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Nutrition and Immunity: Lessons for COVID-19

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ABSTRACT:

The immune system's job is to defend the person from harmful pathogens. The immune response is influenced by a variety of factors, and a healthy diet is crucial for promoting immunity. Aging adults, especially those who are fragile, obese, malnourished, or who consume insufficient amounts of micronutrients, can have reduced immunity. Due to immune system deficits brought on by inadequate nutrition, people are more susceptible to infections, which can worsen or even prove fatal. The detrimental effects of inadequate nutrition on the immune system, especially its inflammatory component, may be one of the explanations for the greater risk of more severe consequences from SARS-CoV-2 infection reported in older individuals and those who are obese. Studies on specific micronutrients, such as zinc and vitamin D, suggest roles in lowering the severity of SARS-CoV-2 infection. A diverse gut microbiota, which supports the immune system, can be encouraged through healthy eating. Assuring strong responses to vaccinations is also based on the significance of nutrition in promoting the immune response. For the fight against SARS-CoV-2, there are numerous lessons to be learned from the research on immunity and nutrition.

INTRODUCTION:

A wide class of single-stranded RNA viruses called coronaviruses are responsible for respiratory and, less frequently, gastro-intestinal disorders. Coronaviruses can produce a variety of respiratory symptoms, from severe pneumonia to symptoms similar to the common cold or moderate influenza. A new coronavirus that causes pneumonia and death was discovered in Wuhan, China, in December 2019. It is known as the severe acute respiratory distress syndrome coronavirus (SARS-CoV) 2 (SARS-CoV-2) because it shares genetic similarities with the SARS-CoV that caused an outbreak of the condition in 2002. Although The SARS-CoV-2 virus, also known as COVID-19 or coronavirus disease found in 2019, is the eighth known human coronavirus. Because it is unfamiliar to the human immune system, SARS-CoV-2 spread quickly and produced such severe illness. This is because there was no underlying immunity to the virus. Due to the severity of COVID-19 and the extent of the health, societal, and economic consequences that have resulted from the presence of SARS-CoV-2, there has been increased awareness of the destruction that infectious diseases can cause as well as the significance of immune systems that are in good working order. Whereas earlier this was either not properly recognised or just accepted, inadequate immune responses

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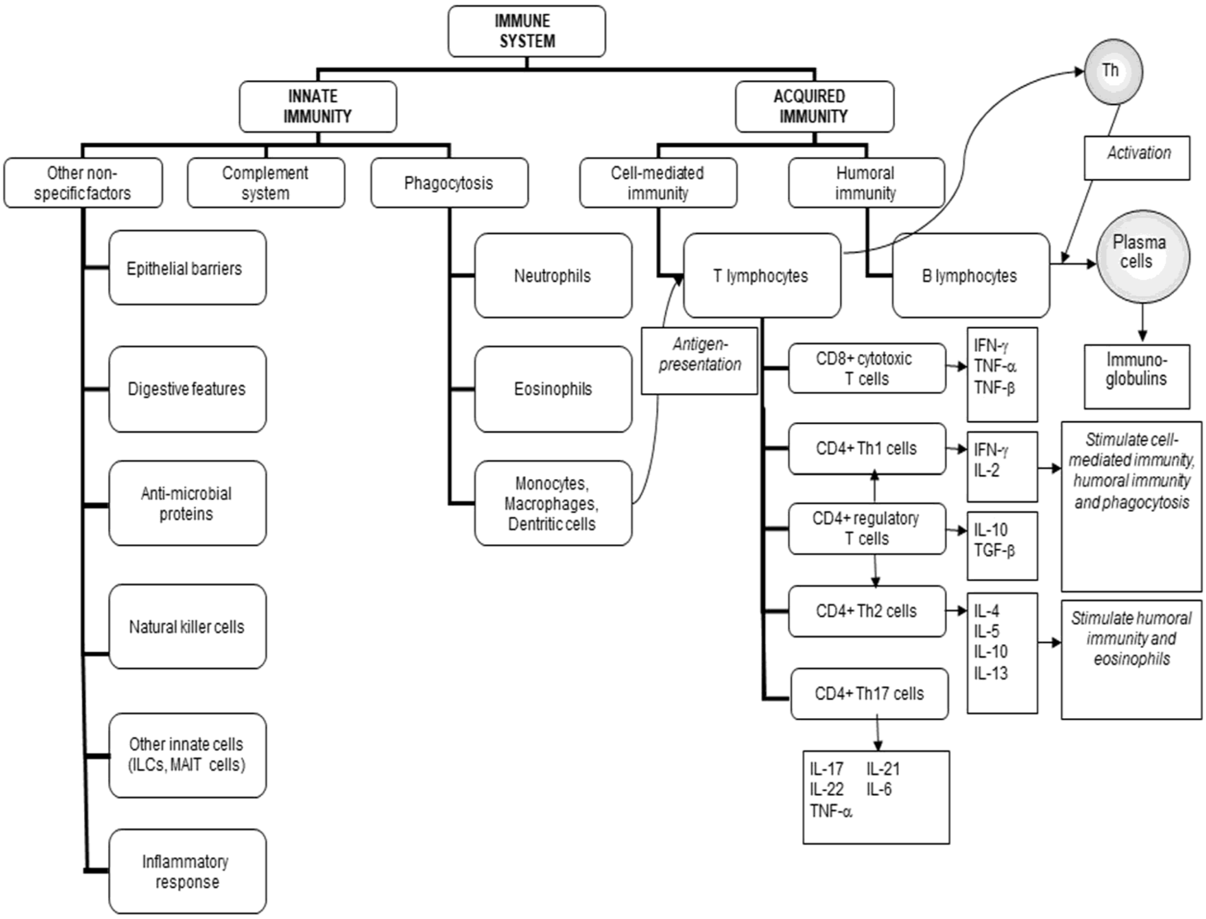
have been shown as a significant public health liability. Vaccines function by instructing the immune system how to effectively combat a virus. "However, vaccinations themselves require a robust immune response to work properly, and there has been some discussion about the usefulness of some of the vaccines among those groups of the population who may have weak immune responses. The apparent efficacy of the recently developed vaccines to protect against COVID-19 is evidence of the innate immune system weakness among significant subgroups in the population. It is also likely that additional vaccines will be developed in the future as a result of the emergence of new SARS-CoV-2 variants". Along with the current vaccination programmes, in the interim, the



"Fig. 1The components of the immune system and their division into innate and acquired immunity. IFN interferon, IL interleukin, ILCs innate lymphoid cells, MAIT mucosal associated invariant T, TGF transforming growth factor, TNF tumour necrosis factor".

It's crucial to take into account additional measures that can be taken to assist the immune system when developing new vaccinations and testing new anti-viral medications. The impact of ageing, frailty, obesity, micronutrients, and the gut microbiota on the human immune system will be discussed in this paper, with specific reference to COVID-19 and SARS-CoV-2 infections.

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AN OVERVIEW OF THE ROLE AND ORGANIZATION OF THE IMMUNE SYSTEM:

“The immune system's main job is to defend the body against harmful organisms such bacteria, viruses, fungi, and parasites. The human immune system has developed to encompass a vast variety of cell types, numerous communicating molecules, and numerous functional responses so that it may effectively defend against a variety of hazardous species (Fig.1). There are four main functions of the immune system”. It serves as a barrier to prevent microorganisms from entering the body in the first place. Second, the immune system recognises germs and determines whether or not they are hazardous. Thirdly, the immune system works to eradicate dangerous microbes; this entails the damaging effects of numerous immunological cell. Fourthly, the immune response creates immunological memory, causing the immune response to be quicker and stronger than it was for the initial response if the harmful germ is exposed again. The human immune system is made up of a variety of cell types (Fig. 1), each with unique functional capabilities, allowing for the accomplishment of these intricate and sophisticated actions. As part of their immune response to provide adequate protection of the host from infections, these various cell types communicate with one another. The immune system can be divided into innate (or natural) and acquired (or adaptive) immunity, which is the most frequent classification (Fig. 1). Fig. 2[1] summarises the relationship between innate and acquired immunity and how it contributes to antiviral immunity.

FACTORS AFFECTING THE IMMUNE RESPONSE:

It goes without saying that a healthy immune system is necessary for successful defence against harmful germs. As a result, those with compromised immune systems are more likely to contract an illness and have more severe or even fatal infections. Many of the elements that affect the immunological response are highlighted in Figure 3. These include some immutable elements like genetics and stage of development.

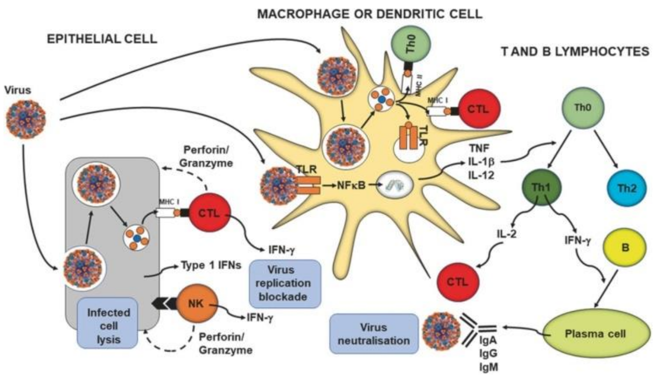

Fig.2 “Overview of anti-viral immunity. B B-cell, CTL cytotoxic T- cell, IFN interferon, Ig immunoglobulin, IL interleukin, MHC major histo compatibility class, NF κ Bnuclear factor kappa-light-chain”

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NK natural killer cell, Th helper T-cell, TLR toll-like receptor, and TNF tumour necrosis factor enhancer. borrowed from ref. [1].

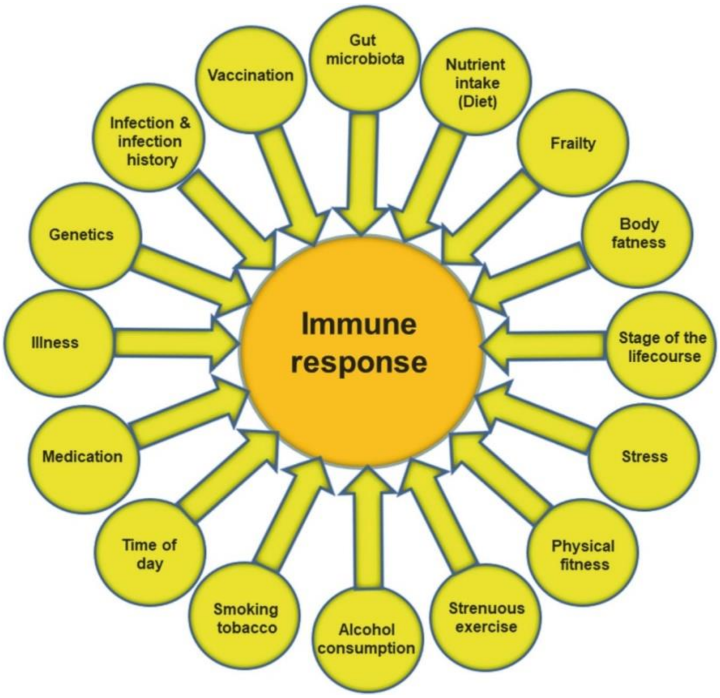

Fig. 3 "Factors that influence the immune response. Note that the listing is not exclusive".

The time of day, but several changeable factors also affect the immune response, such as the life course (such as pregnancy, infancy, and old age). These include stress, physical fitness, vulnerability, body fat, and diet. Early on in the SARS-CoV-2 pandemic, it became evident that older people, especially those who were fragile, and those who were obese were more susceptible than younger people and those who were in good health to COVID-19's more serious disease and mortality.

THE EFFECT OF AGEING AND FRAILTY ON IMMUNITY AND SUSCEPTIBILITY TO INFECTION:

Immune senescence is a process that occurs as people get older where immune competence is reduced [2, 3]. The decreasing immune cell production from bone marrow, which is where all immune cells originate, as people age is probably one factor in immune senescence. In addition, ageing causes the thymus to produce fewer naive T cells, which reduces the body's ability to respond to foreign invaders. Immune cells' function is frequently compromised in addition to their changed quantities in the circulation. Neutrophils, for instance, exhibit poor phagocytosis, respiratory burst, and bacterial killing. The cyto-toxicity of natural killer cells toward virally infected and cancer cells has been compromised. Immune signals are not properly responded to by dendritic cells. T cells are less able to multiply and produce crucial cytokines like interleukin-2 and interferon. Both the activity of cytotoxic T-cells and the

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production of antibodies by B cells are changed. Therefore, a variety of immunological deficiencies can occur in elderly adults, leaving them more prone to infections [4, including viral respiratory diseases]. Immunosenescence also affects how the body reacts to vaccinations, particularly the seasonal flu vaccine [5, 6]. Age-related immunological decline may be exacerbated by poor nutritional status, as immune decline is reduced in older adults with improved micronutrient status or intake [7]. Additionally, undernutrition in older individuals encourages immunological decline [8] and fragility leads to modest immune deficiencies. For example, Yao et al. [9] reported that responses to all When compared to non-frail older adults (72–95 years of age), responses to three strains of a seasonal influenza vaccination (measured as anti-vaccine antibody titres) were significantly lower in the frail; responses in the pre–frail were intermediate. In the post-vaccination follow-up period, 30% of the elderly who were frail and 50% of the non-frail developed confirmed influenza, respectively. "The pre-frail was again intermediate between the frail and non-frail groups. According to a recent study, seroconversion to the four strains of a quadrivalent sea- sonal influenza vaccine was 8, 5, 0, and 8% in more fragile older adults while it was 23, 21, 23, and 26% in less frail older adults" [10]. The discovery that older hospitalised patients who were less well-nourished had a higher risk of infections than those who were better-nourished suggests that these immunological deficiencies are of clinical consequence [11, 12]. Consequently, the reisa relationship between immunosenescence and

elevated infection severity and vulnerability. It's possible that immunosenescence contributes to the severity of COVID-19 in older adults. Additionally, a lot of studies find a connection between frailty and a worse COVID-19 outcome (see ref. [13]). Numerous inflammatory mediators' blood concentrations are known to rise with ageing, a condition known as inflammaging [14]. This state is thought to raise the risk of chronic age-related illnesses and may make an infection more likely to result in an exaggerated inflammatory response. As a result, older individuals, and again in particular those who are fragile, may be predisposed to mounting an uncontrolled inflammatory response, sometimes referred to as a "cytokine storm," which has been associated with poor results from COVID-19. In conclusion, older persons may have decreased immunological responses, which predisposes them to infection, and a propensity for uncontrolled inflammation, which predisposes them to negative effects of infection. Both of these conditions appear to be worse in the frail.

THE EFFECT OF OBESITY O NIMMUNITY AND SUSCEPTIBILITY TO INFECTION:

Obesity can affect immune function [15], resulting in decreased generation of antibodies and interferon- as well as helper T cell, cytotoxic T cell, B cell, and natural killer cell activity. This indicates that those who live with obesity are more susceptible to a variety of bacterial, viral, and fungal diseases than people who are of a healthy weight [16] and have less favourable reactions to vaccinations [17]. In regard to influenza infection and influenza vaccine, the effects of obesity have been thoroughly investigated. When compared to people

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with a healthy weight, those who were obese during the 2009 H1N1 influenza A virus pandemic displayed delayed and impaired anti-viral responses to infection and had worse illness recovery [18]. Studies on animals and human case studies demonstrate that obesity is linked to extended influenza virus shedding, which points to a problem with viral control and death. Obesity is also linked to the establishment of pathogenic minor variations [18]. The effectiveness of vaccines may also be reduced in people who are obese. For example, obese people who have had a flu shot have a double the risk of getting an influenza-like illness compared to people who are of a healthy weight [19]. Sheridan et al. [20] looked at the in vitro reactions of immune cells from the blood of people with normal weight and those who were overweight or obese to the influenza vaccine. The number of activated cytotoxic T cells and granzyme-expressing cytotoxic T cells rose when the blood immune cells were exposed to the vaccination.

T cells and the quantity of cytotoxic T cells that produce interferon are essential elements of antiviral immunity (Fig. 2). Cells from obese people, on the other hand, showed lower responses by 40%, roughly 60%, and 65%, respectively. Cells from overweight individuals displayed responses that fell in the middle of those from healthy weight and obese persons. Paich et al. [21] revealed findings that were consistent with the blood cells' reaction to the pandemic H1N1 influenza A virus. As a result, obesity is associated with a variety of immunological dysfunctions, including actions that involve viral defence. Additionally, an increase in blood levels of various inflammatory mediators and a state of persistent low-grade inflammation are linked to obesity. This syndrome may make a person more susceptible to developing chronic obesity-related illnesses and predispose them to mounting an overactive inflammatory response in the event of infection. “As of late, research has shown that people who are obese are more vulnerable than those who are of a healthy weight to severe COVID-19 and COVID-19-related death. For instance, a recently published systematic review and meta-analysis of 22 studies from seven countries in North America, Europe, and Asia found that obesity is linked to a higher likelihood of presenting with more severe COVID-19 symptoms (odds ratio 3.03; four studies), needing hospitalisation (odds ratio 1.68; four studies), being admitted to an intensive care unit (odds ratio 1.35; nine studies), and requiring invasive mechanical ventilation (odds ratio 1.35; nine studies”. Overall, persons who live with obesity may have compromised immunological responses, making them more susceptible to infection, as well as a propensity for unchecked inflammation, making them more vulnerable to the negative effects of infection.

THE ROLE OF MICRONUTRIENTS IN SUPPORTING THE IMMUNE RESPONSE:

Nutrition plays multiple roles in supporting the immune system. The diet provides:

- “Building blocks for the creation of RNA and DNA, as well as for the development of proteins (antibodies, cytokines, receptors, acute phase proteins, etc.) and new cells.

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- Specific materials for the formation of immune-active metabolites (e.g.arginineasasubstratefornitricoxide).
- Immune cell metabolism regulators (e.g.vitamin A, zinc).
- Foods have specialised antiviral, antibacterial, or other functions (e.g. vitamin D, zinc).

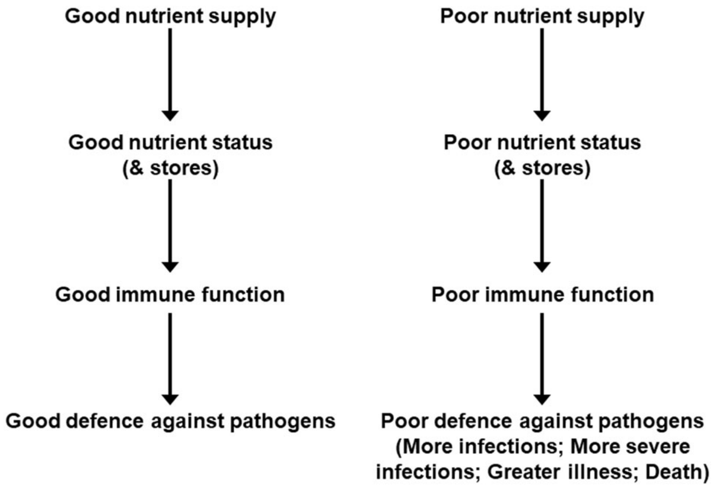

Fig. 4 "Relationships between good and poor nutrition, immunity and infection".

- Controls that guard the body from oxidative and inflammatory stress (e.g. vitamin C, vitamin E, zinc, selenium, long-chain omega-3 fatty acids and many plant polyphenols).
- Serve as a substrate for the gut microbiota, which affects the immune system (see next section)".

Lack of certain nutrients may prevent the immune system from functioning properly if there is poor diet. Increased infection risk and an incapacity to manage the effects of infection would be linked to this (Fig.4). As previously covered [1, 24-26], a lot of research has been done on the effect of micronutrients in assisting the immune system. A variety of micronutrients are crucial for maintaining the immune response (Table 1). B vitamins, vitamin E, vitamin K, selenium, magnesium, and other minerals and elements also play a part in health. Vitamins A, C, and D, as well as zinc, copper, and iron, have well-studied functions. Infection susceptibility is increased and several elements of innate and acquired immunity are impaired by deficiencies of several of these micronutrients [1, 24]. Repletion can restore immunological deficiencies, which lowers the likelihood of contracting an infection. "Since the onset of the SARS-CoV-2 pandemic, there has been discussion regarding several micronutrients and anti-viral immunity in the context of infection with SARS-CoV-2 and COVID-19, and there have been a lot of papers on this subject".

The immune system responds to vitamin D in a variety of ways, but it also supports the activity of various cell types [27]. Additionally, the ability of some immune cells to synthesise vitamin D's active form (macrophages, dendritic cells) suggests that this vitamin is

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crucial to immunity. The synthesis of antimicrobial proteins like cathelicidin is also aided by vitamin D. The effectiveness of the seasonal influenza vaccination is hampered by vitamin D insufficiency [28], and meta-analyses of randomised controlled trials of vitamin D supplementation show a decrease in the prevalence of respiratory tract infections.

Table I Summary of the effects of various micro-nutrients on different aspects of immunity.

Micronutrient	Role in barrier function	RoleincellularaspectsofinnateimmunityRoleinT-cellmediatedimmunity		Role in B-cell mediated immunity
Vitamin A	Promotes differentiation of epithelial tissue; promotes gut homing of B- and T cells; promotes intestinal immunoglobulin A+ cells; promotes epithelial integrity	Regulates number and function of NK cells; supports phagocytic and oxidative burst activity of macrophages	Regulates development and differentiation of Th1andTh2cells; promotes conversion of naive T cell store gulatory T cells; regulatesIL-2, IFN-γ and TNF production	Supports function of B cells; required for immunoglobulin A production
VitaminB6	Promotes gut homing of T cells	Supports NK-cell activity	Promotes T-cell differentiation, proliferation and function, especiallyTh1cells; regulates(promotes)IL-2 production	Supports anti-body production
VitaminB9(Folate)	Survival factor for regulatory T cells in the small intestine	Supports NK-cell activity	Promotes proliferation of T cells and the Th1-cellresponse	Supports anti-body production
VitaminB12	Important co-factor for gut microbiota	Supports NK-cell activity	Promotes T-cell differentiation, proliferation and function, especially cytotoxic T cells; controls ratio of T-helper to cytotoxic T cells	Required for anti-body production
Vitamin C	Promotes collagen synthesis; promotes keratinocyte differentiation; protects against oxidative damage; promotes wound healing; promotes complement	Supports function of neutrophils, monocytes and macrophages including phage cytosis; supports NK-cell activity	Promotes production, differentiation and proliferation of T cells especially cytotoxic T cells; regulates IFN-γ production	Promotes anti-body production
Vitamin D	Promotes production of antimicrobial proteins (Catholicity, β-defensin); promotes gut tight junctions (via E-cadherin, connexon 43); promotes homing of T cells to the skin	Promotes differentiation of mono cytostome macro phages; promotes macro phage phagocytosis and oxidative burst	Promotes anti-gen processing but can in habitancies presentation; can inhibit T-cell proliferation, Th1-cell function and cytotoxic T-cell function; Promotes the development of regulatory T cells; inhibits differentiation and maturation of dendritic cells; regulates IFN-γ production	Can decrease anti-body production
Vitamin E	Protects against oxidative damage	Supports NK- cell activity	Promotes interaction between dendritic cells and T cells; promotes T-cell pro-life ration and function, especially Th1 cells; regulates (promotes) IL-2production	Supports anti-body production
Zinc	Maintains integrity of the skin and mucosal membranes; promotes complement activity	Supports monocyte and macro phage phago-cytosis; supports NK-cell activity	PromotesTh1-cellresponse; Promotes pro-life ration of cytotoxic T cells; promotes development of regulatory T cells; regulates (promotes) IL-2 and IFN-γ production; reducesdevelopmentofTh9andTh17 cells	Supports antibody production particularly immune globulin G
Copper		Promotes neutrophil, mono-cyte and Macro phage phago-cytosis; supports NK-cell activity	Regulates differentiation and proliferation of T cells; regulates (promotes) IL-2 production	
Iron	Essential for grow than differentiation of epithelial tissue	Promotes bacterial killing by neutrophils; regulates balance of M1 and M2macrophages; supports NK-cell activity	Regulates differentiation and proliferation of T cells; regulates IFN-γ production	
Selenium		Supports NK-cell activity	Regulates differentiation and proliferation of T cells; regulates (promotes) IFN-γ production	Supports anti-body production

*IFN*Interferon,*IL*interleukin,*NK*naturalkiller,*Th*T-helper,*TNF*tumournecrosisfactor.

"Numerous studies show a link between low vitamin D status and heightened vulnerability to and severity of COVID-19. Low vitamin D status was linked to an increased incidence of COVID-19 hospitalisation and SARS-CoV-2 infection, according to a sizable Israeli investigation [30]. According to meta-analyses, a vitamin D deficiency increases the probability of COVID-19 mortality, hospitalisation for COVID-19, and severe COVID-19 [31]. After accounting for numerous variables, a sizable study [32] that used data from the UK Biobank found that taking vitamin D supplements reduced the probability of testing positive for SARS-CoV-2. A bolus of vitamin D was found to lower mortality from COVID-19 in research conducted in an Italian residential care facility [33].

In patients hospitalised with COVID-19, vitamin D treatment is said to lessen the severity of the condition (need for intensive care unit admission [34]; need for intensive care unit admission or mortality [35]; mortality [36]).

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Numerous immune system cells are supported by zinc's activity [37], which also aids in reducing oxidative stress and inflammation and has specialised antiviral properties [38], such as preventing the spread of coronaviruses [39]. A meta-analysis of randomised controlled trials of zinc supplementation reports a decreased incidence of diarrhoea and respiratory tract infections, especially in older adults or those with inadequate zinc consumption. Zinc supplementation significantly improves vaccine responses (seeref.[1] for references). Numerous studies have revealed an association between low zinc levels and increased susceptibility to and severity of COVID-19 (e.g. [42]). In patients hospitalised for COVID-19, supplementing with zinc is said to lower the risk of adverse outcomes, including mortality [43, 44]".

Selenium has not been the subject of as much research as zinc and vitamin D, which have both seen significant increases in literature since the pandemic. But selenium might play crucial roles in supporting the immune system generally and in fostering antiviral immunity in particular [45]. Selenium supports the function of numerous immune system cells and aids in reducing oxidative stress and inflammation. "Large-scale studies in mice have demonstrated that sele- nium deficiency affects immunological responses, raises susceptibility to viral infection, allows viruses (particularly influenza viruses) to evolve, and allows typically weak viruses to become more aggressive. Selenium supplementation enhances some immune markers, particularly in older adults or those who consume little selenium. For instance, a supplementation study carried out in UK adults with marginal selenium status revealed that selenium enhanced ex vivo anti-viral immune responses, promoted viral clearance, and reduced viral mutation" [46]. According to several research, individuals with low selenium status are more vulnerable to and experience worse COVID-19 symptoms (e.g. [42, 47]).

All things considered, the evidence currently available suggests that a variety of micronutrients are essential for supporting every aspect of the immune response and that their status and intake should be taken into account when determining one's vulnerability to SARS-CoV-2 infection and the severity of COVID-19. In the context of the formation of SARS-CoV-2 variations, the capacity of selenium to suppress viral mutation is noteworthy. Specific nutrients, such as vitamin D and zinc, appear to play essential roles in anti-viral immunity. The existing and upcoming COVID-19 vaccination programmes must take into account the fact that poor intakes of a number of micronutrients affect vaccine responses. "This is probably crucial for the elderly [48] but also for other populations who are more likely to have low intakes or deficiencies in one or more micronutrients. Although micronutrients are part of a varied, plant-based diet (see ref. [1]), it is debatable whether enough of some of the important immune-active micronutrients, such as vitamin D, vitamin C, vitamin E, zinc, and selenium, can be obtained from the diet or whether supplements are required to provide the relevant intakes" [26].

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THE IMPORTANCE OF THE GUT MICROBIOTA:

As a barrier against pathogen colonisation and by producing lactic acid and antimicrobial proteins that can directly hinder the growth of pathogens, commensal bacteria in the gastrointestinal system contribute to the host immunological defence. Additionally, commensal microbes communicate with the intestinal epithelium and immunological tissues of the host. These interactions with the host take place either directly between cells or via substances secreted by the bacteria. It is suggested that probiotic organisms, especially some lactobacilli and bifidobacteria, can be employed to enhance host immunity as a result of these effects. In fact, many research have looked at how different probiotic organisms, alone or in combination, affect immune function and infection in human patients. Although other probiotic organisms seem to have a less marked impact on acquired immunity, they do seem to improve innate immunity (especially phagocytosis and natural killer cell activity) [49]. However, as previously reviewed [50], studies demonstrate enhanced vaccine responses in people taking probiotics. Probiotics (or prebiotics) have been shown in systematic reviews and meta-analyses to improve the antibody response to the seasonal influenza vaccine in adults [51, 52]. Probiotic organisms may be able to defend against infections, according to the immunological reactions seen. Some probiotics can lower the risk or duration of diarrhoea, particularly diarrhoea caused by antibiotics, according to recent systematic reviews and meta-analyses.

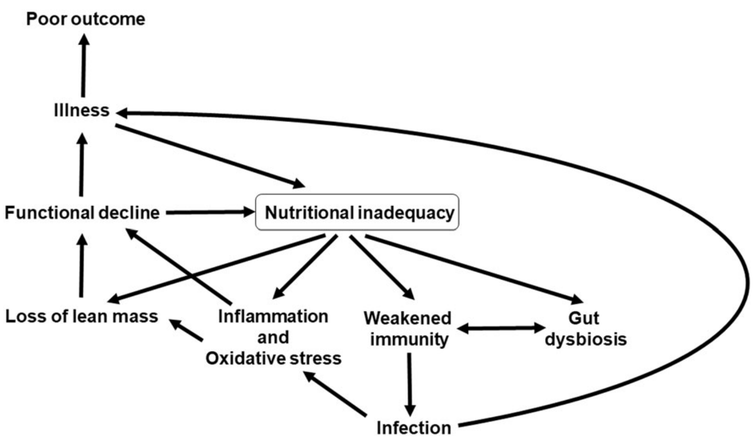

Fig. 5 "Factors linking nutritional inadequacy with infection and poor outcome from infection".

diarrhoea linked to Clostridium difficile (see ref. [1] for references). It may not come as a surprise that probiotics have an impact on gastrointestinal infection, but they may also offer protection from respiratory infections. According to studies in mice, poorer immune responses and worsened outcomes after bacterial or viral respiratory infections are caused by gut microbiota depletion or absence. "Studies on probiotics, especially those including lactobacilli and bifidobacterial strains, have shown some evidence of a decreased incidence and improved outcomes of respiratory infections in humans (see ref. [1] for references). The

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sum of the data suggesting that probiotics, particularly lactobacilli and bifidobacteria, may increase immunological function and the response to seasonal influenza vaccine (which mimics a viral infection), It would be advantageous to use these organisms as a technique to lower the risk and severity of viral respiratory infections, such as SARS-CoV-2, and to enhance outcomes in patients with respiratory infections. In this context, intestinal dysbiosis with reduced lactobacillian and bifidobacterial counts has been documented in COVID-19 patients [53, 54]. When D'Ettore et al. [55] treated COVID-19 patients with a combination of medications, antibiotics of the same sort, and oral probiotics (five lactobacilli, two bifidobacteri, and Streptococcus thermophilus), they observed better resolution of diarrhoea and other discomfort symptoms, including respiratory disease, in the probiotics-treated group".

DISCUSSION AND CONCLUSIONS:

One of the many variables that affect the immune response is nutrition (Fig. 3), and a healthy diet is crucial for promoting the immunological response (Fig. 4). Immunity can be compromised in elderly individuals, especially those who are fragile, obese, undernourished, and those who consume insufficient amounts of micronutrients. These immune deficiencies linked to inadequate nutrition enhance infection susceptibility and allow illnesses to become more severe, even lethal (Fig. 5). Inadequate nutrition also permits uncontrolled inflammation and oxidative stress, which contribute to frailty and a poor recovery from infection (Fig.5). One of the reasons why older people and obese people are at a higher risk of experiencing more severe effects from SARS-CoV-2 infection is because of the negative effects that poor nutrition has on the immune system, including its inflammatory component. It is important to remember that the gut microbiota is also influenced by ageing and obesity. Good diet has a crucial role in fostering a diverse gut microbiota, which in turn supports the immune system (see [1] for references). In order to ensure positive reactions to vaccination, The immune system needs good diet to function properly. Thus, in order to better support the immune response, attention should be given to correcting the current dietary deficiencies (frailty, obesity, general undernutrition, micronutrient insufficiency or deficiency) that are pervasive in the community. This is the most important takeaway from the research on nutrition and immunity that is pertinent to the fight against COVID-19, the disease that COV-2 produces, and making sure that the public is better prepared for upcoming pandemics.

COMPLIANCE WITH ETHICAL STANDARDS:

"Conflict of interest PCC serves as an advisor or consultant to BASF AS, DSM, Cargill, Smartfish, Nutrileads, Bayer Consumer Care, and GSK Consumer Healthcare while receiving research funding from Bayer Consumer Care.

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