2 diabetes. *Nat Commun* 2022;13:. doi: 10.1038/s41467-022-30068-2 pmid: 35484164

22 Hippisley-Cox J, Coupland CA, Mehta N, etal. Risk prediction of covid-19 related death and hospital admission in adults after covid-19 vaccination: national prospective cohort study. *BMJ* 2021;374:. doi: 10.1136/bmj.n2244 pmid: 34535466

23 Should I get a COVID-19 booster?. *Science* 2023.

24 Davis HE, McCorkell L, Vogel JM, Topol EJ. Long COVID: major findings, mechanisms and recommendations. *Nat Rev Microbiol* 2023;21:-46. doi: 10.1038/s41579-022-00846-2 pmid: 36639608

25 Thompson EJ, Williams DM, Walker AJ, etalOpenSAFELY Collaborative. Long COVID burden and risk factors in 10 UK longitudinal studies and electronic health records. *Nat Commun* 2022;13:. doi: 10.1038/s41467-022-30836-0 pmid: 35764621

26 Wei Y, Horne EM, Knight R, etal. Patient characteristics associated with clinically coded long COVID: an OpenSAFELY study using electronic health records.*medRxiv* 2023:2023.06.23.23291776. [Preprint.] doi: 10.1101/2023.06.23.23291776

27 Calder PC. Nutrition and immunity: lessons for COVID-19. *Eur J Clin Nutr* 2021;75:-18. doi: 10.1038/s41430-021-00949-8 pmid: 34163017

28 Kim H, Rebholz CM, Hegde S, etal. Plant-based diets, pescatarian diets and COVID-19 severity: a population-based case-control study in six countries. *BMJ Nutr Prev Health* 2021;4:-66. doi: 10.1136/bmjnph-2021-000272 pmid: 34308134

29 Perez-Araluce R, Martinez-Gonzalez MA, Fernández-Lázaro CI, Bes-Rastrollo M, Gea A, Carlos S. Mediterranean diet and the risk of COVID-19 in the 'Seguimiento Universidad de Navarra' cohort. *Clin Nutr* 2022;41:-8. doi: 10.1016/j.clnu.2021.04.001 pmid: 33934925

30 Merino J, Joshi AD, Nguyen LH, etal. Diet quality and risk and severity of COVID-19: a prospective cohort study. *Gut* 2021;70:-104. doi: 10.1136/gutjnl-2021-325353 pmid: 34489306

31 Zhou L, Li H, Zhang S, Yang H, Ma Y, Wang Y. Impact of ultra-processed food intake on the risk of COVID-19: a prospective cohort study. *Eur J Nutr* 2023;62:-87. doi: 10.1007/s00394-022-02982-0 pmid: 35972529

32 Abdulah DM, Hassan AB. Relation of dietary factors with infection and mortality rates of COVID-19 across the world. *J Nutr Health Aging* 2020;24:-8. doi: 10.1007/s12603-020-1512-3 pmid: 33155630

33 Vu TT, Rydland KJ, Achenbach CJ, Van Horn L, Cornelis MC. Dietary behaviors and incident COVID-19 in the UK Biobank. *Nutrients* 2021;13:. doi: 10.3390/nu13062114 pmid: 34203027

34 Brunvoll SH, Nygaard AB, Ellingjord-Dale M, etal. Prevention of covid-19 and other acute respiratory infections with cod liver oil supplementation, a low dose vitamin D supplement: quadruple blinded, randomised placebo controlled trial. *BMJ* 2022;378:e071245. doi: 10.1136/bmj-2022-071245 pmid: 36215222

35 Beran A, Mhanna M, Srour O, etal. Clinical significance of micronutrient supplements in patients with coronavirus disease 2019: A comprehensive systematic review and meta-analysis. *Clin Nutr ESPEN* 2022;48:-77. doi: 10.1016/j.clnesp.2021.12.033 pmid: 35331487

36 Louca P, Murray B, Klaser K, etal. Modest effects of dietary supplements during the COVID-19 pandemic: insights from 445 850 users of the COVID-19 Symptom Study app. *BMJ Nutr Prev Health* 2021;4:-57. doi: 10.1136/bmjnph-2021-000250 pmid: 34308122

37 Bergman P. Can vitamin D protect against covid-19?*BMJ* 2022;378:doi: 10.1136/bmj.o1822.

38 Townsend MJ, Kyle TK, Stanford FC. Outcomes of COVID-19: disparities in obesity and by ethnicity/race. *Int J Obes (Lond)* 2020;44:-9. doi: 10.1038/s41366-020-0635-2 pmid: 32647359

39 Larson N, Slaughter-Acey J, Alexander T, Berge J, Harnack L, Neumark-Sztainer D. Emerging adults' intersecting experiences of food insecurity, unsafe neighbourhoods and discrimination during the coronavirus disease 2019 (COVID-19) outbreak. *Public Health Nutr* 2021;24:-30. doi: 10.1017/S136898002000422X pmid: 33092665

40 Nagata JM, Seligman HK, Weiser SD. Perspective: the convergence of coronavirus disease 2019 (covid-19) and food insecurity in the United States. *Adv Nutr* 2021;12:-90. doi: 10.1093/advances/nmaa126 pmid: 32970098

41 UN Food and Agriculture Organisation. The state of food security and nutrition in the world. 2021. http://www.fao.org/state-of-food-security-nutrition.

42 Li T, Zhang Y, Gong C, etal. Prevalence of malnutrition and analysis of related factors in elderly patients with COVID-19 in Wuhan, China. *Eur J Clin Nutr* 2020;74:-5. doi: 10.1038/s41430-020-0642-3 pmid: 32322046

43 Silverio R, Gonçalves DC, Andrade MF, Seelaender M. Coronavirus disease 2019 (covid-19) and nutritional status: the missing link?*Adv Nutr* 2021;12:-92. doi: 10.1093/advances/nmaa125 pmid: 32975565

44 Joint Committee on Vaccination and Immunisation. *Advice on priority groups for COVID-19 vaccination.* Department of Health and Social Care, 2020.

45 O'Hearn M, Liu J, Cudhea F, Micha R, Mozaffarian D. Coronavirus disease 2019 hospitalizations attributable to cardiometabolic conditions in the United States: a comparative risk assessment analysis. *J Am Heart Assoc* 2021;10:e019259. doi: 10.1161/JAHA.120.019259 pmid: 33629868

46 Carr MJ, Wright AK, Leelarathna L, etal. Impact of COVID-19 on diagnoses, monitoring, and mortality in people with type 2 diabetes in the UK. *Lancet Diabetes Endocrinol* 2021;9:-5. doi: 10.1016/S2213-8587(21)00116-9 pmid: 33989537

47 Valabhji J, Barron E, Gorton T, etal. Associations between reductions in routine care delivery and non-COVID-19-related mortality in people with diabetes in England during the COVID-19 pandemic: a population-based parallel cohort study. *Lancet Diabetes Endocrinol* 2022;10:-70. doi: 10.1016/S2213-8587(22)00131-0 pmid: 35636440