# 22. Infectious diseases across the life course: an inequalities perspective

*Nico Dragano*

## INTRODUCTION

Infections with viruses, bacteria or parasites are an unavoidable part of life for most living beings on this planet – they are, so to speak, biological normality. Humans are hosts to hundreds of such pathogens, some of which are entirely harmless, while others can have serious or even fatal consequences. Diseases caused by infections continue to shape global population health despite the epidemiological transformation of the last 150 years, which has been marked by a sharp increase in the importance of chronic degenerative diseases. Accordingly, among the ten leading causes of death currently identified by the World Health Organization (WHO), three are communicable diseases (neonatal conditions, diarrhoeal disease, lower respiratory diseases) (World Health Organization, 2022). The burden of disease from non-fatal infectious diseases is also enormous, although difficult to quantify at a global level. Therefore, to take just one – arbitrary – example from the country where I work: in 2019, 52,979,966 sick days were reported for acute upper respiratory infections (ICD-10 J00-J06) for employees in the statutory health insurance system alone (Bundesgesundheitsministerium, 2021). In addition, infections also play a role in the aetiology of non-communicable diseases, so that their importance tends to be underestimated when looking at main diagnoses alone.

Not unlike chronic degenerative diseases, social determinants play a central role in the spread of infectious diseases. This is most obvious for agents that are transmitted from person to person, as they necessarily require social interaction to transmit. Social practices such as dietary or hygienic behaviour, as well as processes and structures at the societal level, such as the regulation of food production, are also essential for pathogens that are ingested through food or water (van Seventer & Hochberg, 2017). And like all diseases in which the social environment has a strong influence on their development, social inequalities can be observed for infectious diseases. To take up an already mentioned example: if one compares the main causes of death between high- and low-income countries, the burden of disease due to infections is exorbitantly higher in low-income countries. In these countries, six of the ten main causes of death are communicable diseases (e.g. lower respiratory infections, diarrhoeal disease, malaria, HIV), while in high-income countries there is only one (lower respiratory infections) (World Health Organization, 2022).

Poverty and deprivation have always been a breeding ground for infectious diseases and therefore a social perspective is necessary when dealing with these diseases (Mamelund & Dimka, 2021; Quinn & Kumar, 2014). This applies to both the cross-sectional and the longitudinal view in a life-course perspective. Nevertheless, in the research on health inequality in general as well as in research oriented towards the ideas of life-course epidemiology in particular, infectious diseases have so far played a minor role, as the focus of previous life-course epidemiological research was primarily on non-communicable diseases. With the global crisis

of the COVID-19 pandemic this could change, and in the two years of the pandemic so far, numerous new research papers on social inequality in COVID-19 have been published. They allow new insights into the extent and causes of health inequalities not only for the current pandemic, but also in relation to infectious diseases in general. Nevertheless, research has not yet come to a point where a coherent life-course picture of the origins of inequalities in infectious diseases can be drawn. Many questions remain open and therefore this chapter is somewhat preliminary. It begins with a description of basic characteristics of infectious diseases and the introduction of the key terminology. It then summarises the research on social inequalities in infectious diseases and presents a preliminary aetiological model. This model is initially cross-sectional. Based on general concepts of life-course epidemiology, the concluding sections then discuss which longitudinal influences act on infectious diseases and whether these could contribute to the emergence of social inequalities in disease.

## GENERAL CHARACTERISTICS OF INFECTIOUS DISEASE CAUSATION

Infectious diseases have peculiarities that must be taken into account when analysing their aetiology. The essential difference compared to non-communicable diseases is the necessary presence of a specific *infectious agent* (or *pathogen*). These agents have biologically different natures, but can be roughly divided into viruses, bacteria, fungi, parasites and other forms of microbes. Agents can colonise a *host* – in the case of this chapter, a human being – and possibly infect it, that is infiltrate host tissue, and trigger a pathogenic reaction or disease (= infectious disease) (Horsburgh & Mahon, 2008). The third variable is the *environment* in which both pathogen and host are present and which has a significant influence on whether transmission of the pathogen to the host occurs and what the consequences are. This so-called *epidemiological triad* of agent, host, environment is an old concept in epidemiology to describe and analyse infectious disease causation (Snieszko, 1974).

Following a concept paper by van Seventer and Hochberg (2017), the three variables of the epidemiological triad can be assigned properties that determine the probability of infection and the severity of the course of a disease. First, the biological properties of the *agent* must be considered. They can be described along the temporal sequence of exposure, colonisation, infection, disease and outcome. Crucial at the beginning is infectivity, which describes the potential of the agent to actually infect a host after exposure. If an infection occurs, the pathogenicity of the agent determines whether a symptomatic disease occurs at all. Closely related to this is virulence, that is the extent of pathogenic damage or the resulting severity of the symptomatic disease as it progresses (Barreto et al., 2006; Krämer et al., 2010). These properties are determined to a certain extent by the biology of the pathogen. However, this does not mean that they are static. Rather, they can change through mutations as an evolutionary adaptation process – rapidly, as in the case of the SARS-CoV-2 virus, or rather slowly, as in the case of longer-lived parasites, depending on the life cycle of the pathogen. The specific mode of transmission, that is the way in which a pathogen colonises the host, can also be assigned to the agents' properties. Here, a rough distinction can be made between direct (i.e. from person-to-person) and indirect transmission (Krämer et al., 2010). Indirect transmission means that the agent uses another vehicle on its way to colonise the host. This vehicle can be an organism (vector-born) or inanimate matter (e.g. water-borne, airborne, food-borne, object-borne) (Giesecke, 2017).

A well-known example of a vector-borne disease is malaria, in which the plasmodia parasite is transmitted to the human host via the vector of the "malaria mosquito" (*Anopheles gambiae*). It should be noted, however, that very few pathogens are fixed to one pathway and both direct and indirect transmission are often possible at the same time (Giesecke, 2017).

These properties of the agent interact with those of the *host*. First of all, the host can, through its behaviour, (a) avoid exposure or (b) prevent an infection if exposure has occurred, for example by eliminating superficially colonising pathogens through hand hygiene. However, the decisive factor for the overall course is the susceptibility of the host, which denotes the probability that a host gets infected if exposed to the agent (Abubakar et al., 2016). On a biological level, this is determined by the immune system and the general constitution or resilience of the organism. Both have a genetic component, but are also variable. The immune system, for example, is capable of learning and can either develop immunity through previous infections or be trained through external immunisation (i.e. vaccination) in order to be able to show a defence reaction in subsequent exposures to the same pathogen (Abubakar et al., 2016). If an infection nevertheless occurs, immunity and constitution remain important, as they also influence the course of the disease (pathogenicity and virulence). For example, older people with chronic non-infectious diseases react more frequently with more severe symptoms in case of infection than younger, healthier people do. In the example of COVID-19, certain biomedical risk factors or pre-existing conditions such as obesity or diabetes significantly increase the likelihood of a severe course of disease in the case of infection (Gao et al., 2021). Susceptibility to infection and vulnerability to severe courses of disease thus depend on biological and behavioural characteristics of the host (age, immunisation status, stress, previous illnesses, hygiene behaviour, etc.).

The third variable is the environment, which influences both agent and host and also moderates the probability of whether and under what conditions agent and host meet. Environment is to be understood here in the broadest sense, that is in addition to the natural environment, it also includes the social environment with all its levels (Krickenberg & Klemperer, 2010). Properties of the natural environment are decisive for the evolutionary development and spread of pathogens. For example, numerous bacterial, viral or parasitic pathogens are bound to certain climatic zones, weather conditions and/or seasons and need certain biotopes to reproduce effectively and, if necessary, to find suitable vehicles (van Seventer & Hochberg, 2017). Equally important is the social environment, which, in the sense of an ecosocial model of disease causation, moderates the interaction of exposure and susceptibility/resilience (Krieger, 2008). The first level is the man-made physical environment which is closely interwoven with the natural environment. This refers to aspects such as the built environment, degree of urbanisation, supply infrastructure or land use, which directly influence pathogens, hosts and transmission routes (van Seventer & Hochberg, 2017). Man-made climate change, with its fundamental consequences for the global ecosystem, can also be included here (Krämer & Khan, 2010). Other social environmental determinants are technological and/or organisational systems that are related to transmission. These are, for example, production, storage and transport systems for food, water treatment systems or the handling of waste. The probability of transmission of infections is also determined by the type, duration and organisation of personal human contacts. Next, everyday living and working conditions are important. The extent of occupational and private mobility, work-related contacts, private contacts, the occupancy density of homes and neighbourhoods, childcare, education and many other areas determine both the extent and form of social contacts (and thus possible exposures) and the exposures to

vehicles (e.g. working in indoor air) and thus form the framework for possible transmissions (Arthur et al., 2017). The organisation and effectiveness of health care and the public health system are another aspect. Targeted prevention and care of infectious diseases influence all stages of the spread and development of disease and are therefore a key area of the social environment. Naturally, social norms related to the contact and/or hygiene behaviour of individuals are also highly relevant. (Arthur et al., 2017). Examples are sexual norms, conventions for distance or closeness in everyday encounters, hygiene norms, for example regarding hand washing or illness behaviour when having a symptomatic disease. This description of the social determinants of infectious diseases is not exhaustive, but it should make clear the elementary importance of social structures and practices for the spread of infectious diseases. With this knowledge, a bridge can be built to the unequal distribution of disease risks, since social determinants tend to be unequally distributed and affect certain groups in society more or less frequently (Krieger, 2008).

## SOCIOECONOMIC INEQUALITIES AND INFECTIOUS DISEASE: GENERAL CONSIDERATIONS

Before adopting a longitudinal perspective, it is important to clarify whether patterns of social inequality in the incidence and severity of infectious diseases can be identified. The empirical findings to date clearly point in this direction: numerous infectious diseases affect socially disadvantaged people more often, both in terms of incidence and severity (Mamelund & Dimka, 2021). Such inequalities are already historically documented, for example in Friedrich Engels' reports on the health situation of the working class in England in 1845 or Rudolf Virchow's report on an outbreak of typhus in Upper Silesia in 1848. Retrospective data analyses of major historic pandemics such as the Spanish flu, also show socially differential distributions, such as higher mortality rates in poorer neighbourhoods of Chicago in the autumn of 1918 (Grantz et al., 2016).

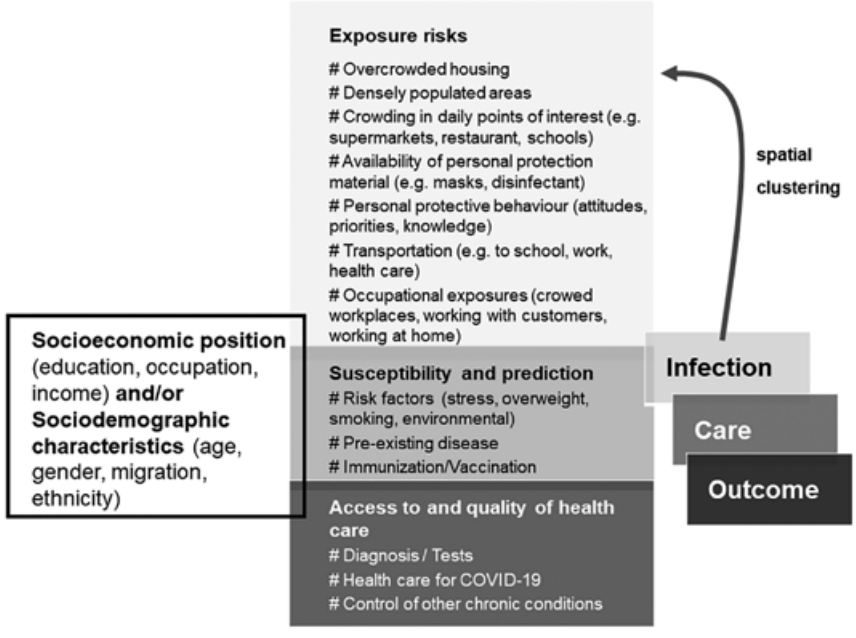
This pattern has not changed significantly to date and there is much evidence of inequalities both between social classes within societies and between rich and poor countries globally. Higher incidences and severe courses in socioeconomically disadvantaged groups compared to more advantaged groups are, for example, found for seasonal influenza (Chandrasekhar et al., 2017; Lowcock et al., 2012; Manabe et al., 2012), SARS (Bucchianeri, 2010), gastrointestinal infections in children (Adams et al., 2018), severe respiratory disease in children (Rod et al., 2021), sexually transmitted diseases such as HIV or gonorrhoea (Ekholuenetale et al., 2021; Harling et al., 2013; Nakagawa et al., 2014), neglected tropical disease (Houweling et al., 2016) or hepatitis (Tosun et al., 2018). The same applies to the country comparison. The populations of low-income countries not only have higher incidences of hepatitis (Cao et al., 2021; Jacobsen & Koopman, 2005), HIV (Challacombe, 2020) or malaria (Carrasco-Escobar et al., 2021), but also severe courses of common infections such as respiratory or diarrhoeal diseases (Ugboko et al., 2020). Another recent example is the COVID-19 pandemic. Worldwide, marked socioeconomic inequalities (measured in terms of socioeconomic position, e.g. income, education, low occupational status and/or sociodemographic characteristics such as gender, race/ethnicity, migration background) in the risk of infection, hospitalisation and mortality have been documented for all age groups (Batty et al., 2020; Bergman et al., 2021;

Chadeau-Hyam et al., 2020; Chang et al., 2020; Ginsburgh et al., 2021; Hoebel, Michalski, et al., 2021; Muhsen et al., 2021; Patel et al., 2020).

How such inequalities emerged must be answered in detail on an agent-specific basis, since the interactions between agent–host–environment take on specific forms and the connection to societal inequality structures can be correspondingly diverse. However, general principles can be derived, and the most elaborate model of health inequalities in infectious disease to date is a model proposed by Quinn and Kumar (Quinn & Kumar, 2014). Building on an older concept by Blumenshine et al. (2008) and informed by empirical findings on epidemic and pandemic influenza waves, the two researchers propose to organise the social determinants along the central variables of the temporal course of infectious diseases. First is the probability of exposure, which depends on numerous social factors such as living conditions, occupational activities or hygiene behaviour. This is followed by influences on susceptibility, which modify the probability of infection (e.g. immune status, nutritional status), and the severity of the disease (e.g. previous illnesses). The third mediating pathway in this model is access to and quality of medical care in the case of illness, which also influence the severity and duration of the disease.

Figure 22.1 shows a modified version of Quinn and Kumar's model specifically for SARS-CoV-2 and COVID-19, respectively, prepared for this chapter. The figure displays three broader domains of mediating factors, all related to the process of infection and disease (i.e. exposure, susceptibility and vulnerability, health care; see above). It also lists single risk factors in each domain that are known from previous research to be socially unequally distributed. For example, the likelihood of exposure increases when people live together in crowded living conditions (Ahmad et al., 2020). Since the size of the home and the number of its occupants correlate with income in many regions of the world, this is a pathway that can lead from social disadvantage to infection. Factors that influence susceptibility are also found more often in socially disadvantaged people. For example, the prevalence of risk factors such as stress, smoking or obesity is generally higher in socially disadvantaged populations than in better-off population groups. The issue of immunisation is also important. Recent data on global immunisation campaigns suggest that people with low incomes, low education or in discriminated social situations are less likely to have access to vaccines and, when access is available, are less likely to take it up (Bergmann et al., 2021; Butter et al., 2021; Caspi et al., 2021; Momplaisir et al., 2021; Muhsen et al., 2021). Most factors that increase susceptibility also increase the risk of a severe course of COVID-19 (prediction). In addition to the factors already mentioned, pre-existing conditions or comorbidities are of central importance. Numerous contributions in this book clearly show that chronic degenerative disease such as hypertension, cardiovascular disease, chronic obstructive pulmonary disease or diabetes are more prevalent among people in disadvantaged social positions. At the same time, all these diseases increase the risk of a severe course of COVID-19, including case fatality, so that a plausible mediating path can be assumed here as well. Furthermore, the care system plays a role in several respects. Good care for chronic diseases, for example, could attenuate the relationship described above. COVID-19-specific care can also explain social inequalities, for example when people with low incomes do not have access to tests or medical care in case of illness (Hoebel, Grabka, et al., 2021).

The aetiological model, simplistic as it is, nevertheless illustrates how and at what point in the disease inequalities might arise. The question of this chapter is whether this cross-sectional




*Source:* Disease-specific adaptation from Quinn and Kumar (2014).

*Figure 22.1 Model of associations between social position, mediating factors and COVID-19*

model can and should be extended to include the dimension of time (in the sense of development over the life course).

## BASIC PRINCIPLES OF LIFE-COURSE EPIDEMIOLOGY

The examination of infectious diseases with concepts and methods of life-course epidemiology has so far remained an exception, and this is even more true with regard to the development of health inequalities over the life course (Ben-Shlomo et al., 2016; Hall et al., 2002). Yet assumptions of life-course epidemiology are transferable – even if they were primarily developed for researching the development of chronic diseases over the course of people's lives. Before discussing this transferability, general principles of life-course epidemiology should first be brought to mind. They can then serve as a framework for later consideration of infectious diseases over the life course. For the purposes of this chapter, it will be sufficient to stick to simple principles and not to exhaust the entire wealth of current epidemiological knowledge on the life course.

The core idea of this research paradigm is that time plays an elementary role in the development of diseases and must accordingly be explicitly taken into account in causal research (Ben-Shlomo et al., 2016). From this, life course epidemiology derives various principles. A classical hypothesis is that the effect of an exposure on health depends on the timing of

its impact (Ben-Shlomo & Kuh, 2002; Burton-Jeangros et al., 2015; Kuh et al., 2003). This timing determines in particular the degree of possible pathogenic damage. The assumption is that there are certain *sensitive periods* in the life course in which people's health is particularly susceptible to external and internal disturbances. If exposures act in such periods, they can cause more lasting damage than in other periods. The focus is usually on early phases of life, such as pregnancy or infancy, but sensitive periods can also occur later in life. In this context, a distinction is often made between critical and sensitive periods (Kuh et al., 2003). *Critical periods* are time windows with special significance for the further development of health, for example the maturation steps of the foetus during pregnancy. If disturbances occur during this time, their consequences may be no longer reversible (i.e. biological programming). Sensitive periods are also times of increased vulnerability, but the effects of disruptions are less absolute and may disappear or at least be alleviated over time.

Another central idea is that exposures or first subclinical damage in earlier phases of the life course influence later health trajectories as a whole, as well as increasing the probability of the occurrence of individual diseases in later phases of life (*lag between exposure and disease*). The respective time periods can vary depending on the underlying pathogenic processes, but in certain cases can even span many decades. For example, negative influences on the development of the foetus may set the course for chronic degenerative diseases in older adulthood (Barker, 1990). It is also possible that exposures and their consequences skip generations, for example when traumas of grandparents still shape the mental health of grandchildren (Bowers & Yehuda, 2016). However, the correlations are not necessarily linear or deterministic. Rather, it is postulated that additional factors that occur later in life can have an influence by either mediating the effect of early exposures or modifying their effect (Ben-Shlomo & Kuh, 2002).

This idea of mediation and modification leads to another principle, namely accumulation. Especially in the case of chronic degenerative diseases, the aetiology is usually complex and it is not a single exposure that triggers the disease, but the interaction of several exposures over time. Such risks can accumulate and only when sufficient component causes come together is the critical threshold for pathogenic damage crossed (Blane et al., 2007). A variant of this concept is the pathway model. Here, certain trajectories in the life course lead to later exposures, for example when a person acquires a low educational qualification and then has to perform physically demanding work in adult life because other, less harmful activities are not available to him or her. This example is not chosen at random. Accumulation and pathways are closely linked to social structure and social dynamics in the concepts of life-course epidemiology. Social characteristics may thus predetermine the accumulation of risks on the one hand, and, at a long run, social transitions and trajectories are component parts of aetiological pathways that lead to health-relevant exposures, mediators and modifiers.

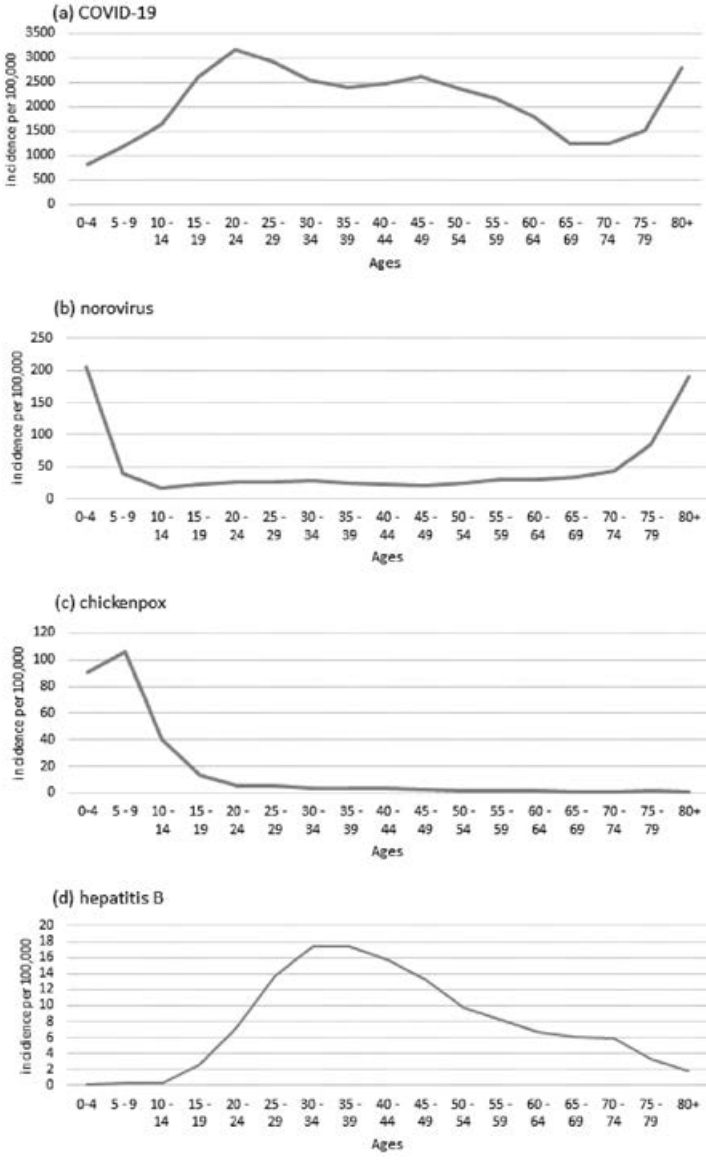
Life-course epidemiology has therefore dealt with the aspect of social inequality early in its development. This can be interpreted as a necessity, since the diseases that have been researched with the new methods and approaches are all socially unequally distributed (e.g. ischaemic heart disease, diabetes, obesity). The insight that health inequalities in adulthood may at least partly be attributed to disadvantages in childhood and adolescence was an important milestone in health inequality research that opened up new explanatory possibilities.

Health inequalities arise over the life course when people in low social positions experience health-related risks more frequently during critical or sensitive periods or systematically accumulate more risks over time. Various models exist on the emergence of social inequalities in health during the life course, describing how socioeconomic position, risk factors and diseases

interact over time. With regard to the accumulation of risks over the life course, it is assumed that this is strongly socially patterned (Bartley, 2017; Ferraro & Shippee, 2009; Larson et al., 2018). Social disadvantage in childhood and adolescence is associated with increased health burdens in this period, which marks the beginning of accumulation (Kelly-Irving & Delpierre, 2021). This then continues, as social disadvantage in early life makes disadvantage in later life more likely, which in turn is accompanied by higher health burdens, and so on. In addition, health burdens in the life course have an influence on social mobility and can perpetuate or reinforce social disadvantage (for example, if a chronic illness prevents the acquisition of a higher educational qualification). Thus, complex chains of risk can emerge, in which social and health trajectories combine and ultimately lead to socially unequal patterns of disease across the life course (Arcaya et al., 2015; Ferraro & Shippee, 2009; Larson et al., 2018). Empirically, such cumulative inequalities or chains of risk have been demonstrated in many cases, ranging from correlations between social disadvantage in childhood and premature mortality in older adulthood to inequities in complex health trajectories of individual biological variables (e.g. cardiovascular risk factors) over longer periods of time (Bartley, 2017; Karlamangla et al., 2005; Pavalko & Caputo, 2013). However, these general concepts need to be specified for the study of individual diseases. In a recent article, Kelly-Irving and Delpierre call for a close look at the "social-to-biological processes" and for the investigation of which socially patterned exposures have which biological consequences and how these consequences reverberate over time (Kelly-Irving & Delpierre, 2021). How this idea could be applied for infectious disease is the subject of the next section.

## APPLYING BASIC PRINCIPLES OF LIFE-COURSE EPIDEMIOLOGY TO INFECTIOUS DISEASE AETIOLOGY AND INEQUALITIES

As an introduction to life-course epidemiology of infectious diseases, a look at the age-specific development of individual infectious diseases should demonstrate the significance of a longitudinal view on the emergence of infectious disease. Although there are numerous pathogens that can infect and make people ill at any age, a majority of them show certain age peaks in the probability of infection. Well-known examples are childhood diseases such as rubella, sexually transmitted diseases with a high incidence in adulthood or the high susceptibility to certain bacterial diseases in older age. The variance in the life course is clearly visible in the descriptive representation and there is hardly an infectious disease that would not show a specific age course. Figure 22.2 lists four examples of this. The data come from a register of notifiable diseases in 2020 in Germany. The cumulative age-specific incidences are shown, each of which reveals very characteristic age curves. Systematic age differences also exist in the severity of the disease (Glynn & Moss, 2020), although these do not necessarily have to show the same pattern as the incidences. For example, people may be more likely to be infected at a younger age but not develop symptoms, while older people may be less likely to be infected but become more severely ill when infected. A recent example of this is the SARS-CoV-2 variant Omicron (B.1.1.529), which showed the same pattern in the winter of 2021/2022.




*Source:* RKI, 2021 (Robert Koch Institut, 2021).

*Figure 22.2 Cumulative incidences per 100,000 for COVID-19, norovirus, chickenpox and hepatitis B by age groups in Germany in 2020*

**Critical and Sensitive Periods**

Whether and why there is increased exposure, infectivity, susceptibility or vulnerability at certain stages in the life course must be answered on a pathogen-specific basis. Jia and col-

leagues suggest, for example, that the epidemiological triad for a particular pathogen should be considered separately for all developmental stages of human ageing because, on the one hand, all components of the triad could have an influence on whether and why an age-specific sensitive or critical period occurs and, on the other hand, different components of the triad could have different effects at different age stages (Jia et al., 2020). It is not possible to examine this in detail here. However, two variables seem to be particularly relevant: the probability of exposure and the stage of development of the immune system.

Although it is secondary to the risk of exposure in the temporal sequence, it makes sense to start with the immune system. It is of particular importance because it influences the probability of infection independently of the pathogen and at the same time represents the key biological mechanism for critical and sensitive periods. In terms of a life-course perspective, it should be noted that the immune system is in a constant state of change in the course of biological ageing (Hall et al., 2002). Particularly sensitive periods are the beginning of life and old age. In the first years of life, both the innate and the adaptive immune system of humans are not yet fully developed, so that an immune response to defend against pathogens is absent or at least underdeveloped (Simon et al., 2015; Zhang et al., 2017). This makes perfect biological sense, because the adaptive immune system must first be trained and antibodies developed after birth, which requires a certain susceptibility. On the other hand, it also makes young children particularly susceptible to certain pathogens, for example to gastro interstitial pathogens such as norovirus (Figure 22.2) or respiratory pathogens such as respiratory syncytial virus (RSV) (Glynn & Moss, 2020; Ruckwardt et al., 2016). After the immune system reaches its peak performance in adolescence and young adulthood, its functionality decreases again significantly in old age (Hall et al., 2002; Simon et al., 2015). Thus, the older as well as the very young age can be interpreted as a sensitive period. Certain periods could even be considered critical periods, for example, there is evidence that intrauterine developmental disorders can impair the immune system throughout life (Hall et al., 2002).

If we now look at the factors that have a negative influence on the immune system during these periods, it quickly becomes clear that many of them are socially unequally distributed. An important example is malnutrition and undernourishment, which severely impair the development of the immune system in children, having lifelong consequence for the functionality of the immune system (Rytter et al., 2014). Malnutrition in childhood is clearly a consequence of poverty (in low- as well as in high-income countries) and can thus represent a mediating mechanism. This also applies to other factors with a negative influence on the immune system, such as maternal stress during pregnancy (Marques et al., 2015) or chronic psychosocial stress due to disadvantaged living conditions, both of which are often socially unequally distributed. Individual longitudinal studies have then also been able to demonstrate associations between social disadvantage in childhood and impaired immune function in older age (Austin et al., 2018; West et al., 2012). Such associations can also occur in the sensitive period of old age, since factors such as malnutrition or stress do not only have a negative effect on the immune system in childhood (Wick & Grubeck-Loebenstein, 1997). Another aspect is indirect immunisation through vaccinations. Effective vaccinations have been developed for diseases that pose a particular threat to people in young and old age, which can prevent infections in vulnerable phases of life and – in the case of many childhood vaccinations – can in some instances establish lifelong immunity. However, despite global efforts, coverage of these vaccines remains socially unequal, with coverage mostly lower in poorer countries than in richer ones and lower in socioeconomically disadvantaged populations than in better-off

populations. This inequality exists both for childhood vaccinations (Bobo et al., 2022) and for vaccines that protect older people in particular (e.g. influenza or COVID-19) (Ayers et al., 2021; Muhsen et al., 2021).

The second variable is the probability of exposure. Whether exposure occurs depends on environmental conditions that change over the life course. This is especially true for social environments. Infants, for example, have significantly fewer social contacts than a working person and are therefore less likely to be exposed to certain pathogens. Behaviour also changes over the life stages, which has an influence on the probability of pathogen contacts. An example is sexually transmitted diseases, whose transmission is largely limited to the sexually active phase of life. Links to social inequality can now be drawn here. They arise from the logic of transmission, which usually takes place in concrete social interactions or social practices (e.g. eating, drinking). Many of these interaction contexts and practices are in turn socio-culturally shaped, including class-specific differences. This applies both to behaviour and to the respective living and working conditions that constitute the environment for transmission. Poverty is a factor that is particularly associated with infectious environments. For example, children in poor families are more likely to grow up in cramped housing with critical hygiene conditions, which can significantly increase the risk of exposure (Evans, 2004). This issue can be exacerbated by clustering, as living with people who have an increased individual susceptibility to infection due to poverty and/or health conditions also increases one's own risk of infection (both direct and indirect transmission). Low material resources can also lead to a lack of access to clean water or non-contaminated food, resulting in the need to resort to potentially contaminated food (Evans, 2004). Furthermore, personal behaviour plays a role. Socially disadvantaged people sometimes show riskier hygiene behaviour and have poorer access to information on how to avoid infections, as well as lower overall health literacy, than more privileged groups of people (Crichton et al., 2014; Eaton et al., 2003; Stormacq et al., 2019).

### Lag between Exposure and Disease

The principle of the time lag between exposure and disease can also play a role in infectious diseases, but it is less central than in chronic diseases. The reason is that the incubation period, i.e. the time between exposure and the onset of the first symptoms, is only long enough for a few pathogens to justify a general consideration in the life course (Horsburgh & Mahon, 2008). Nevertheless, there are individual pathogens that only become apparent and trigger symptoms after years in the host. These are often bacterial (e.g. mycobacterium tuberculosis) pathogens, but individual viruses, such as varicella-zoster virus, can also remain unapparent for long periods after initial infection (Behr et al., 2018; Laing et al., 2018). However, the extent to which incubation periods for such diseases show social inequality has hardly been researched. Yet, an influence of social disadvantage cannot be ruled out in view of the connections between social factors and the immune system already described.

### Accumulation

Moving on to the principle of accumulation and pathways, a fundamental difference from the analysis of chronic diseases must first be highlighted. While the aetiology of most chronic diseases is multifactorial in most cases, an infectious disease is always monocausal. This is true at

least with regard to the exposure, which must always be the specific pathogen. In this respect, a pure accumulation of exposures is not possible, even if sometimes a repeated infection with the same pathogen can increase the probability of disease. Nevertheless, accumulation is also relevant here, because at least the susceptibility and vulnerability are influenced by multiple factors independent of the pathogen. Of particular importance is again the immune system, which, as has already been described, changes over the course of life. For example, immunity against certain pathogens can be built up actively or passively. As a positive form of accumulation, immunization at a young age can, for example, protect against diseases in the following phase of life. Accumulation in the negative sense, on the other hand, occurs when factors such as malnutrition, stress or substance use negatively influence the immune system, thus increasing susceptibility over the life course and thus susceptibility to infection in later exposure. More broadly, behaviours could also be understood as factors that accumulate over time. Many of the behaviours that play a role in infections, such as hygiene, personal preventive action (e.g. attitudes towards vaccination) or sexual behaviour, are shaped in childhood, adolescence and young adulthood. If risk behaviour is formed there, this can increase the risk of exposure in later phases of life. The fact that such immune characteristics and behaviours are often socially unequally distributed has already been mentioned. However, it is also important to consider effect modifiers that influence the impact of disadvantage over the life course. For example, there are studies that show that factors such as a close parent–child bond are able to modify the increased susceptibility to infection as a result of socioeconomic disadvantage in adulthood (Cohen et al., 2020).

Other factors that influence susceptibility and virulence also develop over the life course and can thus be classified in a model of accumulation. An important point in this context is that infectious diseases interact with other, non-infectious diseases in the life course. This relationship is two-sided. First, non-infectious diseases can influence the likelihood and severity of infections. People who develop diseases such as diabetes or chronic obstructive pulmonary disease over the life course are both more susceptible to becoming infected when exposed to a pathogen and more at risk of suffering a severe course when infected. Currently, this can be observed in connection with the SARS-CoV-2 virus, which makes its host more likely to become ill and more severely if pre-existing conditions such as diabetes, obesity or hypertension are present (Gao et al., 2021). Since most of these risk factors and pre-existing disease are socially unequally distributed, they are likely to play a fundamental role in the accumulation of infectious disease risks over the life course. How inequality arises over the life course of these non-infectious risk factors can be seen from numerous contributions in this book.

Secondly, infections in the life course can also be part of the aetiology of chronic degenerative diseases. For example, frequent infections in childhood and adolescence are suspected to promote the development of atherosclerosis and thus cardiovascular diseases (Burgner et al., 2015). Another example is an infection with cancer-causing human papillomavirus (HPV) types, which is often acquired at a young age, remains inconspicuous for a long time, but then significantly increases the risk of cervical cancer (Burd, 2003). Longitudinal studies suggest that such infections affect children from socially disadvantaged families more frequently and that this circumstance could be part of the explanation for the socially unequal distribution of diseases in adulthood (Liu et al., 2016). In this respect, a life-course approach to infectious diseases is also important for the study of social inequalities in non-communicable diseases.

## CONCLUSION

Infections and infectious diseases accompany humans throughout their lives and, historically, they have been the defining cause of death in all age groups for the longest period of evolutionary development. Accordingly, the fight against infectious diseases was and is a central public health issue. It is important to consider in this respect that infectious diseases affect people in disadvantaged socio-economic positions more often. A recent example is pronounced inequalities in COVID-19 incidence and severity. This chapter describes how infectious diseases develop over the life course and how they can be explained with common concepts of life-course epidemiology. Behind this background, life-course-related reasons for the unequal distribution of infectious diseases are discussed. It becomes clear that socially disadvantaged people experience more exposures to pathogens during sensitive periods and have a higher susceptibility (mainly as a result of reduced immune responses and pre-existing conditions) to infection and severe disease. Accumulation of risk over the life course is also socially shaped.

Against this background, increased longitudinal research on health inequalities in infectious diseases seems promising, for example to identify "infectious environments" in childhood or the influence that social disadvantage has on the immune system at different stages of the life course. Yet, it is also important to keep the global dimension of this topic in mind. Infectious diseases affect populations in low-income countries to a much greater extent and therefore researchers from these countries should be enabled to investigate the background of social inequalities on site with complex longitudinal study designs. However, and this applies to all countries, it also became clear that a life-course approach does not necessarily make sense per se. Especially for diseases with short latency periods and those that can occur at all stages of life, cross-sectional studies are still necessary.

## REFERENCES

Abubakar, I., Cohen, T., Stagg, H. R., & Rodrigues, L. C. (Eds.). (2016). *Oxford specialist handbooks in infectious diseases*: *Infectious disease epidemiology* (First edition). Oxford University Press.

Adams, N. L., Rose, T. C., Hawker, J., Violato, M., O'Brien, S. J., Barr, B., Howard, V. J. K., Whitehead, M., Harris, R., & Taylor-Robinson, D. C. (2018). Relationship between socioeconomic status and gastrointestinal infections in developed countries: A systematic review and meta-analysis. *PLOS ONE*, *13*(1), e0191633. https://doi.org/10.1371/journal.pone.0191633

Ahmad, K., Erqou, S., Shah, N., Nazir, U., Morrison, A. R., Choudhary, G., & Wu, W-C. (2020). Association of poor housing conditions with COVID-19 incidence and mortality across US counties. *PLOS ONE*, *15*(11), e0241327. https://doi.org/10.1371/journal.pone.0241327

Arcaya, M. C., Arcaya, A. L., & Subramanian, S. V. (2015). Inequalities in health: Definitions, concepts, and theories. *Global Health Action*, *8*, 27106. https://doi.org/10.3402/gha.v8.27106

Arthur, R. F., Gurley, E. S., Salje, H., Bloomfield, L. S. P., & Jones, J. H. (2017). Contact structure, mobility, environmental impact and behaviour: The importance of social forces to infectious disease dynamics and disease ecology. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *372*(1719). https://doi.org/10.1098/rstb.2016.0454

Austin, M. K., Chen, E., Ross, K. M., McEwen, L. M., MacIsaac, J. L., Kobor, M. S., & Miller, G. E. (2018). Early-life socioeconomic disadvantage, not current, predicts accelerated epigenetic aging of monocytes. *Psychoneuroendocrinology*, 97.

Ayers, C. K., Kondo, K. K., Williams, B. E., Kansagara, D., Advani, S. M., Smith, M., Young, S., & Saha, S. (2021). Disparities in H1N1 vaccination rates: A systematic review and evidence synthesis to inform COVID-19 vaccination efforts. *Journal of General Internal Medicine*, *36*(6), 1734–1745. https://doi.org/10.1007/s11606-021-06715-7

Barker, D. J. (1990). The fetal and infant origins of adult disease. *BMJ: British Medical Journal*, *301*(6761), 1111. https://doi.org/10.1136/bmj.301.6761.1111

Barreto, M. L., Teixeira, M. G., & Carmo, E. H. (2006). Infectious diseases epidemiology. *Journal of Epidemiology and Community Health*, *60*(3), 192–195. https://doi.org/10.1136/jech.2003.011593

Bartley, M. (2017). *Health inequality: An introduction to concepts, theories and methods* (Second edition). Polity.

Batty, G. D., Deary, I. J., Luciano, M., Altschul, D. M., Kivimäki, M., & Gale, C. R. (2020). Psychosocial factors and hospitalisations for COVID-19: Prospective cohort study based on a community sample. *Brain, Behavior, and Immunity*, *89*, 569–578. https://doi.org/10.1016/j.bbi.2020.06.021

Behr, M. A., Edelstein, P. H., & Ramakrishnan, L. (2018). Revisiting the timetable of tuberculosis. *BMJ*, *362*, k2738. https://doi.org/10.1136/bmj.k2738

Ben-Shlomo, Y., Cooper, R., & Kuh, D. (2016). The last two decades of life course epidemiology, and its relevance for research on ageing. *International Journal of Epidemiology*, *45*(4), 973–988. https://doi.org/10.1093/ije/dyw096

Ben-Shlomo, Y., & Kuh, D. (2002). A life course approach to chronic disease epidemiology: Conceptual models, empirical challenges and interdisciplinary perspectives. *International Journal of Epidemiology*, *31*(2), 285–293.

Bergman, J., Ballin, M., Nordström, A., & Nordström, P. (2021). Risk factors for COVID-19 diagnosis, hospitalization, and subsequent all-cause mortality in Sweden: A nationwide study. *European Journal of Epidemiology*, *36*(3), 287–298. https://doi.org/10.1007/s10654-021-00732-w

Bergmann, M., Hannemann, T.-V., Bethmann, A., & Schumacher, A. (2021). Determinants of SARS-CoV-2 vaccinations in the 50+ population. *SHARE Working Paper*, *72*.

Blane, D., Netuveli, G., & Stone, J. (2007). The development of life course epidemiology. *Revue d'Épidémiologie et de Santé Publique*, *55*(1), 31–38. https://doi.org/10.1016/j.respe.2006.12.004

Blumenshine, P., Reingold, A., Egerter, S., Mockenhaupt, R., Braveman, P., & Marks, J. (2008). Pandemic influenza planning in the United States from a health disparities perspective. *Emerging Infectious Diseases*, *14*(5), 709–715. https://doi.org/10.3201/eid1405.071301

Bobo, F. T., Asante, A., Woldie, M., Dawson, A., & Hayen, A. (2022). Child vaccination in sub-Saharan Africa: Increasing coverage addresses inequalities. *Vaccine*, *40*(1), 141–150. https://doi.org/10.1016/j.vaccine.2021.11.005

Bowers, M. E., & Yehuda, R. (2016). Intergenerational transmission of stress in humans. *Neuropsychopharmacology: Official Publication of the American College of Neuropsychopharmacology*, *41*(1), 232–244. https://doi.org/10.1038/npp.2015.247;

Bucchianeri, G. W. (2010). Is SARS a poor man's disease? Socioeconomic status and risk factors for SARS transmission. *Forum for Health Economics & Policy*, *13*(2), 115. https://doi.org/10.2202/1558-9544.1209

Bundesgesundheitsministerium. (2021). *Arbeitsunfähigkeit: Fälle und Tage nach Diagnosen 2019. Ergebnisse der Krankheitsartenstatistik der gesetzlichen Krankenversicherung*. https://www.bundesgesundheitsministerium.de/fileadmin/Dateien/3_Downloads/Statistiken/GKV/Geschaeftsergebnisse/Diagnosen_und_Alter_2019.pdf

Burd, E. M. (2003). Human papillomavirus and cervical cancer. *Clinical Microbiology Reviews*, *16*(1), 1–17. https://doi.org/10.1128/CMR.16.1.1-17.2003

Burgner, D. P., Sabin, M. A., Magnussen, C. G., Cheung, M., Sun, C., Kähönen, M., Hutri-Kähönen, N., Lehtimäki, T., Jokinen, E., Laitinen, T., Viikari, J. S. A., Raitakari, O. T., & Juonala, M. (2015). Early childhood hospitalisation with infection and subclinical atherosclerosis in adulthood: The Cardiovascular Risk in Young Finns Study. *Atherosclerosis*, *239*(2), 496–502. https://doi.org/10.1016/j.atherosclerosis.2015.02.024

Burton-Jeangros, C., Cullati, S., Sacker, A., & Blane, D. N. (Eds.). (2015). *A life course perspective on health trajectories and transitions* (First edition). Springer.

Butter, S., McGlinchey, E., Berry, E., & Armour, C. (2021). Psychological, social, and situational factors associated with COVID-19 vaccination intentions: A study of UK key workers and non-key workers. *British Journal of Health Psychology.* Advance online publication. https://doi.org/10.1111/bjhp.12530

Cao, G., Jing, W., Liu, J., & Liu, M. (2021). The global trends and regional differences in incidence and mortality of hepatitis A from 1990 to 2019 and implications for its prevention. *Hepatology International*, *15*(5), 1068–1082. https://doi.org/10.1007/s12072-021-10232-4

Carrasco-Escobar, G., Fornace, K., & Benmarhnia, T. (2021). Mapping socioeconomic inequalities in malaria in Sub-Sahara African countries. *Scientific Reports*, *11*(1), 15121. https://doi.org/10.1038/s41598-021-94601-x

Caspi, G., Dayan, A., Eshal, Y., Liverant-Taub, S., Twig, G., Shalit, U., Lewis, Y., Shina, A., & Caspi, O. (2021). Socioeconomic disparities and COVID-19 vaccination acceptance: A nationwide ecologic study. *Clinical Microbiology and Infection: The Official Publication of the European Society of Clinical Microbiology and Infectious Diseases*, *27*(10), 1502–1506. https://doi.org/10.1016/j.cmi.2021.05.030

Chadeau-Hyam, M., Bodinier, B., Elliott, J., Whitaker, M. D., Tzoulaki, I., Vermeulen, R., Kelly-Irving, M., Delpierre, C., & Elliott, P. (2020). Risk factors for positive and negative COVID-19 tests: A cautious and in-depth analysis of UK biobank data. *International Journal of Epidemiology*, *49*(5), 1454–1467. https://doi.org/10.1093/ije/dyaa134

Challacombe, S. J. (2020). Global inequalities in HIV infection. *Oral Diseases*, *26*(Suppl 1), 16–21. https://doi.org/10.1111/odi.13386

Chandrasekhar, R., Sloan, C., Mitchel, E., Ndi, D., Alden, N., Thomas, A., Bennett, N. M., Kirley, P. D., Hill, M., Anderson, E. J., Lynfield, R., Yousey-Hindes, K., Bargsten, M., Zansky, S. M., Lung, K., Schroeder, M., Monroe, M., Eckel, S., Markus, T. M., … Lindegren, M. L. (2017). Social determinants of influenza hospitalization in the United States. *Influenza and Other Respiratory Viruses*, *11*(6), 479–488. https://doi.org/10.1111/irv.12483

Chang, S., Pierson, E., Koh, P. W., Gerardin, J., Redbird, B., Grusky, D., & Leskovec, J. (2020). Mobility network models of COVID-19 explain inequities and inform reopening. *Nature.* Advance online publication. https://doi.org/10.1038/s41586-020-2923-3

Cohen, S., Chiang, J. J., Janicki-Deverts, D., & Miller, G. E. (2020). Good relationships with parents during childhood as buffers of the association between childhood disadvantage and adult susceptibility to the common cold. *Psychosomatic Medicine*, *82*(6), 538–547. https://doi.org/10.1097/PSY.0000000000000818

Crichton, J., Hickman, M., Campbell, R., Heron, J., Horner, P., & Macleod, J. (2014). Prevalence of chlamydia in young adulthood and association with life course socioeconomic position: Birth cohort study. *PLOS ONE*, *9*(8), e104943. https://doi.org/10.1371/journal.pone.0104943

Eaton, L., Flisher, A. J., & Aarø, L. E. (2003). Unsafe sexual behaviour in South African youth. *Social Science & Medicine*, *56*(1), 149–165. https://doi.org/10.1016/s0277-9536(02)00017-5

Ekholuenetale, M., Onuoha, H., Ekholuenetale, C. E., Barrow, A., & Nzoputam, C. I. (2021). Socioeconomic inequalities in Human Immunodeficiency Virus (HIV) sero-prevalence among women in Namibia: Further analysis of population-based data. *International Journal of Environmental Research and Public Health*, *18*(17). https://doi.org/10.3390/ijerph18179397

Evans, G. W. (2004). The environment of childhood poverty. *The American Psychologist*, *59*(2), 77–92. https://doi.org/10.1037/0003-066X.59.2.77

Ferraro, K. F., & Shippee, T. P. (2009). Aging and cumulative inequality: How does inequality get under the skin? *The Gerontologist*, *49*(3), 333–343. https://doi.org/10.1093/geront/gnp034

Gao, Y.-D., Ding, M., Dong, X., Zhang, J.-J., Kursat Azkur, A., Azkur, D., Gan, H., Sun, Y.-L., Fu, W., Li, W., Liang, H.-L., Cao, Y.-Y., Yan, Q., Cao, C., Gao, H.-Y., Brüggen, M.-C., van de Veen, W., Sokolowska, M., Akdis, M., & Akdis, C. A. (2021). Risk factors for severe and critically ill COVID-19 patients: A review. *Allergy*, *76*(2), 428–455. https://doi.org/10.1111/all.14657

Giesecke, J. (2017). *Modern infectious disease epidemiology* (Third edition). CRC Press.

Ginsburgh, V., Magerman, G., & Natali, I. (2021). Covid-19 and the role of inequality in French regional departments. *European Journal of Health Economics: HEPAC: Health Economics in Prevention and Care.* Advance online publication. https://doi.org/10.1007/s10198-020-01254-0

Glynn, J. R., & Moss, P. A. H. (2020). Systematic analysis of infectious disease outcomes by age shows lowest severity in school-age children. *Scientific Data*, *7*(1), 329. https://doi.org/10.1038/s41597-020-00668-y

Grantz, K. H., Rane, M. S., Salje, H., Glass, G. E., Schachterle, S. E., & Cummings, D. A. T. (2016). Disparities in influenza mortality and transmission related to sociodemographic factors within

Chicago in the pandemic of 1918. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(48), 13839–13844. https://doi.org/10.1073/pnas.1612838113

Hall, A. J., Yee, L. J., & Thomas, S. L. (2002). Life course epidemiology and infectious diseases. *International Journal of Epidemiology*, *31*(2), 300–301.

Harling, G., Subramanian, S., Bärnighausen, T., & Kawachi, I. (2013). Socioeconomic disparities in sexually transmitted infections among young adults in the United States: Examining the interaction between income and race/ethnicity. *Sexually Transmitted Diseases*, *40*(7), 575–581. https://doi.org/10.1097/OLQ.0b013e31829529cf

Hoebel, J., Grabka, M. M., Schröder, C., Haller, S., Neuhauser, H., Wachtler, B., Schaade, L., Liebig, S., Hövener, C., & Zinn, S. (2021). *Socioeconomic position and SARS-CoV-2 infections: seroepidemiological findings from a German nationwide dynamic cohort.* https://doi.org/10.1101/2021.06.21.21259001

Hoebel, J., Michalski, N., Diercke, M., Hamouda, O., Wahrendorf, M., Dragano, N., & Nowossadeck, E. (2021). Emerging socio-economic disparities in COVID-19-related deaths during the second pandemic wave in Germany. *International Journal of Infectious Diseases: IJID: Official Publication of the International Society for Infectious Diseases*, *113*, 344–346. https://doi.org/10.1016/j.ijid.2021.10.037

Horsburgh, C. R., & Mahon, B. E. (2008). Infectious disease epidemiology. In K. J. Rothman, S. Greenland, & T. L. Lash (Eds.), *Modern epidemiology* (Third edition) (pp. 549–563). Wolters Kluwer Lippincott Williams & Wilkins.

Houweling, T. A. J., Karim-Kos, H. E., Kulik, M. C., Stolk, W. A., Haagsma, J. A., Lenk, E. J., Richardus, J. H., & de Vlas, S. J. (2016). Socioeconomic inequalities in neglected tropical diseases: A systematic review. *PLoS Neglected Tropical Diseases*, *10*(5), e0004546. https://doi.org/10.1371/journal.pntd.0004546

Jacobsen, K. H., & Koopman, J. S. (2005). The effects of socioeconomic development on worldwide hepatitis A virus seroprevalence patterns. *International Journal of Epidemiology*, *34*(3), 600–609. https://doi.org/10.1093/ije/dyi062

Jia, P., Dong, W., Yang, S., Zhan, Z., La Tu, & Lai, S. (2020). Spatial lifecourse epidemiology and infectious disease research. *Trends in Parasitology*, *36*(3), 235–238. https://doi.org/10.1016/j.pt.2019.12.012

Karlamangla, A. S., Singer, B. H., Williams, D. R., Schwartz, J. E., Matthews, K. A., Kiefe, C. I., & Seeman, T. E. (2005). Impact of socioeconomic status on longitudinal accumulation of cardiovascular risk in young adults: The CARDIA Study (USA). *Social Science & Medicine*, *60*(5), 999–1015. https://doi.org/10.1016/j.socscimed.2004.06.056

Kelly-Irving, M., & Delpierre, C. (2021). Framework for understanding health inequalities over the life course: The embodiment dynamic and biological mechanisms of exogenous and endogenous origin. *Journal of Epidemiology and Community Health*, *75*(12), 1181–1186. https://doi.org/10.1136/jech-2021-216430

Krämer, A., Akmatov, M., & Kretzschmar, M. (2010). Principles of infectious disease epidemiology. In A. Krämer, M. Kretzschmar, & K. Krickeberg (Eds.), *Modern infectious disease epidemiology: Concepts, methods, mathematical models, and public health* (pp. 85–99). Springer New York.

Krämer, A., & Khan, M. H. (2010). Global challenges of infectious disease epidemiology. In A. Krämer, M. Kretzschmar, & K. Krickeberg (Eds.), *Modern infectious disease epidemiology: Concepts, methods, mathematical models, and public health* (pp. 23–38). Springer New York.

Krickenberg, K., & Klemperer, D. (2010). Social risk factors. In A. Krämer, M. Kretzschmar, & K. Krickeberg (Eds.), *Modern infectious disease epidemiology: Concepts, methods, mathematical models, and public health* (pp. 100–115). Springer New York.

Krieger, N. (2008). Proximal, distal, and the politics of causation: What's level got to do with it? *American Journal of Public Health*, *98*(2), 221–230. https://doi.org/10.2105/AJPH.2007.111278

Kuh, D., Ben-Shlomo, Y., Lynch, J., Hallqvist, J., & Power, C. (2003). Life course epidemiology. *Journal of Epidemiology and Community Health*, *57*(10), 778–783. https://doi.org/10.1136/jech.57.10.778

Laing, K. J., Ouwendijk, W. J. D., Koelle, D. M., & Verjans, G. M. G. M. (2018). Immunobiology of Varicella-Zoster virus infection. *Journal of Infectious Diseases*, *218*(Suppl 2), S68–S74. https://doi.org/10.1093/infdis/jiy403

Larson, K., Russ, S. A., Kahn, R. S., Flores, G., Goodman, E., Cheng, T. L., & Halfon, N. (2018). Health disparities: A life course health development perspective and future research directions. In N. Halfon, C. B. Forrest, E. M. Faustman, & R. M. Lerner (Eds.), *Handbook of life course health development* (pp. 499–520). Springer. https://doi.org/10.1007/978-3-319-47143-3_20

Liu, R. S., Burgner, D. P., Sabin, M. A., Magnussen, C. G., Cheung, M., Hutri-Kähönen, N., Kähönen, M., Lehtimäki, T., Jokinen, E., Laitinen, T., Taittonen, L., Dwyer, T., Viikari, J. S. A., Kivimäki, M., Raitakari, O. T., & Juonala, M. (2016). Childhood infections, socioeconomic status, and adult cardiometabolic risk. *Pediatrics*, *137*(6). https://doi.org/10.1542/peds.2016-0236

Lowcock, E. C., Rosella, L. C., Foisy, J., McGeer, A., & Crowcroft, N. (2012). The social determinants of health and pandemic H1N1 2009 influenza severity. *American Journal of Public Health*, *102*(8), e51–58. https://doi.org/10.2105/AJPH.2012.300814

Mamelund, S.-E., & Dimka, J. (2021). Social inequalities in infectious diseases. *Scandinavian Journal of Public Health*, *49*(7), 675–680. https://doi.org/10.1177/1403494821997228

Manabe, T., Higuera Iglesias, A. L., Vazquez Manriquez, M. E., Martinez Valadez, E. L., Ramos, L. A., Izumi, S., Takasaki, J., & Kudo, K. (2012). Socioeconomic factors influencing hospitalized patients with pneumonia due to influenza A(H1N1)pdm09 in Mexico. *PLOS ONE*, *7*(7), e40529. https://doi.org/10.1371/journal.pone.0040529

Marques, A. H., Bjørke-Monsen, A-L., Teixeira, A. L., & Silverman, M. N. (2015). Maternal stress, nutrition and physical activity: Impact on immune function, CNS development and psychopathology. *Brain Research*, *1617*, 28–46. https://doi.org/10.1016/j.brainres.2014.10.051

Momplaisir, F. M., Kuter, B. J., Ghadimi, F., Browne, S., Nkwihoreze, H., Feemster, K. A., Frank, I., Faig, W., Shen, A. K., Offit, P. A., & Green-McKenzie, J. (2021). Racial/ethnic differences in COVID-19 vaccine hesitancy among health care workers in 2 large academic hospitals. *JAMA Network Open*, *4*(8), e2121931. https://doi.org/10.1001/jamanetworkopen.2021.21931

Muhsen, K., Na'aminh, W., Lapidot, Y., Goren, S., Amir, Y., Perlman, S., Green, M. S., Chodick, G., & Cohen, D. (2021). A nationwide analysis of population group differences in the COVID-19 epidemic in Israel, February 2020–February 2021. *The Lancet Regional Health. Europe*, *7*, 100130. https://doi.org/10.1016/j.lanepe.2021.100130

Nakagawa, F., Phillips, A. N., & Lundgren, J. D. (2014). Update on HIV in Western Europe. *Current HIV/AIDS Reports*, *11*(2), 177–185. https://doi.org/10.1007/s11904-014-0198-8

Patel, A. P., Paranjpe, M. D., Kathiresan, N. P., Rivas, M. A., & Khera, A. V. (2020). Race, socioeconomic deprivation, and hospitalization for COVID-19 in English participants of a national biobank. *International Journal for Equity in Health*, *19*(1), 114. https://doi.org/10.1186/s12939-020-01227-y

Pavalko, E. K., & Caputo, J. (2013). Social inequality and health across the life course. *American Behavioral Scientist*, *57*(8), 1040–1056. https://doi.org/10.1177/0002764213487344

Quinn, S. C., & Kumar, S. (2014). Health inequalities and infectious disease epidemics: A challenge for global health security. *Biosecurity and Bioterrorism: Biodefense Strategy, Practice, and Science*, *12*(5), 263–273. https://doi.org/10.1089/bsp.2014.0032

Robert Koch Institut. (2021). *SurvStat@RKI 2.0*. https://survstat.rki.de

Rod, N. H., Bengtsson, J., Elsenburg, L. K., Taylor-Robinson, D., & Rieckmann, A. (2021). Hospitalisation patterns among children exposed to childhood adversity: A population-based cohort study of half a million children. *The Lancet Public Health*, *6*(11), e826–e835. https://doi.org/10.1016/S2468-2667(21)00158-4

Ruckwardt, T. J., Morabito, K. M., & Graham, B. S. (2016). Determinants of early life immune responses to RSV infection. *Current Opinion in Virology*, *16*, 151–157. https://doi.org/10.1016/j.coviro.2016.01.003

Rytter, M. J. H., Kolte, L., Briend, A., Friis, H., & Christensen, V. B. (2014). The immune system in children with malnutrition – a systematic review. *PLOS ONE*, *9*(8), e105017. https://doi.org/10.1371/journal.pone.0105017

Simon, A. K., Hollander, G. A., & McMichael, A. (2015). Evolution of the immune system in humans from infancy to old age. *Proceedings: Biological Sciences*, *282*(1821), 20143085. https://doi.org/10.1098/rspb.2014.3085

Snieszko, S. F. (1974). The effects of environmental stress on outbreaks of infectious diseases of fishes *Journal of Fish Biology*, *6*(2), 197–208. https://doi.org/10.1111/j.1095-8649.1974.tb04537.x

Stormacq, C., van den Broucke, S., & Wosinski, J. (2019). Does health literacy mediate the relationship between socioeconomic status and health disparities? Integrative review. *Health Promotion International*, *34*(5), e1–e17. https://doi.org/10.1093/heapro/day062

Tosun, S., Aygün, O., Özdemir, H. Ö., Korkmaz, E., & Özdemir, D. (2018). The impact of economic and social factors on the prevalence of hepatitis B in Turkey. *BMC Public Health*, *18*(1), 649. https://doi.org/10.1186/s12889-018-5575-6

Ugboko, H. U., Nwinyi, O. C., Oranusi, S. U., & Oyewale, J. O. (2020). Childhood diarrhoeal diseases in developing countries. *Heliyon*, *6*(4), e03690. https://doi.org/10.1016/j.heliyon.2020.e03690

van Seventer, J. M., & Hochberg, N. S. (2017). Principles of infectious diseases: Transmission, diagnosis, prevention, and control. In *International Encyclopedia of Public Health* (pp. 22–39). Elsevier. https://doi.org/10.1016/B978-0-12-803678-5.00516-6

West, D. A., Leung, G. M., Jiang, C. Q., Elwell-Sutton, T. M., Zhang, W. S., Lam, T. H., Cheng, K. K., & Schooling, C. M. (2012). Life-course origins of social inequalities in adult immune cell markers of inflammation in a developing southern Chinese population: The Guangzhou Biobank Cohort Study. *BMC Public Health*, *12*(1), 269. https://doi.org/10.1186/1471-2458-12-269

Wick, G., & Grubeck-Loebenstein, B. (1997). The aging immune system: Primary and secondary alterations of immune reactivity in the elderly. *Experimental Gerontology*, *32*(4–5), 401–413. https://doi.org/10.1016/s0531-5565(96)00152-0

World Health Organization. (2022). *The top 10 causes of death*. https://www.who.int/news-room/fact-sheets/detail/the-top-10-causes-of-death

Zhang, X., Zhivaki, D., & Lo-Man, R. (2017). Unique aspects of the perinatal immune system. *Nature Reviews: Immunology*, *17*(8), 495–507. https://doi.org/10.1038/nri.2017.54