Long-Term Drivers of Future Mortality

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Long-Term Drivers of Future Mortality

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1. Introduction

The purpose of this paper is to provide a discussion and analysis of potential drivers of future mortality. Many of the drivers are based on a research workpaper[1] by a collaboration of 10 mortality and longevity experts[2] from seven countries, in which they compiled and discussed a list of future potential significant drivers of future mortality. The work originated from the former Mortality Working Group of the International Actuarial Association (IAA). The selected drivers in this paper are those considered significant by these experts, as well as others added by the authors of this paper. The collection of drivers is not claimed to be new, unique or comprehensive. In fact, there will likely be new advances and catastrophes that occur after the paper is published that could not have been known in advance by the authors. That said, we believe that studying the drivers we describe will help you be better prepared for what may occur in the future.

The paper is intended for consideration by actuaries, underwriters, insurers, demographers, academics, economists, public health officials and other decision makers to help them improve their estimates of future mortality, including potential trends, costs and implications.

Drivers of mortality can include items such as individual lifestyle behavior, population-related issues, health care and technological advances. These drivers can lead to higher or lower mortality, including potentially delaying mortality by slowing the aging process. Naturally, all major phenomena that affect the way we live are drivers of mortality. To demonstrate, the information-internet revolution enables us to better identify sources of diseases and alerts us to catastrophes, improves the management of health care and does much more; all of these affect our lifestyle and vulnerability to life events, and thus also our future mortality rates.

There are overlaps among the drivers presented herein, and other categorizations or selections of key drivers may be suggested. This, or any research, cannot cover all possible drivers, as the list is limitless and constantly changing. Our selection of drivers likely will differ from those of other authors on this topic.

A major question in these discussions is whether and how past trends of a driver will continue. Also, the list of drivers can never be complete, as we can look only so far into the future, and we have only partial and/or developing knowledge of societal, environmental, medical, technical and scientific changes.

The estimate of the impact of each driver of mortality, and the direction and strength of the resulting changes in mortality, could vary considerably, depending on many factors, including being conservative in the estimates, looking at a worst-case scenario, financial projections, etc. Other factors include the demographic or region (e.g., developed vs. developing countries), the interaction and correlation with other drivers, and various changes in these and other variables over time. Also, differences may be found by age, gender, socioeconomic group, etc. The emphasis and discussion are on each driver individually, and

[1] Y. Babad, A. Billig, S. Brimblecombe et al., "Long Term Drivers of Future Mortality," 2019, available by request from ybabad@uic.edu or al.klein@milliman.com.
[2] Yair Babad, Assia Billig, Simon Brimblecombe, Matthew Edwards, Michael Eves, Sam Gutterman, Al Klein, Mika Makinen, Lars Pralle, and Marianne Purushotham.

not necessarily on interactions between various drivers, which can often amplify or mitigate the impact of drivers.

We have identified various key broad drivers and then drilled down to examine various aspects of each of them. For example, aging is generally the most significant driver of mortality and thus is the first driver discussed in our paper. The second driver we explore is lifestyle, where we explore the impact of diet and obesity, exercise and physical activity, smoking and other factors.

The authors believe it is more important to determine what will impact future mortality than to precisely categorize the drivers. To aid the reader, the authors summarize their perspective on the drivers discussed in most chapters at the end of the chapter. However, no specific conclusion is provided because, as mentioned above, too many considerations exist that will vary by users and their specific purposes. It is up to the readers to choose the view they think is the most likely and meaningful for them.

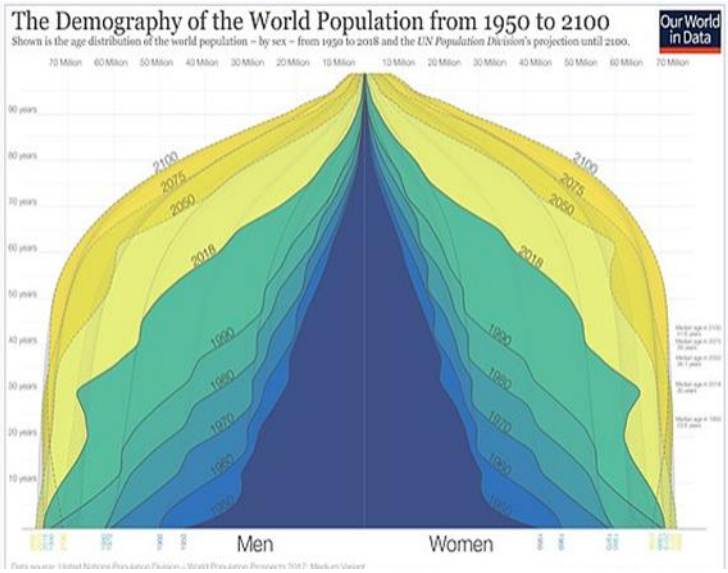
Many sources of information, data and opinions differ on the items we discuss. Although the authors strived to present current and recent known sources and information, as well as information on potential future drivers, a full discussion of these drivers, their breadth and details, and their impacts will change with new developments and advances and is beyond the scope of this paper.

2. Aging

Aging is the process of growing old, generally along with decreased physical and/or mental functioning, decreased quality of life and increased probability of death, regardless of chronological age. Aging is often characterized by gradual decline in body systems, increased frailty, diminished ability to perform physical activities, and possibly loss of memory and cognitive ability. The last may be driven by lack of social interaction and possibly depression, as well as lack of physical and mental activities and other factors. Insurers typically measure aging by the increasing inability to perform key activities of daily living (ADLs), such as mobility, bathing, dressing and eating, or when individuals begin to require some level of assistance in these areas. Aging also can lead to increased susceptibility to a wide range of impairments.

Aging, maybe the most significant driver of mortality, is the sum of many changes—physiological, genetic, molecular and mental—that occur with the passage of time, and it is the most significant hazard and greatest risk factor to a person's longevity and quality of life. The timing and progression of aging differ widely by individual, depending on a person's genetic makeup, life experiences and other factors. One outcome of aging is the impact of mortality—as a cohort of people (i.e., born in the same year) ages, it decreases in size. A graphical illustration of the distribution of a population by age groups and sex thus typically takes the shape of a pyramid; the pyramid for the newer years is wider than the pyramids for former years, with higher percentage of the population near the top which represent the older individuals. Figure 2.1 shows the age distribution and impact of aging of the world population since 1950 and projected to 2100.

Figure 2.1
WORLD POPULATION DEMOGRAPHY 1950–2100



Source: United Nations—World Population Prospects 2017.

The impact on mortality of almost all diseases increases by age, suggesting a dependency between aging and diseases. This can be explained at a molecular level by the physical wearing down of the body as time advances. Delaying or slowing aging will generally increase lifespan and slow the progression of higher age-related diseases leading to death. However, it may also expose the individual to longer-incubating latent diseases (e.g., cancer), which could also lead to death. Aging will remain a significant risk factor for mortality, independently or in conjunction with other factors.

People, harboring dreams of "eternal youth," have struggled for eons to overcome the impacts of aging. Medicine and technology strive to overcome the diseases and limitations inherent in aging and increase one's longevity, and societal, legal, ethical and religious efforts are invested in improving the quality of life of the aged. As the Society of Actuaries states,[3] most of the mortality improvements seen in recent decades were achieved through medical advances and reductions in smoking; that said, "aging is still the biggest driver of U.S. Mortality." As will be detailed below, research has shown that a healthy lifestyle, in terms of nutrition, physical and mental activity, social interaction and financial well-being, is likely to slow aging, enhance quality of life and reduce the incidence and severity of problems associated with activities of daily living among the aged. It is possible to extend healthy longevity, but each individual benefits in different ways and for different lengths of time.

2.1 THEORIES OF AGING

Aging is a multifactorial and complex process. There are many theories on it, but no one theory is fully able to explain aging. To better understand aging, it may be helpful to study the various models and theories of aging. All modern theories of aging strive, generally, to answer the following questions: Why do we age? How do we age? Why do we live as long as we do?

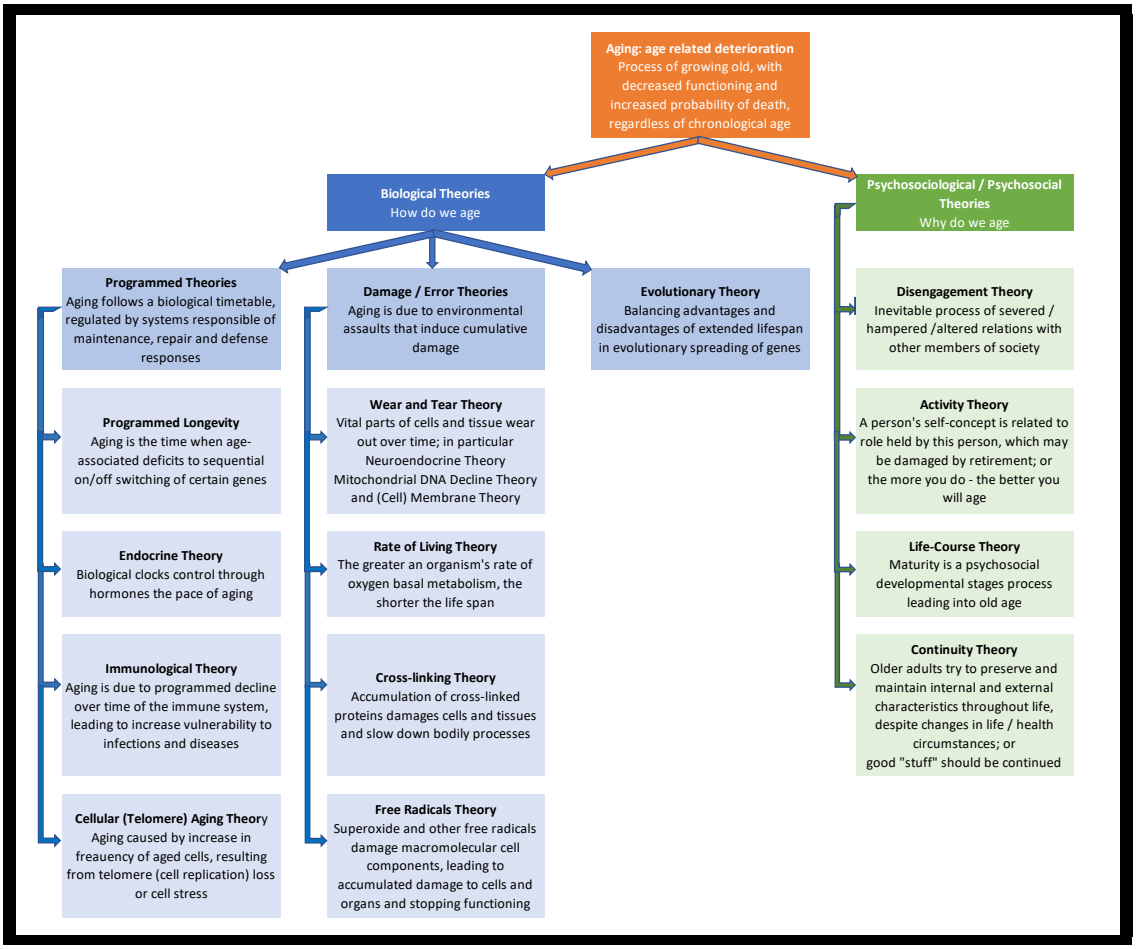
Biology is the common denominator of many aging theories. The biology of aging[4] explains aging as the loss of cellular and molecular fidelity or structure that leads to dysfunction and the onset of age-related diseases. This "loss" begins right after birth. Biological aging can be viewed as the random and systemic accumulation of dysfunctional molecules that exceed the body's repair capacity. This process may or may not follow a programmed biological timetable, driven by the relative strength of the chemical bonds that hold molecules together. The prevention of chemical bond breakage is a primary evolutionary molecular function, at least until reproductive maturation. After this point, the balance shifts in favor of the accumulation of dysfunctional molecules that begin to exceed the capacity for repair. This process, known as senostatic, may define the aging process and the subsequent increase in vulnerability to pathology or age-associated diseases.

Social and psychological theories relate the aging process to the interactions of people with their surroundings, society and the psychological processes associated with the declining physical and social functioning of the aged. These include the level and scope of interactions with other human beings, the diminishing contacts with others, and the role and stature of the aged within society. This can result in potential decreased self-respect and increased depression that often develop during the aging process.

Figure 2.2 summarizes various theories of aging we found in our research.

[3] L. N. Stern, "Drivers of U.S. Mortality Improvement: Expert Panel Forum Report," Society of Actuaries Longevity Advisory Group, January 2019, https://www.soa.org/globalassets/assets/Files/resources/research-report/2019/drivers-of-us-mortality-improvement.pdf.
[4] National Institute of Aging, "Biology of Aging," https://www.nia.nih.gov/about/budget/biology-aging-3.

Figure 2.2
THEORIES OF AGING



2.2 PHYSICAL AND MENTAL MALADIES OF AGING

Frailty is a clinically recognizable state of increased vulnerability in older adults resulting from aging-associated decline in reserves and functions across multiple physiologic systems, including compromised ability to cope with stresses and stressors, low grip strength, low energy, slowed waking speed, low physical activity and/or unintentional weight loss.[5] According to a study of males aged 65 and above living in retirement communities, Cawthon et al. found that frail men were approximately twice as likely to die as robust men (hazard ratio=2.05). The mortality risk for frail men was greater in all weight categories than for nonfrail men and was highest for normal-weight frail men (hazard ratio=2.39).[6]

[5] L. P. Fried, C. M. Tangen, J. Walston et al., "Frailty in Older Adults: Evidence for a Phenotype," *Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 56, no. 3 (2001): M146–M156.
[6] P. Cawthon, L. M. Marshall, Y. Michael et al., "Frailty in Older Men: Prevalence, Progression, and Relationship with Mortality," *Journal of the American Geriatrics Society* 55, no. 8 (August 2007): 1216–1223, https://agsjournals.onlinelibrary.wiley.com/doi/10.1111/j.1532-5415.2007.01259.x.

The prevalence of frailty and disability is expected to increase as death rates from diseases decline. Although the recent epidemic of obesity[7] would appear to reduce the prevalence of frailty as represented by low body weight, and some have even indicated that the additional weight may provide some protection against some diseases, the additional weight may reduce physical activity, put additional strain on the musculoskeletal body structure and, more generally, cause adverse health conditions. Furthermore, obesity increases the prevalence of many diseases, particularly diabetes, and thus further endangers aging people.

One of the greatest risks for the elderly is a fall. According to the 2014 Behavioral Risk Factor Surveillance survey (U.S.),[8] falls were the leading cause of fatal and nonfatal injuries for those older than 65. They report that 28.7% of all those older than age 65 reported at least one fall a year (26.7% for those aged 65 to 74, 29.8% between 75 and 84, and 36.5% for those older than 84). Twenty-nine million falls occurred, 7 million of these resulting in hip fracture or other injuries, and 2.8 million were treated in emergency rooms, with 0.8 million subsequently hospitalized. The rate of falls is reported to be higher for females than males. According to a World Health Organization (WHO) 2021 report, "falls are the second leading cause of unintentional injury deaths worldwide, each year an estimated 684,000 individuals die from falls globally, and 37.3 million falls occur annually that are severe enough to require medical attention."[9]

Aging is the greatest risk factor for morbidity and mortality, particularly because of the preponderance of chronic diseases. Certain drivers of mortality, such as stress, can also speed up the aging process and its outcomes. According to the National Council of Aging (NCOA), "Older adults are disproportionally affected by chronic diseases, such as diabetes, arthritis, and heart diseases. 80% have at least one chronic condition, and nearly 70% of Medicare beneficiaries have two or more. Multiple chronic diseases account for two-thirds of all health care costs and 93% of Medicare spending; this is unsurprising, as most seniors have hypertension and many have hypercholesterolemia (so 70% of beneficiaries account for 93% of Medicare spending). The leading causes of death among older adults in the U.S. are chronic diseases—heart disease, cancer, respiratory diseases, stroke, Alzheimer's disease, and diabetes."[10]

According to the same NCOA study, "One in four older adults experiences a mental or behavioral health problem such as depression, anxiety, or substance abuse. In 2014, nearly 11,000 people 60+ died by suicide. Men aged 85+ have a suicide rate that is about four times higher than the rate for all ages."

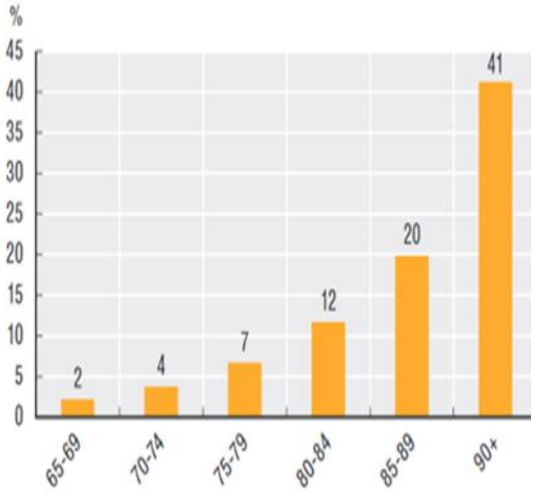
According to the WHO, 20% of adults aged 60 and over worldwide experience some mental or neurological disorder.[11] This is alarming, considering that the WHO estimates that the number of older adults will double from 1 billion individuals today to 2 billion by 2050. There has been a rapid increase in reported deaths due to these causes, especially Alzheimer's disease.

According to an editorial published in *The Lancet*, "Dementia is one of the major causes of disability and dependency among older people, affecting individuals and devastating whole families and network of

[7] K. N. Porter Starr, S. R. McDonald and C. W. Bales, "Obesity and Physical Frailty in Older Adults: A Scoping Review of Intervention Trials," *Journal of Medical Directors Association* 15, no. 4 (April 2014), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4023554/.
[8] Centers for Disease Control and Prevention, "2014 BRFSS Survey Data and Documentation," https://www.cdc.gov/brfss/annual_data/annual_2014.html.
[9] World Health Organization, "Falls," April 2021, https://www.who.int/news-room/fact-sheets/detail/falls.
[10] National Council of Aging, "Get the Facts on Healthy Aging," 2021, https://www.ncoa.org/article/get-the-facts-on-healthy-aging.
[11] World Health Organization, "Mental Health of Older Adults," December 2017, https://www.who.int/news-room/fact-sheets/detail/mental-health-of-older-adults.

friends and loved ones, and with huge economic and societal impacts."[12] The OECD prevalence of dementia in 2017 is seen in Figure 2.3. The editorial notes that "according to the Global Burden of Disease (GBD) study published in the February 2022 issue of *The Lancet Public Health*, dementia cases are projected to triple by 2050—from an estimated 57 million in 2019 to 153 million in 2050." The study noted that "there was geographical heterogeneity in the projected increases, with the smallest percentage changes in the number of projected dementia cases in high-income Asia Pacific (53%) and western Europe (74%), and the largest in north Africa and the Middle East (367%) and eastern sub-Saharan Africa (357%)."

Figure 2.3
OECD: PREVALENCE OF DEMENTIA



Source: OECD analysis of data from the World Alzheimer Report 2015.

The quotation continues: "Projected increases in cases could largely be attributed to population growth and population aging, although their relative importance varied by world region, with population growth contributing most to the increases in sub-Saharan Africa and population ageing contributing most to the increases in east Asia." At the same time, "[T]he 2020 Lancet Commission on dementia estimated that 40% of dementia cases could be prevented or delayed if exposure to 12 known risk factors were eliminated: high blood pressure, smoking, obesity, low education, depression, diabetes, physical inactivity, hearing impairment, social isolation, excessive alcohol consumption, head injury, and air pollution."

The Geroscience hypothesis posits that "since aging physiology plays a major role in many—if not all—chronic diseases, therapeutically addressing aging physiology directly will prevent onset or mitigate severity of multiple chronic diseases."[13] At this time we still have no practical way to slow down the aging process, as recommended by the hypothesis; however, it may be reasonable to assume that future medical and technological developments will make the slowing—or potentially even reversing—of the aging process feasible.

[12] "Will Dementia Hamper Healthy Aging?" https://www.thelancet.com/journals/lanpub/article/PIIS2468-2667%2822%2900009-3/fulltext. *The Lancet Public Health* 7 (February 2022).
[13] American Federation for Aging Research, "What Is Geroscience?" 2022, https://www.afar.org/what-is-geroscience.

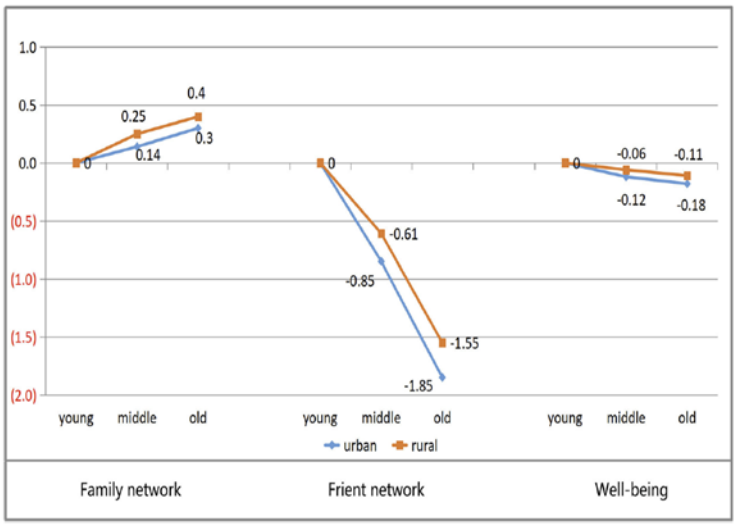
Indeed, age-reversal research is being studied. One focus is on understanding the cellular and molecular mechanisms and pathways regulating aging, and searching for molecules that may interact, slow and modify these processes. "The sirtuins, a family of nicotinamide adenine dinucleotide (NAD+)-dependent deacylases, have shown remarkable abilities to prevent diseases and even reverse aspects of aging."[14]

2.3 LONELINESS AND THE SUPPORT NETWORK

Social interactions with family, friends and community can contribute to mental healthiness and longer lives. As people age, spouses, companions and friends die, and family and social support networks disappear. This lack of social interactions often leads to depression and mental disorders and is a significant risk factor that increases as one ages. The U.K. Mental Health Foundation reported that people aged 65 and over are the least satisfied with their personal relationships of any age group, with only 46% of over 65 reporting that they spent time with their family most or every day, compared to 65% to 76% reported by other age groups. For almost half of individuals over age 65, the main source of company was the television or pets. People aged 75 and over are least likely to have at least one close friend, with 11% having no close friends at all, compared to only 2% of those aged 18 to 24.[15]

Figure 2.4

COMPARISON OF FAMILY AND FRIEND NETWORKS AND WELL-BEING BETWEEN URBAN-RURAL ELDERLY OF DIFFERENT AGES



Source: Z. Zheng and H. Chen, "Age Sequences of the Elderly Social Network and Its Efficacies on Well-Being: An Urban-Rural Comparison in China," BMC Geriatrics, 2020, https://bmcgeriatr.biomedcentral.com/track/pdf/10.1186/s12877-020-01773-8.pdf.

These results agree with Zheng and Chen's findings, shown in Figure 2.4, that compared the efficacies of family and friends social networks with respect to the well-being of urban and rural people at various age

[14] M.S. Bonkowski and D.A. Sinclair, "Slowing Aging by Design: The Rise of NAD+ and Sirtuin-Activating Compounds," *Nature Reviews Molecular Cell Biology*, 17, 679–690 (November 2016), https://www.nature.com/articles/nrm.2016.93 See also G. Gonzales, "The Prospect of Human Age Reversal" keynote presentation at the Life Extension–sponsored Revolution against Aging and Death Conference 2021, May 2022, https://www.lifeextension.com/magazine/2022/3/human-age-reversal.

[15] Mental Health Foundation, "Relationships in the 21st Century," May 2016, https://www.mentalhealth.org.uk/explore-mental-health/publications/relationships-21st-century-forgotten-foundation-mental-health-and-well-being.

groups, based on the 2014 China Longitudinal Aging Society Survey.[16] The rural population studied had somewhat higher efficacies and well-being as compared to the urban population. Family networks did much better than friends networks, probably because of the closer interactions. Notably, the overall well-being decreased with age, possibly because of the relatively large impact of the friends' networks.

Many societal efforts such as senior-day care centers, independent adult living communities, social services support for the aged and protected living facilities are devoted to safety net support groups and improvement of the quality of life of the aged. Such programs often cater to needs that are beyond the support that familial caregivers can offer to their aging family members. The efforts of family and friends are hampered by the decrease in the number of supporting children because of their migration to metropolitan areas; these efforts are also affected by the deterioration of the traditionally expected children's roles, with the increasing pressures on middle-aged people to support both their young children and their aging parents. All these factors lead to potential issues with, and endanger, the traditional support network of aging people, potentially leaving them with minimal or no support from their children at the time they most need it.

Furthermore, the projected future increase in the size of the aged population may result in a parallel increase in demand for public support and funds to aid the growing population. However, as more people age into retirement, the working population proportionally decreases, which may also decrease the funding for public support, as many social programs supporting the aged population are funded via income tax. These combined trends complicate the ability of society to support its aging segment.

Although informal caregivers can help, this work can be stressful and draining, and these workers may be challenged to continue such engagements over time. These pressures on the informal caregivers, as well as on professional at home caregivers, also lead to a considerable increase in protected living and long-term care use, the cost of which may endanger the future stability of many countries; see the IAA report "Long-Term Care: An Actuarial Perspective on Societal and Personal Challenges."[17] Once institutionalized, some progress can be made due to being surrounded by others of a similar age and with social interactions, which may delay deterioration. However, interactions with peers often decrease eventually because of increased frailty and decreased functional and/or mental capabilities, as discussed above.

[16] Z. Zheng and H. Chen, "Age Sequences of the Elderly Social Network and Its Efficacies on Well-Being: An Urban-Rural Comparison in China," *BMC* Geriatrics, 2020, https://bmcgeriatr.biomedcentral.com/track/pdf/10.1186/s12877-020-01773-8.pdf.
[17] International Actuarial Association, "Long-Term Care: An Actuarial Perspective on Societal and Personal Challenges," April 2017. https://www.actuaries.org/LIBRARY/Papers/PIWG_LTC_Paper_April2017.pdf.

SUMMARY TABLE for FUTURE MORTALITY - CHAPTER 2 - AGING			
Sub-Driver	**Near-Term (1-5 years) Impact**	**Longer-Term Future Impact**	**Comments**
Overall	⟺	⇈	Short-term slow increase in life expectancy and quality of life, but overall increase in chronic diseases and dementia
Biological Aging	⇊	↑	Slow mortality decrease due to medical and technological advances, but longer-term limited in its extent
Chronic Maladies	↑	⇈	Impact due to growing aging population, increasing life expectancy, and keeping chronic patients alive
Psychological and Mental	↑	⇈	Lonliness, depression, and mental stress increasing for both young and aged
Social Interaction	↑	↑	Social networks, and the stress of less clear future life expectations, negatively affect human connections
Physical Activity	⟺	⇊	There is active research, with a promise of a longer-term realization
Age Slowing/Reversing	⟺	⇊	There is ongoing active research, with a promise of a longer-term realization
Note: The evaluations reflect the authors' opinion, rather than a scientifically measurable comparison.			
Mortality Legend:	**Increasing: high** ⇈ **low** ↑ **;**	**Decreasing: high** ⇊ **low** ⇊ **;**	**or** ⟺

3. Lifestyle

Many efforts and theories have been devoted to anti-aging activities. Some of these activities have contributed to increased longevity, improved quality of life of the aged and chronically ill, and reduced old age diseases.

As noted earlier, the timing and progression of aging differ widely by the individual, depending on many factors, of which age is one of the most notable. Aging is the outcome of a diverse set of biological changes accumulating over time, and thus can be measured by a "biological— or epigenetic—age," an estimator (or, rather, a set of similar estimators). Epigenetic age is based on an analysis of combinations of the genome's methylation values.[18] The EpiAge acceleration, that is, the discrepancy between epigenetic age and chronological age, is "linked to a wide variety of pathologies, health states, mental state, and life style factors." The knowledge of one's EpiAge can potentially help to motivate people to change their lifestyle and slow or even reverse their EpiAge.

Smart lifestyle changes as well as some medical, genetic and pharmacological advances, have the potential to slow aging. The so-called Blue Zones[19]—areas around the world where more than the usual number of people live to be older than 100—are evidence to the effects of some of these strategies. Despite encompassing very different cultures, researchers have found common themes that they contend may make people live longer, including the following:

- *Lifestyle:* have a purpose in life; make family a priority; participate in a spiritual community; take time to relieve stress; and be with others sharing the same values.
- *Diet:* limit meat and avoid processed food; avoid sugars; drink red wine (because it is usually done in a social situation); restrict caloric intake—essentially undernutrition without malnutrition,[20] where calories are reduced by 30–40%, but without a reduction in essential nutrients and vitamins; and adopt the Confucian teaching *hara hachi bu* (eat until you are 80% full).
- *Exercise and move naturally:* engage in more physical activity: getting up and moving is important for longer life, but not heavy exercise (for example, jogging is not good because it is difficult on the body and ages the person over time), but walking is good. Interval training—involving short bursts of intense exercise followed by periods of rest—is good and is especially helpful if one increases the intensity of the workout over time.

In this paper we define lifestyle as the choices made by individuals in their *daily* habits and activities that may have an impact on their health and mortality. This excludes, for instance, the selection of living area, social or religious group, chosen profession, family type and spouse, or the choice of a health care provider. Similarly excluded are secondary lifestyle choices such as social activities, intellectual games and competitive sports. The key lifestyle factors we consider are diet and obesity, exercise and physical activity, active and passive smoking, alcohol, drug abuse and addiction, and stress.

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[18] S. Kabacik, D. Lowe, L. Fransen, et al., "The Relationship between Epigenetic Age and the Hallmarks of Aging in Human Cells," *Nature Aging* 2 (June 2022), https://www.nature.com/articles/s43587-022-00220-0.pdf.
[19] B. Frates, D. Buettner and S. Skemp, "Blue Zones," *American Journal of Lifestyle Medicine* 10, no. 5 (September–October 2016), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6125071/.
[20] V. M. Mendoza-Nunez, M. A. Sánchez-Rodríguez, R. Retana-Ugalde, et al., "Undernutrition without Malnutrition as a Protective Factor to Prevent DNA Damage in the Elderly," *Nutrition Research* 25, no. 3 (March 2005), https://www.sciencedirect.com/science/article/abs/pii/S0271531705000163.

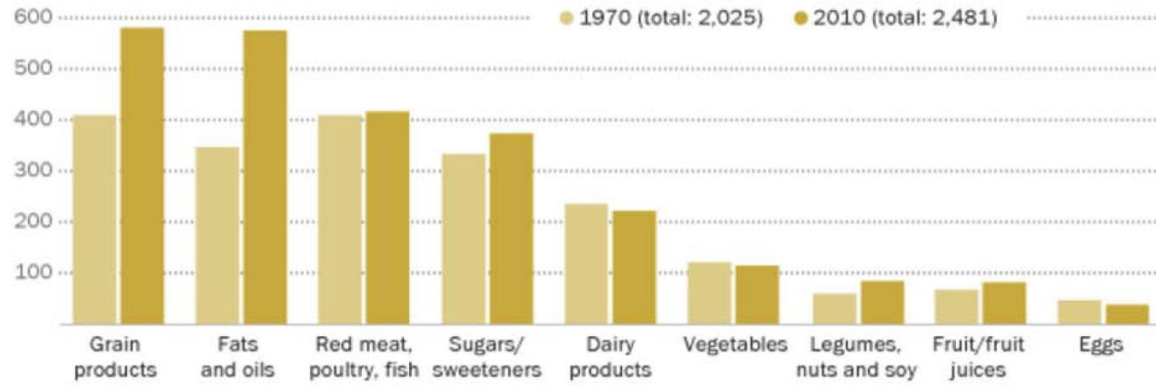
3.1 DIET AND OBESITY

Dietary and eating habits have considerably changed over time. Our ancestors were hunter gatherers with a diet of collected fruits, vegetables, seeds and roots, as well as the meat of hunted animals. Some remote peoples still live in this manner today. Once agriculture became the main lifestyle about 10,000 BC, the human diet generally changed toward the consumption of more starch-rich grains, farm poultry and animals, and for the nobility and wealthy meat as well.[21] Over time diet became more voluminous and richer with meats and specialty foods as prosperity increased. In the last century advances in canning, refrigeration and freezing technology, together with industrial intensive agriculture and selective breeding, further enriched the diet in developed countries, with little dietary change occurring in developing and underdeveloped countries. In the second half of the 20th century, the food industry pushed processed "fast foods" that contain excessive sugars (that could lead to obesity) and salt, unhealthy fats and new chemicals, e.g., preservatives and natural coloring (that could lead to other health problems). The result generally split developed nations into two "diet layers," where the higher socioeconomic groups moved to what they considered to be more balanced diets of nutritious food with less damaging ingredients, while the lower socioeconomic groups often grew obese on diets containing high concentrations of processed ingredients.[22]

These changes in dietary intake in the U.S. over the last 40 years, and the resulting daily per capita caloric increase, are well illustrated in Figure 3.1.

Figure 3.1

MODERN AMERICA DIET AND CALORIC DAILY PER CAPITA CHANGES FROM 1970 TO 2010



Note: "Fats and oils" includes butter, cream and other dairy fats. Figures adjusted for spoilage and other losses.

Source: D. Desilver, "What's on Your Table? How America's Diet Has Changed over the Decades," Pew Research Center, December 2016, https://www.pewresearch.org/fact-tank/2016/12/13/whats-on-your-table-how-americas-diet-has-changed-over-the-decades/.

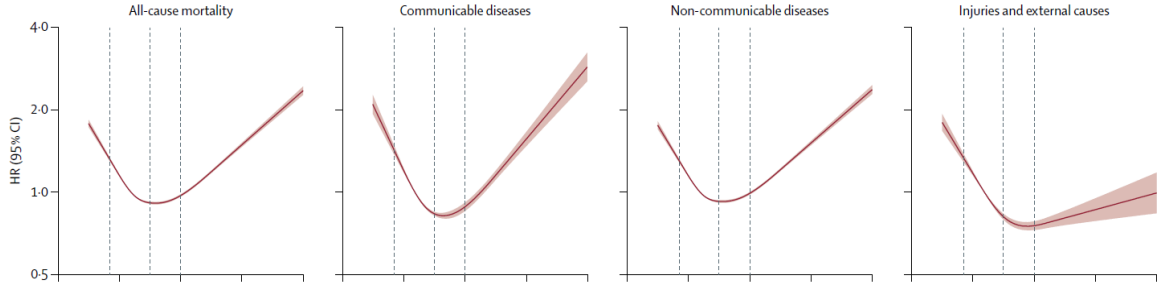
[21] Meat is often grouped into one category, which is wrong and misleading. Healthy meat (grass-fed, hormone and antibiotic free) is very good. The healthy fats, protein and the vitamins and minerals from it are essential for the body for healthy living. The problem comes from farm-raised animals that are fed poorly and given antibiotics to keep them from getting sick. Also, processed meats have harmful chemicals in them. Similarly, although most sugars are harmful, some sugars in fruits are good and essential for good health.

[22] A. Alkerwi, C. Vernier, N. Sauvageot, et al., "Demographic and Socioeconomic Disparity in Nutrition: Application of a Novel Correlated Component Regression Approach," *BMJ Open* 5, no. 5 (2015), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4431064/.

A common measure of obesity, closely connected with improper diet and caloric intake, is the body mass index (BMI), which is strongly associated with overall and cause-specific mortality,[23] as demonstrated in Figure 3.2.

Figure 3.2

ALL-CAUSE MORTALITY AND LEVEL 1 CAUSE-SPECIFIC MORTALITY OUTCOMES IN TOTAL POPULATION



We used a three-level hierarchical classification of causes of death as used by the Global Burden of Diseases, Injuries, and Risk Factors Study.[16] All Level 1 outcomes (communicable diseases, non-communicable diseases, and injuries and external causes) were studied. 5-year exclusion period applied for person-time and events after a BMI record. **Dashed vertical lines represent WHO BMI category thresholds** of 18.5 kg/m2 (underweight to healthy), 25 kg/m2 (healthy weight to overweight), and 30 kg/m2 (overweight to obese). Estimates adjusted for age at BMI record, deprivation, calendar year, diabetes, alcohol status, and smoking (all as defined at date of BMI measure) and stratified for sex. The p values for overall association and p values for non-linearity were less than 0. 0001 for all outcomes, in both full and never-smoker populations. **HR=hazard ratio**.

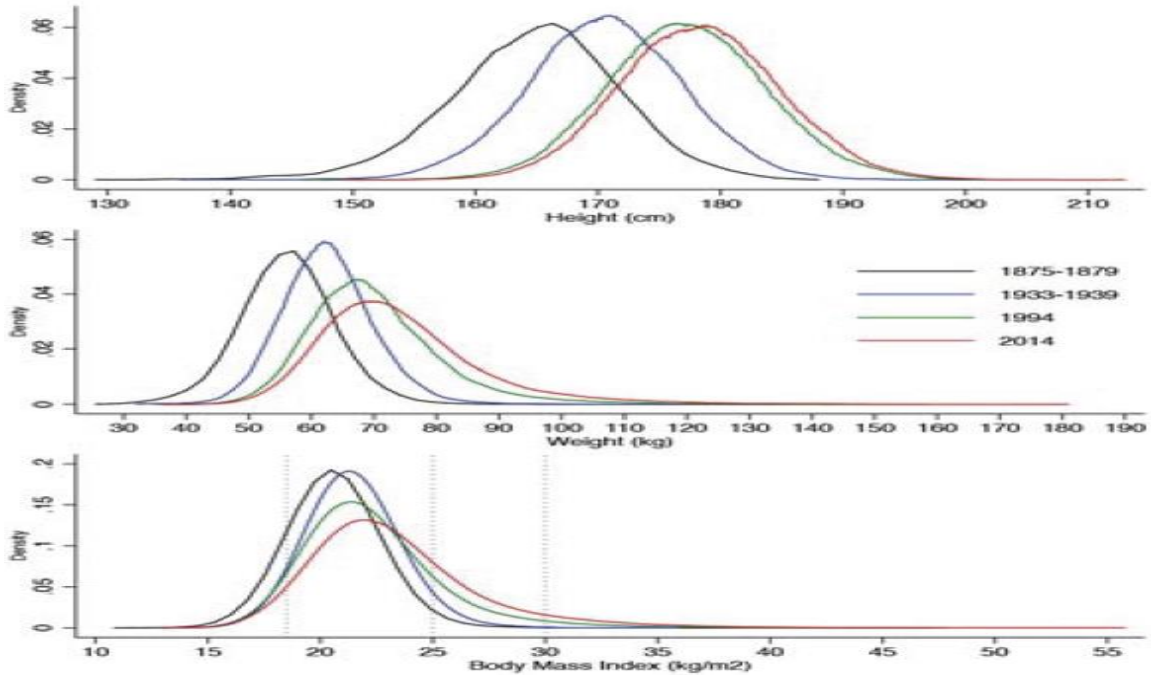
Source: K. Bhaskaran, I. Dos-Santos-Silva, D. A. Leon et al., "Association of BMI with Overall and Cause-Specific Mortality: A Population-Based Cohort Study of 3.6 Million Adults in the UK," Lancet Diabetes Endocrinol, https://www.thelancet.com/action/showPdf?pii=S2213-8587%2818%2930288-2.

The impacts of these diet-related behaviors over the last 150 years in Switzerland, and the resulting BMI distributions, which are similar (though still different, as each country may have its own distributions) to what happened throughout the developed world, are evident in Figure 3.3.

[23] K. Bhaskaran, I. Dos-Santos-Silva, D. A. Leon et al., "Association of BMI with Overall and Cause-Specific Mortality: A Population-Based Cohort Study of 3.6 Million Adults in the UK," *Lancet Diabetes Endocrinol*, https://www.thelancet.com/action/showPdf?pii=S2213-8587%2818%2930288-2.

Figure 3.3

CHANGES IN HEIGHT, WEIGHT AND BMI DISTRIBUTIONS OVER TIME AMONG YOUNG MEN IN SWITZERLAND SINCE THE 19TH CENTURY



Source: K. Staub, N. Bender, J. Floris and F. Ruhli, "From Undernutrition to Overnutrition: The Evolution of Overweight and Obesity among Young Men in Switzerland since the 19th Century," *Obesity Facts* 9, no. 4 (August 2016): 259–272, https://www.researchgate.net/publication/306325149_From_Undernutrition_to_Overnutrition_The_Evolution_of_Overweight_and_Obesity_among_Young_Men_in_Switzerland_since_the_19th_Century.

A number of trends contributed to these changes and the obesity epidemic of the developed world, including the following:

- Excessive intake of calories and poor dietary habits of many people.
- Sugar consumption: overindulgence with sugars and high-fructose corn syrup and sugar replacements, as well as other "attractive" nonhealthy ingredients promoted by the food industry to maximize its revenues and profits.
- Food prices: food in general has become much cheaper as a proportion of rising personal income. However, prices of fruit, vegetables and other healthy foods in many countries have risen substantially, while prices of some processed foods have dropped to increase their sales in poorer areas.
- Eating frequency habits: more people in developed nations adopted a more frequent "grazing strategy," leading to greater consumption of snacks etc.[24]

[24] B. Popkin and A. Duffey, "Does Hunger and Satiety Drive Eating Anymore?" *American Journal of Clinical Nutrition* 91 (2010): 1342–1347.

- Eating away from home: one 2000 report pointed to the responsibility of the 170,000 fast food restaurants and three million soft drink vending machines in the U.S. for only 38% of meals eaten being "home-made," while many adults have never cooked a meal from basic ingredients.[25]

Charting a likely future trajectory of nutritional patterns is particularly hard because there are different opinions about what constitutes a good diet. Even if there was a clear consensus, changing public eating habits is a long and arduous task, with education starting at a young age (e.g., serve fruits and vegetables rather than cookies). The problem with reaching a consensus view is that it goes against the main profit generators of multinational food companies (e.g., breakfast cereals, pseudo-healthy snack products, processed foods and drinks with unnecessarily high sugar). It is reasonable, however, to note that unless a drastic change in public eating habits takes place, the current trends in obesity, diabetes and general unhealthiness in most major countries in the world are likely to continue. Furthermore, such a change is complex and difficult and requires at least three things: a change in the public health policy regarding nutrition, a sustained education campaign and changes in behavior.

3.2 EXERCISE AND PHYSICAL ACTIVITY

The WHO defines physical activity as "any bodily movement produced by skeletal muscles that requires energy expenditure—including activities undertaken while working, walking, playing, carrying out household chores, travelling, and engaging in recreational pursuits."[26] The WHO further notes that "both moderate- and vigorous-intensity physical activity improve health" and that "physical inactivity has been identified as the fourth leading risk factor for global mortality (6% of global deaths), and is estimated to be the main cause for approximately 21–25% of breast and colon cancers, 27% of diabetes, and approximately 30% of ischemic heart diseases burden."[27]

Before urbanization, the internal combustion engine, and labor-saving cleaning and cooking devices, most people engaged in a substantial amount of physical activity. Work on a farm or in a manufacturing plant that required physical activity was common. Today many people are living a sedentary existence in which they are sitting at home, in cars, on public transportation, and in the office, and engaging in long periods in front of television and smartphone screens.

Although many people are still inactive, overall awareness is increasing of the value of physical activity and exercise. The U.K. has physical activity guidelines for adults that recommend that "adults should aim to be active daily. Over a week, activity should add up to at least 150 minutes (2½ hours) of moderate intensity activity in bouts of 10 minutes or more."[28] However, the extent to which this recommendation is spread across age bands and ethnic and socioeconomic groups suggests that many of the health benefits are concentrated at younger, white and affluent segments of society.

Until the arrival of pedometers, the health effects of exercise were studied much less than those of risk factors such as smoking. The health effects also generally relied on self-reporting, a generally inconsistent measure. Pedometers along with more recent wearables and smartphone applications make objective

[25] G. Gardner and B. Halweil, *Overfed and Underfed: The Global Epidemic of Malnutrition* (Washington, DC: Worldwatch Institute, 2000).
[26] World Health Organization, "Physical Activity," February 2018, https://www.who.int/news-room/fact-sheets/detail/physical-activity. The WHO definitions follow the classic article by C. J. Caspersen, K. E. Powell and G. M Christenson, "Physical Activity, Exercise, and Physical Fitness: Definitions and Distinctions for Health-Related Research," *Public Health Report* 100, no. 2 (March–April 1985), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1424733/.
[27] World Health Organization, "Global Strategy on Diet, Physical Activity and Health," 2019, https://www.who.int/dietphysicalactivity/pa/en/.
[28] "Physical Activity Guidelines for Adults (19–64 Years)," https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/213740/dh_128145.pdf.

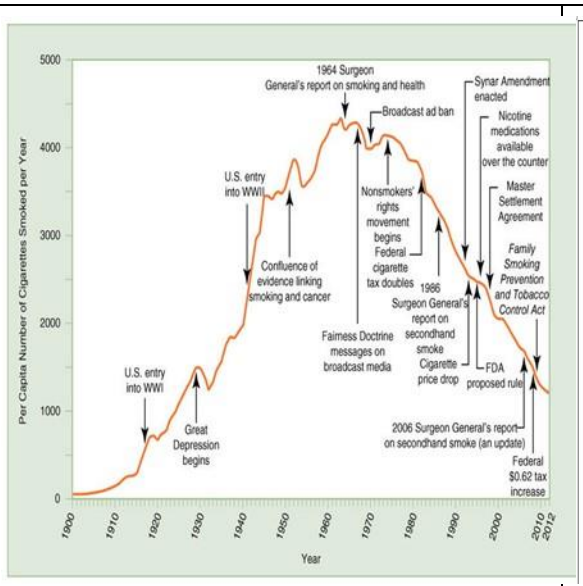
activity measurements feasible, enabling quantitative research into the benefits of exercise. For instance, each unit of 2,000 steps per day increment is associated with a 10% reduction in probability of a cardiovascular event,[29] and increasing the baseline daily steps from sedentary to 10,000 per day is associated with 46% reduction in mortality.[30]

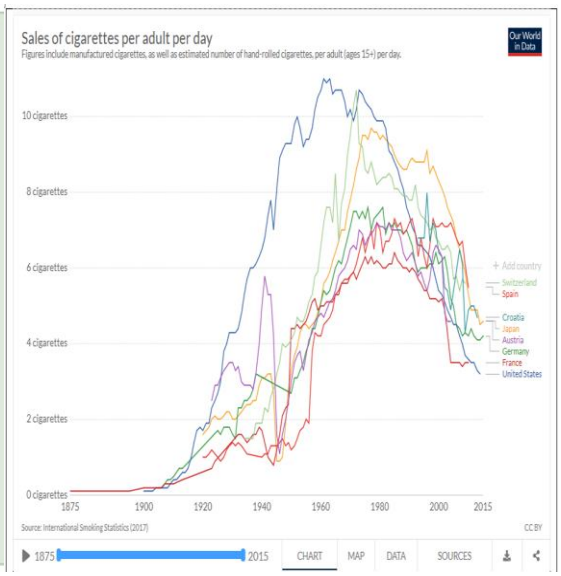
3.3 SMOKING

Smoking in this paper refers primarily to regular cigarette smoking, as well as quasi-smoking, or electronic nicotine delivery systems (ENDS), such as using e-cigarettes or vaping.[31] Smoking is generally considered the lifestyle choice with the greatest impact on health for the total population; hard drug use may have a greater impact per individual, but the number of individuals affected is relatively small compared to that of tobacco. As Fenlon and Preston state, "tobacco use is the largest single cause of premature death in the developed world."[32] Smoking prevalence rose dramatically through the first half of the 20th century, as seen in Figure 3.4 for the U.S. (left) and selected countries (right), owing to a combination of factors: the creation of blends and curing processes allowing inhalation and improving the desirability of the product (through incorporation of sugar in the process), the invention of the safety match, mass production and particularly mass media advertising. Smoking prevalence reached its peak between 1950 and 1980, and in many countries smokers exceeded half of males and a slightly lower percentage of females. The gradual recognition of the health hazard of smoking in the 1950s and 1960s led many countries to introduce smoking reduction measures (e.g., punitive taxation, health education, encouragement of alternatives, tar and nicotine reductions in cigarettes, and restrictions on cigarette advertising),[33] and some of these are reflected in the left chart in Figure 3.4. Prevalence by 2022 is down to 22% average worldwide, and less in certain developed countries (e.g., U.K. 19%, Canada 17.5% and 8% Sweden).[34]

[29] T. Yates, S. Haffner, P. Schulte, et al., "Change in Daily Ambulatory Activity and Cardiovascular Events," *The Lancet* 383 (March 2014).
[30] T. Dwyer, A. Pezic, C. Sun, et al., "Objectively Measured Daily Steps and Subsequent Long-Term All-Cause Mortality," *PLoS ONE* 10, no. 11: e0141274, https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0141274.
[31] For simplicity we ignore here pipe and cigar smoking, as well as infrequent or low-intensity cigarette smoking and nonsmoking tobacco-use such as chewing tobacco, which have somewhat different characteristics and (frequently) lower health effects.
[32] Andrew Fenelon and Samuel H. Preston, "Estimating Smoking–Attributable Mortality in the United States," *Demography* 49, no. 3 (August 2012), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3809994/.
[33] World Health Organization, "Tobacco," July 2019, https://www.who.int/news-room/fact-sheets/detail/tobacco.
[34] "Smoking Rates by Country 2022," *World Population Review*, https://worldpopulationreview.com/country-rankings/smoking-rates-by-country.

Figure 3.4
SMOKING PREVALENCE IN SELECTED COUNTRIES





Reproduced from U.S. Centers for Disease Control and Prevention, *The Health Consequences of Smoking—50 years of Progress. A Report of the Surgeon General*, Figure 2.1 2014. https://www.ncbi.nlm.nih.gov/books/NBK179276/	https://ourworldindata.org/grapher/sales-of-cigarettes-per-adult-per-day?=1875..2015

The effect of smoking on mortality has been well studied in many countries since the 1950s. Smoking has traditionally been associated with cancer. As reported by Doll et al.,[35] the all-cause mortality ratio for smokers compared with nonsmokers is on the order of a factor of two, while lung cancer rates were around 20 times higher in regular smokers than in nonsmokers.[36]

The longitudinal Seven Countries' Study[37] was an effort to study joint questions about heart and vascular diseases among countries having varied traditional eating patterns and lifestyles. It started with a pilot study in 1952–1956 in five countries, a first phase in 1958–1983 of 16 cohorts of middle-aged men from seven countries, and a second phase in 1984–1989 studying the epidemiology of healthy aging. The study concluded that life expectancy at age 40 was 6.8 years shorter for cigarette smokers than for nonsmokers and found a reduction of 8.8 years for men who smoked more than 30 cigarettes per day. The study also determined that smokers had a 60% higher all-cause mortality than nonsmokers.[38] At the same time, the study demonstrated the value of stopping smoking: men who stopped smoking at age 40 had 4.6 years greater life expectancy, and even stopping at age 70 added 2.5 years to their life expectancy. However, the

[35] R. Doll, R. Peto, J. Boreham et al., "Mortality in Relation to Smoking: 50 Years' Observations on Male British Doctors," *BMJ* 328 (2004): 1519.
[36] Since the length of exposure to smoking is important, a longitudinal cohort analysis of smoking mortality would be useful for better understanding.
[37] "Smoking, All-Cause Mortality and Long-Term Survival," Seven Countries Study, http://www.sevencountriesstudy.com/smoking-all-cause-mortality-and-long-term-survival/. See also "About the Study," https://www.sevencountriesstudy.com/about-the-study/.
[38] As often happens, the estimate of Doll et al. (see note 34) is significantly different from the Seven Countries' Study's estimate. This difference may be due to many experimental, geographical or timing factors, but it was not discussed in either of the studies.

effects of smoking, even if it is abandoned, remain (though they decrease over time)[39] and can affect health many years later.

Smoking is associated with many diseases, such as cancer (particularly lung cancer), cardiovascular (particularly coronary heart disease) and respiratory (particularly chronic obstructive pulmonary disease or COPD). It can also affect those who have regular exposure to an active smoker, such as family members and co-workers, who inhale the smoke. This is called passive or second-hand smoking. The impacts of smoking are evident in the Centers for Disease Control and Prevention (CDC) statistics on annual cigarette smoking-related mortality in the U.S. from 2005 to 2009, as presented in Figure 3.5.[40] Cancers are responsible for about one-third of the smoking deaths, and another third is attributable to cardiovascular diseases. Respiratory diseases also have a significant share at a quarter of the deaths.

[39] World Health Organization, "Tobacco: Health Benefits of Smoking Cessation," 2020, https://www.who.int/tobacco/quitting/benefits/en/, claims that the effect wears gradually over about 15 years of cessation of smoking.
[40] Centers for Disease Control and Prevention, "Tobacco-Related Mortality," January 2018, https://www.cdc.gov/tobacco/data_statistics/fact_sheets/health_effects/tobacco_related_mortality/index.htm.

Figure 3.5

ANNUAL CIGARETTE SMOKING-RELATED MORTALITY IN THE U.S., 2005–2009

Disease	Male	Female	Total	% of Total
Cancer				
Lung cancer	74,300	53,400	127,700	27%
Other cancers[a]	26,000	10,000	36,000	7%
Subtotal: Cancer	**100,300**	**63,400**	**163,700**	**34%**
Cardiovascular Diseases and Metabolic Diseases				
Coronary heart disease	61,800	37,500	99,300	21%
Other heart disease[b]	13,400	12,100	25,500	5%
Cerebrovascular disease	8,200	7,100	15,300	3%
Other vascular disease[c]	6,000	5,500	11,500	2%
Diabetes mellitus	6,200	2,800	9,000	2%
Subtotal: Cardiovascular and Metabolic	**95,600**	**65,000**	**160,000**	**33%**
Respiratory Diseases				
Pneumonia, influenza, tuberculosis	7,800	4,700	12,500	3%
COPD[d]	50,400	50,200	100,600	21%
Subtotal: Respiratory	**58,200**	**54,900**	**113,100**	**24%**
Total: Cancer, Cardiovascular, Metabolic, Respiratory	**254,100**	**183,300**	**437,400**	**91%**
Perinatal Conditions				
Prenatal conditions	346	267	613	0%
Sudden infant death syndrome	236	164	400	0%
Total: Perinatal Conditions	**582**	**431**	**1,013**	0%
Residential Fires	**336**	**284**	**620**	**0%**
Secondhand Smoke				
Lung cancer	4,374	2,959	7,333	2%
Coronary heart disease	19,152	14,799	33,951	7%
Total: Secondhand smoke	**23,526**	**17,758**	**41,284**	**9%**
TOTAL Attributable Deaths	**278,544**	**201,773**	**480,317**	**100%**

[a]Other cancers include cancers of the lip, pharynx and oral cavity, esophagus, stomach, pancreas, larynx, cervix uteri (women), kidney and renal pelvis, bladder, liver, colon, and rectum; also acute myeloid leukemia

[b]Other heart diseases includes rheumatic heart disease, pulmonary heart disease, and other forms of heart disease.

[c]Other vascular diseases include atherosclerosis, aortic aneurysm, and other arterial diseases.

[d]COPD is chronic obstructive pulmonary disease and includes emphysema, bronchitis, and chronic airways

Source: 2014 Surgeon General's Report: *The Health Consequences of Smoking—50 Years of Progress*, Chapter 12, Table 12.4. https://www.ncbi.nlm.nih.gov/books/NBK179276/

Many people who wish to stop smoking, as well as many other people and particularly young adults, turn to vaping or e-cigarettes.[41] These devices heat nicotine, which is extracted from tobacco, rather than burn tobacco as is done with cigarettes.[42] Vaping exposes the smoker to much fewer than the 7,000[43] or so chemicals that exist in regular tobacco cigarettes and their smoke. Still, vaping, like cigarettes, leads to inhalation of nicotine, which can be addictive, as well as many other ingredients, which can be dangerous, potentially raising blood pressure, increasing heart rate and affecting adrenaline levels and other ill-effects. Thus, vaping is probably bad for one's health,[44] even though not all of its impacts—and particularly the

[41] S. Gutterman, See "E-Cigarettes: A Hazard or a Help?" *North American Actuarial Journal* 24, no. 4 (2020), https://www.tandfonline.com/doi/abs/10.1080/10920277.2019.1683040.

[42] Sometimes vapers use other materials, e.g., marijuana; still, many vapers use nicotine and its by-products.

[43] M. J. Blaha, "5 Vaping Facts You Need to Know," *Johns Hopkins Medicine*, 2019, https://www.hopkinsmedicine.org/health/wellness-and-prevention/5-truths-you-need-to-know-about-vaping.

[44] Centers for Disease Control and Prevention, "Quick Facts on the Risks of E-Cigarettes for Kids, Teens, and Young Adults," April 2022, https://www.cdc.gov/tobacco/basic_information/e-cigarettes/Quick-Facts-on-the-Risks-of-E-cigarettes-for-Kids-Teens-and-Young-Adults.html.

long-term ones—are currently known. These risks and more are behind the current campaigns to stop e-cigarettes/vaping.

Many experts expect smoking prevalence to gradually decrease, owing to the combined effect of greater health awareness, continuing tax pressure, public health initiatives and the availability of alternatives such as vaping. The World Health Organization's latest global report on trends in smoking presented the projections in Figure 3.6, exhibiting meaningful smoking reduction in the European and American regions, with the opposite for the African and Eastern Mediterranean regions.[45]

Figure 3.6

PREVALENCE OF CURRENT TOBACCO SMOKING (%) BY REGION AND GENDER, 2010 AND 2025

	2010			2025		
Region	male	female	both sexes	male	female	both sexes
AFRO	23.2	2.5	12.8	34.7	1.6	18.1
AMRO	24.1	14.2	19.0	16.3	8.6	12.3
EMRO	35.1	3.1	19.5	45.3	2.5	24.6
EURO	40.3	19.9	29.6	31.3	15.9	23.3
SEARO	33.1	2.9	18.2	27.5	1.2	14.5
WPRO	49.4	3.6	26.8	43.3	2.4	23.2
GLOBAL	**36.9**	**7.3**	**22.1**	**33.2**	**4.7**	**18.9**

Source : https://apps.who.int/iris/bitstream/handle/10665/272694/9789241514170-eng.pdf

3.4 ALCOHOL AND DRUGS, ABUSE AND ADDICTION

Alcohol, including, for example, beer, wine, liquors and spirits, is the oldest and most widely consumed legal recreational drug, whose overuse may be toxic.[46] Alcohol can decrease anxiety and increase sociability and euphoria, while leading to temporary drunkenness and to impaired cognition, memory, and motor and central nervous system functions. In some situations, long-term use can lead to many physical and mental health maladies. There are three major types of alcohol: isopropyl, methyl and ethyl (or grain) alcohols; only ethyl alcohol can probably be safely consumed by humans and is discussed herein, while the other two are used as fuels and sterilizing agents.

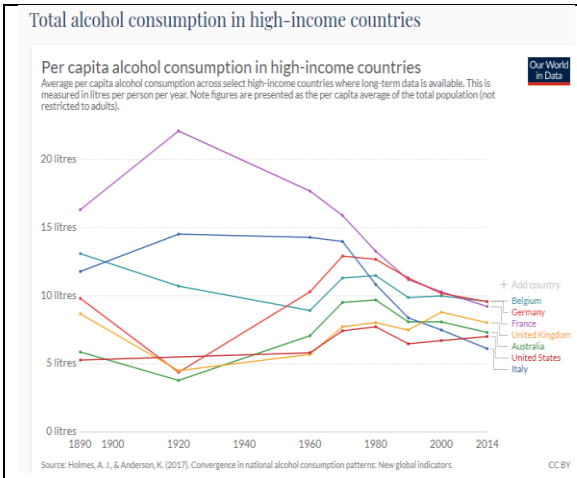
Because of concerns about the health and mortality effects of widespread gin drinking, the U.K. passed the Tippling Act in 1851 to increase gin prices. Temperance societies were started in the early 19th century in the U.S. and UK, aiming to help people avoid the perils of liquor; these culminated in the Prohibition years in the U.S. from 1920 to 1933. As the alcohol consumption per capita in high-income countries in the left chart of Figure 3.7 demonstrates, the high consumption variability in the first half of the 20th century, as well as the levels of consumption, have been reduced considerably. At the same time, as is evident from the right chart of Figure 3.7, in many parts of the world, alcohol and its related maladies contribute to a significant proportion of the mortality. Note that these data were from 2012, and the proportion may be larger later because of increased alcohol consumption during the COVID-19 pandemic.[47]

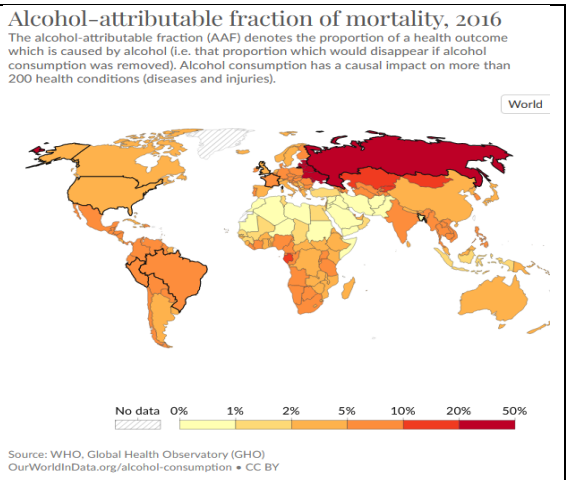
[45] https://www.who.int/publications/i/item/9789240039322

[46] For a detailed discussion and analysis of alcohol, its use and the disorders related to it, see "Alcoholism," https://en.wikipedia.org/wiki/Alcoholism.

[47] According to N. Brown, "Alcohol Consumption during the COVID-19 Pandemic Projected to Case More Liver Disease and Deaths," Massachusetts General Hospital, December 2021, https://www.massgeneral.org/news/press-release/alcohol-consumption-during-the-covid-19-pandemic-projected-to-cause-more-liver-disease-and-deaths, "a national survey of U.S. adults (and) their drinking habits that found that excessive drinking (such as binge drinking) increased by 21% during the COVID-19 pandemic."

Figure 3.7
ALCOHOL CONSUMPTION AND MORTALITY





Source: Holmes, A.J. & Anderson, K. (2017). Convergence in National Alcohol Consumption Patterns. New Global Indicators.	Source: Our World in Data, https://ourworldindata.org/alcohol-consumption

According to the World Health Organization:[48]

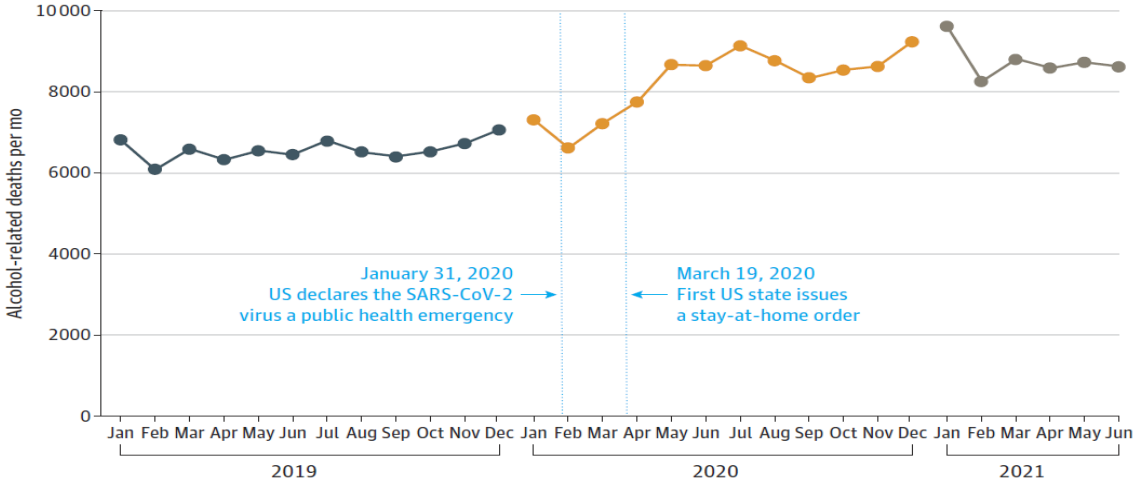
- Three million deaths every year result from harmful use of alcohol (5.3% of all deaths).
- Alcohol consumption can cause death and disability relatively early in life. In the age group 20–39 years, approximately 13.5% of the total deaths are alcohol-attributable. Still, many older adults "drink themselves to death"; further, oftentimes middle-aged Americans and Eastern Europeans (40s and 50s) in the lower to middle income brackets succumb to deaths of despair involving drugs and alcohol.[49]
- The harmful use of alcohol, as reported by the WHO, is a causal factor in more than 200 disease and injury conditions.[50]
- A causal relationship exists between harmful use of alcohol and a range of mental and behavioral disorders (suicide in particular) as well as injuries.

In the second half of the 20th century, increasing attention was paid to the investigation of the role of alcohol in two substantial, but very distinct, causes of death: road traffic accidents and liver cirrhosis. Alcohol-impaired U.S. driving fatalities in 2017 were 10,874 people (29%) out of 37,133 fatalities, though the fatality rate per 100,000 population had declined 63% since 1982.[51] On the other hand, alcohol-related cirrhosis deaths jumped 65% in the U.S. during 1999–2016, disproportionally affecting adults aged 25–34.[52]

[48] World Health Organization, "Alcohol," 2022, http://www.who.int/mediacentre/factsheets/fs349/en/.
[49] See pp. 111–114 of D. Raphael, A. Arik and Y. Babad, "Mortality by Causes of Death" (International Actuarial Association, June 2021). Mortality by Causes of Death (actuaries.org)
[50] World Health Organization, "Alcohol," May 2022, https://www.who.int/news-room/fact-sheets/detail/alcohol.
[51] "Drunk Driving Fatality Statistics," 2019, https://www.responsibility.org/alcohol-statistics/drunk-driving-statistics/drunk-driving-fatality-statistics/.
[52] "Alcohol-Related Cirrhosis Death Skyrocket in Young Adults," *Science Daily*, July 2018, https://www.sciencedaily.com/releases/2018/07/180718183605.htm.

At the same time, a significant variability is seen in the use of and deaths from alcohol in different parts of the world.

Figure 3.8
MONTHLY ALCOHOL-RELATED DEATHS AMONG PEOPLE 16 YEARS AND OLDER



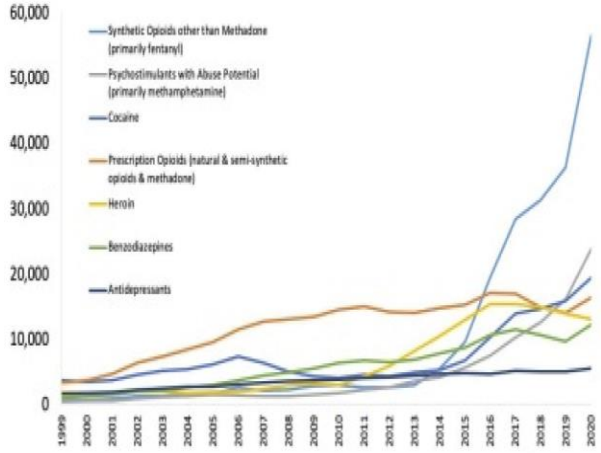
Source: A. M. White, I-J.P. Castle, P. A. Powell et al., "Alcohol-Related Deaths during the COVID-19 Pandemic," *JAMA* 327, no. 17 (2022), https://jamanetwork.com/journals/jama/articlepdf/2790491/jama_white_2022_ld_220016_1647557636.20795.pdf.

As Figure 3.8 by White et al. demonstrates,[53] the use of alcohol increased the mortality risk of the COVID-19 pandemic. As they explain, deaths involving alcohol reflect hidden tolls of the pandemic, because of increased drinking to cope with pandemic-related stressors, shifting alcohol policies and disrupted treatment access, among other factors. They conclude "whether alcohol-related death will decline as the pandemic wanes, warrants consideration."

Alcohol, as noted above, is a legal potentially toxic recreational drug, but is far from being the only drug and addiction that affect mortality. Traditionally, much of the attention was directed at illicit drugs, such as heroin, cocaine and methamphetamine, all of which are characterized by a physical dependence, which later leads to mental dependence, many maladies and sometimes death. Probably the most common illicit substance is marijuana, or cannabis, which is also used for medical treatments in some instances. Indeed, many countries have or are trying to legalize its use. Additionally, some legal prescription drugs manufactured by pharmaceutical companies (e.g., for pain treatment) may also be addictive or have side effects similar to those of illicit drugs. A particularly infamous family of drugs were the pain-relieving opioids, which were heavily promoted in the 21st century and led to 56,516[54] deaths in 2020.[55] Opioid distribution has been heavily curtailed by court actions and resulted in high compensation payments in recent years through litigation settlements.

[53] A. M. White, I.-J.P. Castle, P. A. Powell et al., "Alcohol-Related Deaths during the COVID-19 Pandemic," *JAMA*, 327, no. 17 (March 2022) https://jamanetwork.com/journals/jama/articlepdf/2790491/jama_white_2022_ld_220016_1647557636.20795.pdf.
[54] National Institute on Drug Abuse, "Overdose Death Rates," 2022, https://nida.nih.gov/drug-topics/trends-statistics/overdose-death-rates.
[55] In the U.S., opioid use and drugs peaked in about 2018, then started declining until the COVID-19 pandemic where they began to be prescribed again on a much wider basis, and so opioid overdose deaths have risen again, maybe be even above the prior peak.

Figure 3.9
U.S. DRUG-INVOLVED OVERDOSE DEATHS, ALL AGES, 1999–2020



Source: National Institute on Drug Abuse, "Overdose Death Rates," 2022, https://nida.nih.gov/drug-topics/trends-statistics/overdose-death-rates.

The increase in drug use in the U.S., as expressed by the annual mortality burden, is exhibited in Figure 3.9. According to a 2020 report of the National Center for Drug Abuse Statistics,[56] 11.7% of Americans aged 12 and over used illegal drugs, 19.4% (53 million people) used illegal drugs or misused prescription drugs, and 60.2% (165 million) used these drugs as well as alcohol and tobacco. In the U.S., 22% of males and 17% of females reported using illegal drugs. Also, 20.2% of people residing in metropolitan counties and 5% of people residing in rural counties used drugs.

There has been increased public health concern around excessive intake of alcohol and illegal drugs. As far as likely future trends are concerned, it is particularly hard to foresee how alcohol and drug consumption will vary. Aggressive regulatory or tax-based measures to reduce alcohol consumption are probably infeasible.

3.5 STRESS

White et al.[57] noted that stress is a process in which environmental demands and one's thoughts can strain the organism's adaptive capacity, resulting in psychological and/or physical demands that may affect biological changes and lead to illness. Stress affects everyone, although individuals deal with it in different ways. There are three stress theories regarding the (in)ability to cope with demands: environmental, psychological / emotional, and biological (related to the functioning of certain physiological systems). Researchers agree that all three types of stress can affect health and aging.

Stress "can affect your brain, suppress your thyroid, cause blood sugar imbalances, decrease bone density and muscle tissue, raise blood pressure, reduce your immunity and ability to heal, and increase fat deposits around your abdomen that are associated with heart attacks, strokes and elevated 'bad' cholesterol."[58]

[56] A. M. White, I.-J.P. Castle, P. A. Powell et al., "Alcohol-Related Deaths during the COVID-19 Pandemic," *JAMA*, 327, no. 17 (March 2022) https://jamanetwork.com/journals/jama/articlepdf/2790491/jama_white_2022_ld_220016_1647557636.20795.pdf.
[57] A. M. White, I.-J.P. Castle, P. A. Powell et al., "Alcohol-Related Deaths during the COVID-19 Pandemic," *JAMA*, 327, no. 17 (March 2022) https://jamanetwork.com/journals/jama/articlepdf/2790491/jama_white_2022_ld_220016_1647557636.20795.pdf.
[58] D. S. Hartz-Sheeley, "Chronic Stress Is Linked to the Six Leading Causes of Death," March 2014, *Miami Herald*, https://www.miamiherald.com/living/article1961770.html.

Still, each person has their own unique stressors, and stress over time is potentially one of the primary drivers for many, if not all, chronic diseases.

Stress is common worldwide.[59] About one-third of people around the world felt stressed, worried or angry in 2019, about 284 million have an anxiety disorder, and 12 nations reported more than 50% of their population experienced stress. According to the *United States of Stress 2019*, "chronic stress is a national epidemic for all genders and ages, particularly those 25–35 years old … (with) a complex mixture of socioeconomic, environmental, genetic, physical, and spiritual factors."[60] The same report shows that in the U.S. more than three-quarters of adults reported symptoms of stress and almost one-third of those surveyed visited a doctor about stress-related issues. Fifty-seven percent indicated being paralyzed by stress, but 43% were invigorated by it. Forty-seven percent responded to stress by taking it out on themselves, that is causing self-harm. Stress also affects generations differently: 59% of baby boomers have never been diagnosed with mental health issues, while slightly less, 52%, of "Gen[eration] Z," those born since 1997, have been diagnosed.

The COVID-19 pandemic, compounded with other persistent stresses, negatively affected the behavioral health of 49% of Americans and led the American Psychological Association (APA) to warn that the nation is facing a "mental health crisis that could yield serious health and social consequences for years to come … particularly affecting and depressing the youngest individuals,"[61] Gen Z. Those growing up during these times of disruption and unrest, changes in abortion laws, and unclear personal and national futures experienced increased harassment, more mental stress and higher suicide rates. The APA reports that the average 2020 stress level of all adults is 5.0 (compared with 4.9 in 2018 and 2019), and women reported higher level of stress (5.1) than men (4.4), whereas for Gen Z it was 6.1 (rising from 5.6 in 2018 and 5.8 in 2019).

Much research is devoted to the impact of stress on longevity and mortality. The consensus is that "stress kills," and many studies report that high stress levels result in higher mortality rates linking stress to various diseases (e.g., heart disease, cancer, lung ailments, liver cirrhosis, dementia and diabetes, as well as accidents and suicides).[62] Prior et al. studied 453,648 person-years with 39 morbidity conditions over up to four years from a population-based cohort of 118,410 participants in the 2010 Danish National Health Survey.[63] They reported that "our findings suggest that perceived stress contributes significantly to higher mortality rates, and more stress-related deaths occurred in people with multimorbidity." Rutters et al., in their 20-year follow-up of 2,385 participants in a population-based cohort of older people, found that their mortality was affected by the number of stressful life events experienced during the previous five years.[64] Specifically, having three or more stressful life events significantly increased mortality risk, with smoking, type 2 diabetes and cardiovascular diseases being statistically significant mediators.

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[59] SingleCare Team, "Stress Statistics 2022: How Common Is Stress and Who's Most Affected?" January 2022, https://www.singlecare.com/blog/news/stress-statistics/.
[60] M. Connolly and M. Slade, "The United States of Stress 2019," *Everyday Health*, May 2019, https://www.everydayhealth.com/wellness/united-states-of-stress/.
[61] American Psychological Association, "Stress in America 2020," https://www.apa.org/news/press/releases/stress/2020/sia-mental-health-crisis.pdf.
[62] See the study by this name, P. McGee, "High Stress Levels Result in Higher Mortality Rates," October 2011, High Stress Levels Result in Higher Mortality Rates (hcplive.com)
[63] A. Prior , M. Fenger-Grøn , K. K. Larsen et al., "The Association between Perceived Stress and Mortality among People with Multimorbidity: A Prospective Population-Based Cohort Study," *American Journal of Epidemiology* 184, no. 3 (August 2016): 199–210, https://www.ncbi.nlm.nih.gov/pubmed/27407085.
[64] F. Rutters , S. Pilz , A. D. Koopman et al., "The Association between Psychosocial Stress and Mortality Is Mediated by Lifestyle and Chronic Diseases: The Hoorn Study," *Society of Science Medicine*, 118 (October 2014): 166–172, https://www.ncbi.nlm.nih.gov/pubmed/25137635.

Of particular concern is the impact of stress in the workplace, with increasing costs and stress-related disorders. Both Japan and China have created a word to signify "death by overwork," *karoshi*[65] and *guolaosi*, respectively. Moreover, the extremely high level of stress seen in Millennials (those born between 1981 and 1996), has led some to call them the most stressed generation.[66] Millennials' high level of stress is owed, among other reasons, to social pressures and the impacts of technology and smartphones. Without positive interventions, Millennials may be indicative of a trend in increasingly unhealthy populations with more chronic disease and higher mortality when compared to past generations.

SUMMARY TABLE for FUTURE MORTALITY - CHAPTER 3 - LIFESTYLE			
Sub-Driver	**Near-Term (1-5 years) Impact**	**Longer-Term Future Impact**	**Comments**
Overall	⟺		Increased recognition/support may slow aging processess; however, requires personal resolve/stamina
Diet and Obesity			More industrialized diet will increase obesity and related maladies
Physical Activity			On an individualized basis, shorter-term increased activity which is countered by more sedantary life style, and longer-term reduced physical demand due to robotics, electronics and other work-environment changes
Smoking			Smoking prevalence expected to decrease, but effects of long-term smoking may take a long time to be noticed
Addiction			Addiction to drugs, alcohol, and overconsumption of medications will likely increase
Stress			Social, economical, and workplace stresses are on the rise, and even more noteworthy among youth
Note: The evaluations reflect the authors' opinion, rather than a scientifically measurable comparison.			
Mortality Legend:	**Increasing: high**  **low** **;** **Decreasing: high**  **low** **;** **or** ⟺		

[65] "Karoshi," https://en.wikipedia.org/wiki/Karoshi.
[66] L. Thomas, "Why Millennials Are the Most Stressed Generation," 2019, https://intentioninspired.com/why-millennials-are-the-most-stressed-generation/.

4. Inequality

As Gutin and Hummer note, population trends in life expectancy do not necessarily reflect the health and mortality experiences of key U.S. sociodemographic groups, as the increased life expectancy variability reflects growing rifts in the longevity prospects for different population segments.[67] The impacts of scientific, medical and technological innovations affect different socioeconomic groups differently; for example, new advances generally reach the higher socioeconomic groups and developed countries first, until the costs for these advances decrease. Also, lower socioeconomic groups tend to experience greater non-age-related, premature causes of death—most notably, drug overdoses and infectious diseases—also stratified along racial and ethnic lines. Health and well-being are highly correlated with one's position in the social hierarchy. A select portion of the population—namely, as Gutin and Hummer note, "white adults with high educational attainment, the skill set necessary to participate in an increasingly knowledge-based economy, and adequate financial resources"—will continue to be the more immediate and perpetual beneficiaries of the immense benefits of continued innovations.

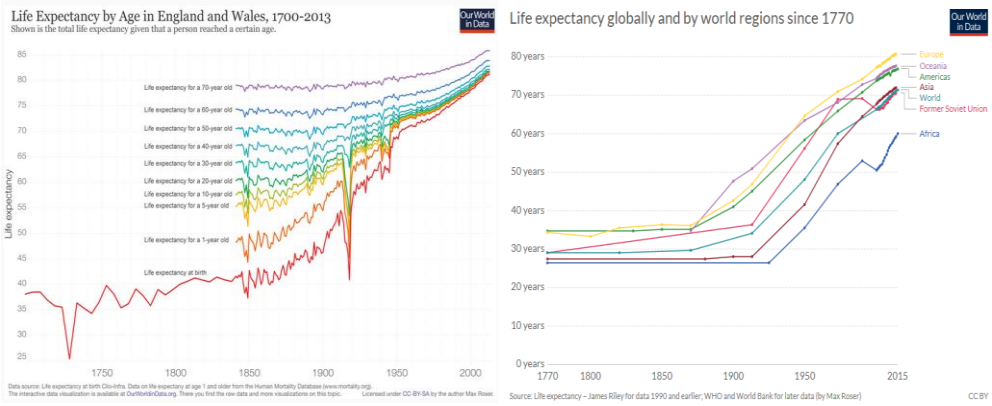
Inequality, of all forms and sources, could translate into different drivers and causes of death and health and different evolution of mortality rates over time. The impacts of these drivers can vary significantly by many factors, including region or country and population subgroups. Thus, although inequality, per se, is not a direct driver of future mortality, it is an underlying cause of many other important drivers. Stated differently, inequality within a given country, and between countries, can be the underlying and/or supportive cause for how other drivers of future mortality affect different subgroups.

Mortality outcomes within a country, as well as around the world, vary, reflecting changes over time due to age, gender, genetic make-up, geographical locations, level of education, lifestyle, access to medical care, ethnic or national identity and other inequality factors. This is evident, for example, in Figure 4.1, which reflects the different development paths of life expectancy[68] over time versus local age variability and global region variability.

[67] I. Gutin and R. A. Hummer, "Social Inequality and the Future of US Life Expectancy," *Annual Review of Sociology* 47 (February 2021), https://www.annualreviews.org/doi/10.1146/annurev-soc-072320-100249.
[68] M. Roser et al., "Life Expectancy," *Our World in Data*, 2019, https://ourworldindata.org/life-expectancy.

Figure 4.1

LIFE EXPECTANCY DEVELOPMENT OVER TIME: BY AGE IN ENGLAND AND WALES, AND GLOBALLY BY REGION



Source: M. Roser, E. Ortiz-Ospina and H. Ritchie, "Life Expectancy," *Our World in Data*, 2019, https://ourworldindata.org/life-expectancy.

These differences reflect socioeconomic inequalities in opportunity (such as being born in a disadvantaged part of town rather than in an affluent suburb), as well as socioeconomic inequalities in outcomes (such as an affluent lifestyle with easy access to high-quality health care). Socioeconomic status (a strong driver and predictor of future mortality, morbidity, health and quality of life) includes geographical location where people live, living conditions (e.g., sanitation), neighborhood safety, ecological environment (e.g., level of pollution, quality of water), access to high-quality education, health care, and governmental services. It is also related to intergenerational transfers, as current high socioeconomic status generally provides a better starting point for offspring of the next generation. Still, socioeconomic inequality does not completely explain all of the mortality differentials. Distributions by age and gender, genetic make-up and ethnic group, among other factors, add to the equation.

Inequality between socioeconomic classes can also be found in HIV-related illnesses, where UNAIDS 2020 estimates include the fact that 62% of all new HIV infections world-wide are in marginalized and stigmatized key-populations, and among sex workers, prisoners and drug injectors.[69] This section does not aim to fully analyze the impacts of inequality and socioeconomic status on mortality and health. The focus is more on how inequality impacts other mortality drivers and outcomes and discusses possible future developments.

4.1 INEQUALITY, LOCALITY AND POVERTY

Inequality can be related to place of residence, such as urban and metropolitan areas, because geographic location is often a proxy for wealth. The Office of the National Statistics in 2014 stated that "several studies have shown that geographical variations in life expectancy can largely be accounted for by area-based deprivation or disadvantage."[70] Indeed, in 2022 they noted that "In 2018 to 2020, male healthy life expectancy (HLE) at birth in the most deprived areas was 52.3 years, compared with 70.5 years in the least

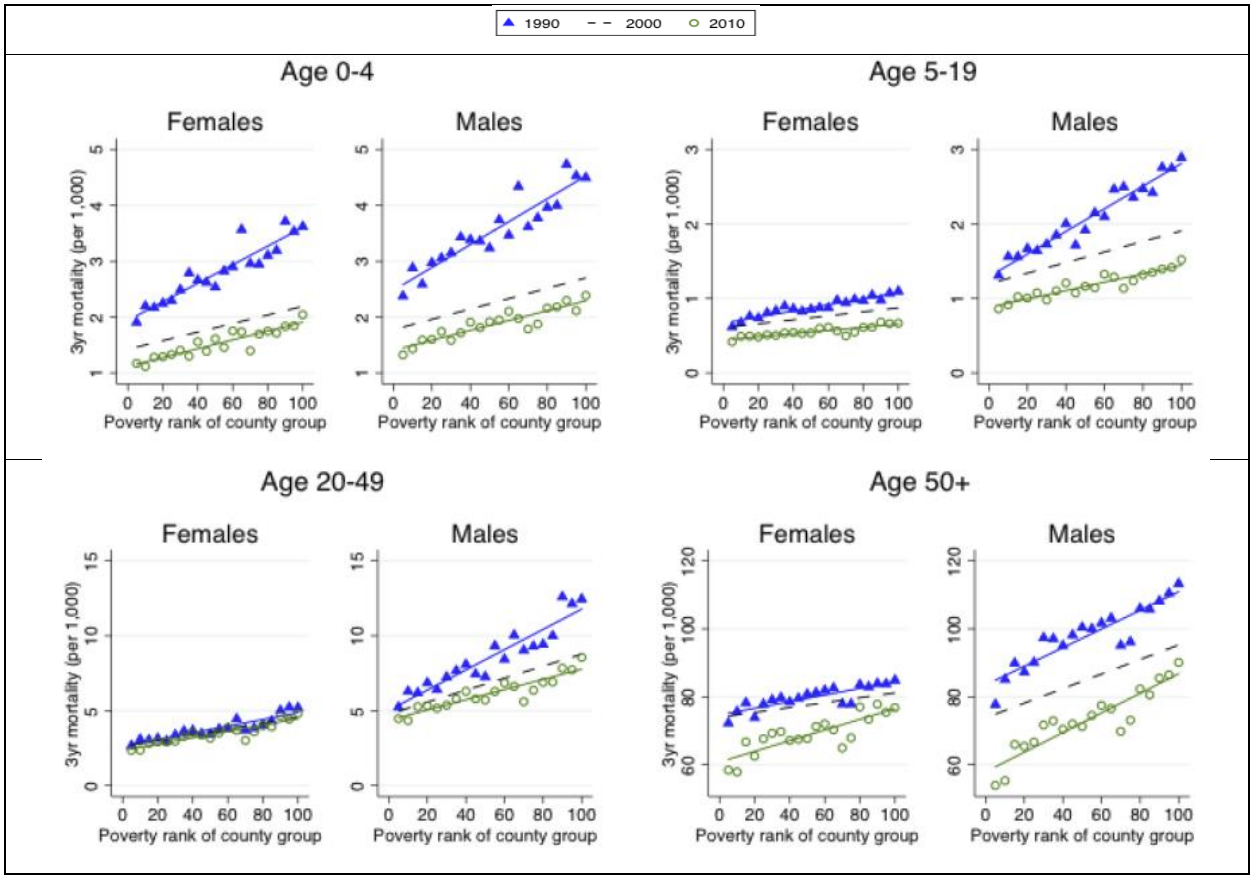
[69] Editorial, "HIV 40: Inequalities Fuel Pandemics," *Lancet Public Health* 6, no. 7 (July 2021), https://www.thelancet.com/journals/lanpub/article/PIIS2468-2667(21)00139-0/fulltext.

[70] ONS, "Life Expectancy at Birth and at Age 65 by Local Areas in England and Wales, 2011–13," Statistical Bulletin (London: United Kingdom Office of National Statistics, November 2014), http://www.ons.gov.uk/ons/rel/subnational-health4/life-expectancy-at-birth-and-at-age-65-by-local-areas-in-england-and-wales/2011-13/stb-life-expectancy-at-birth-2011-13.html.

deprived areas. Female HLE at birth in the most deprived areas was 51.9 years, almost 20 years fewer than those living in the least deprived areas (70.7 years)."[71]

Figure 4.2

COMPARISON OF U.S. THREE-YEAR MORTALITY RATES BY GENDER, AGE GROUP AND COUNTIES RANKED BY POVERTY RATE



Source: H. Schwandt and J. Currie, "Falling Inequality in Mortality in the U.S.," July 2, 2016, https://voxeu.org/article/mortality-inequality-good-news-county-level-approach.

Within a given country, Inequality is often expressed by socioeconomic status, which translates into different mortality outcomes, with the differences often being quite significant. Different measures are used for determining socioeconomic status. Poverty can be used as a surrogate measure for the closely associated low socioeconomic status. As seen in Figure 4.2 taken from Currie and Schwandt,[72] poverty is closely related to mortality rates, as are gender and age group; Currie and Schwandt also present similar results for different ethnic groups (e.g., Blacks/African Americans and whites in the U.S.).

[71] ONS, "Health State Life Expectancies by National Deprivation Deciles, England: 2018 to 2020" (London: United Kingdom Office of National Statistics, April 2022), https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/healthinequalities/bulletins/healthstatelifeexpectanciesbyindexofmultipledeprivationimd/2018to2020.

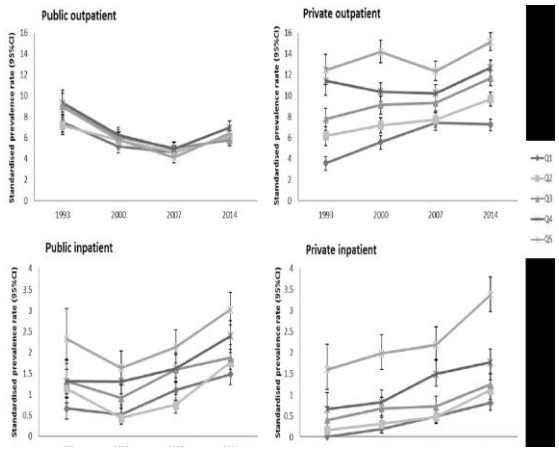
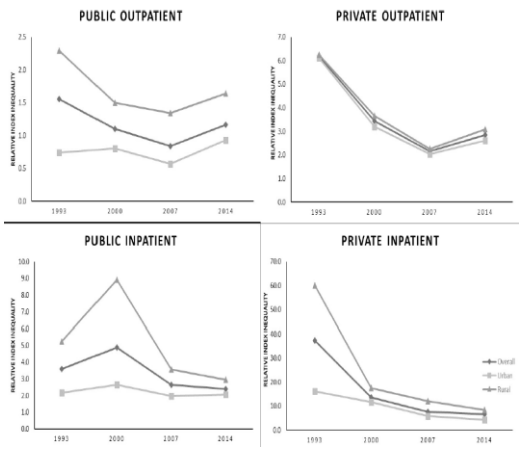
[72] J. Currie and H. Schwandt, "Falling Inequality in Mortality in the U.S.," July 2016, https://voxeu.org/article/mortality-inequality-good-news-county-level-approach.

4.2 ACCESS TO MEDICAL CARE

"People in poor countries tend to have less access to health services than those in better-off countries, and within countries, the poor have less access to health services."[73] One reason for this is that health care services are profit-oriented, and since not all the people in the low socioeconomic areas can pay for care, there generally tend to be less care or fewer facilities available for them. Further, with less money, people tend to wait to get care because they cannot afford it, and those delays often lead to worse health, more difficulty in treatment and higher mortality.

In addition to factors affecting developed countries such as geographical areas (e.g., rural versus urban), financial accessibility and availability of services, factors in developing countries such as cultural, language and communications barriers affect accessibility and acceptance of health services by poor and vulnerable groups.[74] A study of Indonesian income-related utilization of health care in 1993–2014 highlights the relationships between health care utilization, urban-rural areas and income quintiles, as seen in Figure 4.3.[75]

Figure 4.3
INDONESIAN 1993–2014 HEALTH CARE UTILIZATION BY INCOME AND GEOGRAPHIC AREA

Standardized prevalence rate of health care utilization by income quintiles, 1993–2014	Trends of income-related inequalities in various type of health care utilization by urban-rural area, 1993–2014
	

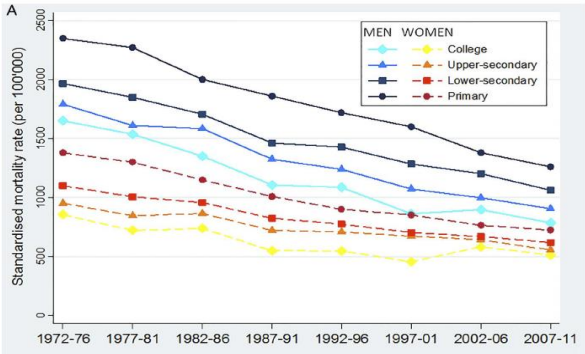
Source: J. Mulyanto, D. S. Kringos and A. E. Kunst, "The Evolution of Income-Related Inequalities in Healthcare Utilization in Indonesia, 1993–2014" PLoS ONE 6 (June 25, 2019)
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0218519.

[73] D. H. Peters, A. Garg, B. Bloom et al., "Poverty and Access to Health Care in Developing Countries," *Annals of the New York Academy of Science* 1136 (2008): 161–171, https://nyaspubs.onlinelibrary.wiley.com/doi/full/10.1196/annals.1425.011.
[74] Center for Aging Society, "Cultural Competence in Health Care: Is It Important for People with Chronic Conditions?," Health Policy Institute, Georgetown University Institute for Health Care and Policy, https://hpi.georgetown.edu/cultural/#.
[75] J. Mulyanto, D. S. Kringos and A. E. Kunst, "The Evolution of Income-Related Inequalities in Healthcare Utilization in Indonesia, 1993–2014," *PLoS ONE* 6 (2019), https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0218519.

4.3 EDUCATION

Educational attainment could be a powerful predictor of mortality. Figure 4.4 demonstrates a well-pronounced correlation between the level of education and level of mortality, with higher educational attainment being associated with lower mortality levels. The figure presents the 40-year trends in standardized mortality rates by educational level among men and women aged 30–99 from the Turin, Italy Longitudinal Study (1972–2011).[76]

Figure 4.4
MORTALITY RATES BY EDUCATIONAL LEVEL



Source: The Turin Longitudinal Study (Italy).

Quality of education is associated with socioeconomic status, as the OECD states: "In most OECD countries, students' attainment is typically lower in schools where most of the students come from disadvantaged backgrounds … students' socioeconomic background has a strong impact on their performance, and many disadvantaged schools are unable to counteract its negative impact, and may indeed accentuate it."[77]

The impact of educational attainment was evident during the COVID-19 pandemic. Yoshikawa and Asaba reported that a study of a large population of European ancestry showed that "educational attainment was significantly associated with a lower risk of COVID-19 severity."[78] Subramanian et al. note that "among the cohort of patients infected with SARS-CoV-2, risk factors of long COVID included female sex, belonging to an ethnic minority, socioeconomic deprivation, smoking, obesity, and a wide range of comorbidities";[79] several of these parameters, such as socioeconomic deprivation, can be closely related to the attained educational level.

4.4 INEQUALITY BETWEEN COUNTRIES

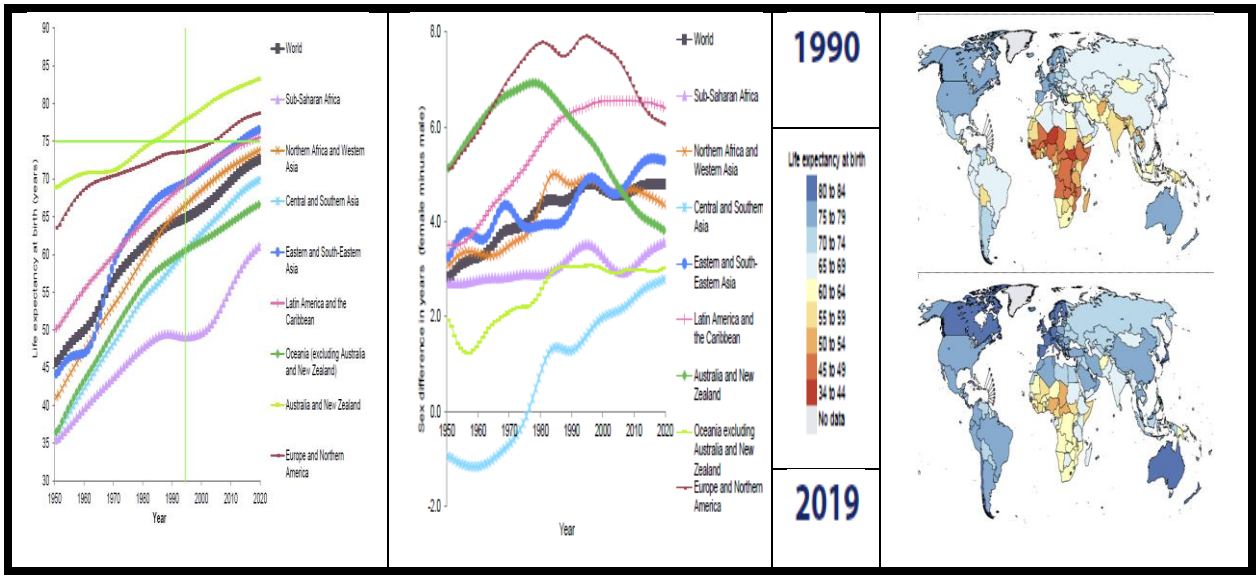
In addition to studying inequalities between populations as done above, one may consider inequality between groups of populations, namely, countries. Inequality in mortality between "poor" and "rich"

[76] S. Stringhini, T. Spadea, M. Stroscia et al., "Decreasing Educational Differences in Mortality over 40 Years: Evidence from the Turin Longitudinal Study (Italy)," *Journal of Epidemiology Community Health* 69 (2015): 1208–1216, https://www.researchgate.net/publication/280117048_Decreasing_educational_differences_in_mortality_over_40_years_Evidence_from_the_Turin_Longitudinal_Study_Italy/link/5721e42e08aee857c3b5cb9b/download.
[77] OECD, "Equity and Quality in Education: Supporting Disadvantaged Students and Schools," 2012, http://dx.doi.org/10.1787/9789264130852-en.
[78] M. Yoshikawa and K. Asaba, "Educational Attainment Decreases the Risk of COVID-19 Severity in the European Population: A Two-Sample Mendelian Randomization Study," *Frontiers in Public Health* 9 (June 2021), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8212884/.
[79] A. Subramanian, K. Nirantharakumar, S. Hughes, et al., "Symptoms and Risk Factors for Long COVID in Non-Hospitalized Adults," *Nature Medicine* 28 (August 2022), https://doi.org/10.1038/s41591-022-01909-w.

countries can be characterized by the relative levels of mortality for different age groups and the evolution of mortality rates. The simplest measure of levels of mortality is life expectancy at birth, as seen in Figure 4.5. Although the average global life expectancy advanced from 64.2 in 1990 to 72.6 in 2019, the high-income OECD countries (with U.S. as a notable exception) reached a life expectancy of over 80 years in 2019, whereas the poorer African countries have life expectancy at birth at about 60 years. Still, life expectancy at birth in developing countries across Africa, Asia and Latin America has increased by 20 to 30 years in recent times, while the increases for Europe and North America were about 10 years. Moreover, although life expectancy increased considerably since the mid-20th century in essentially all countries, the gap between developed and developing nations did not decrease.

Figure 4.5

LIFE EXPECTANCY (LEFT) AND SEX DIFFERENCES (MIDDLE: F. ABOVE M.) AT BIRTH FOR THE WORLD AND REGIONS, 1950-2019, AND CARTOGRAPHIC PRESENTATION OF ADVANCEMENTS IN 1990–2019



Source: World Mortality 2019

One of the prominent causes of such dramatic increases in life expectancy at birth is the decrease in infant, young children and maternal mortality. The main reason for such a reduction is improved sanitation and access to medical care.[80]

Figure 4.6 expands the presentation to several inequality measures: economic status, education, place of residence (rural versus urban) and gender, and compares the level of prompt care seeking for 28 countries. Except for gender impact, the median values increase with increased economic status, education and urbanity of residence.

[80] G. C. Brown, "Living Too Long," *EMBO Reports* 16, no. 2 (February 2015), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4328740/.

Figure 4.6

PROMPT CARE SEEKING FOR CHILDREN UNDER FIVE YEARS OF AGE WITH FEVER BY MULTIPLE DIMENSIONS OF INEQUALITY IN 28 COUNTRIES: 2010–2019

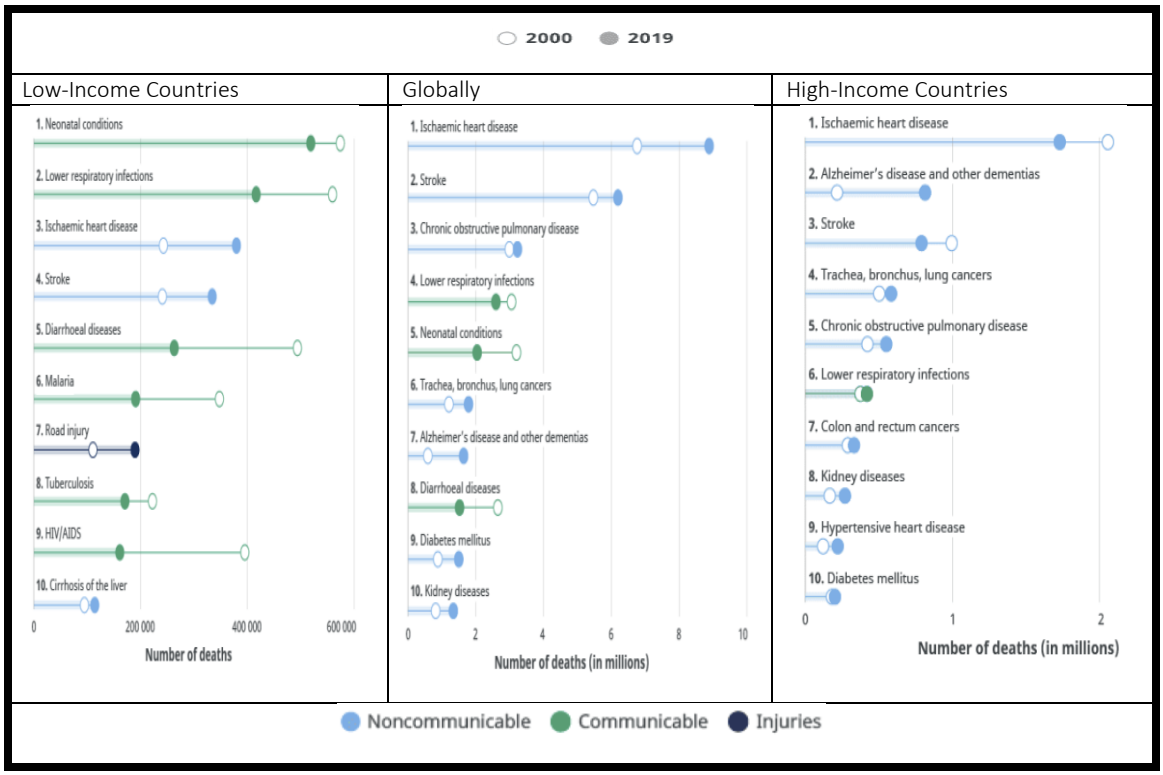
Notes: Circles indicate countries; each country is represented by multiple circles (one for each subgroup). Horizontal black lines indicate the median value (middle point of estimates).

Sources: World Health Statistics 2021: Demographic and Health Surveys (DHS) and Malaria Indicator Surveys (MIS), 2010–2019 (11).

Figure 4.7 presents another dimension of inequality, the leading causes of deaths in poor and rich countries, and how they have been shifted over the first two decades of the 21st century.

Figure 4.7

LEADING CAUSES OF DEATH: 2010–2019



Source: World Health Organization, "The Top 10 Causes of Death," December 9, 2020, https://www.who.int/news-room/fact-sheets/detail/the-top-10-causes-of-death.

With respect to the low-income countries, neonatal conditions (the number 1 cause) and communicable diseases are prominently included in the top 10 causes of death. Note that except for "stroke" and "lower respiratory infections," all other causes of death are different between the low- and high-income countries. Chronic diseases, cancer and illnesses with long incubation periods are among the main killers in the high-income countries; they are not even present in the leading causes for the low-income countries.

Some causes of death in developing countries have roots in societal circumstances, such as "road accidents." It is not clear if, in the future, other societal factors such as unpreparedness for natural disasters, climate change, pollution and poor work conditions will also result in increasing mortality in low-income countries for some age groups.

The majority of medical research is driven by high-income countries, and it stands to reason that medical research will migrate to developing countries and their needs, though the rate of migration will, at least to some extent, depend on the relative economic situations of developed and developing countries. For example, in developed countries, significant resources are being dedicated to the "treatment" of aging. It is unclear how and when such research will effectively benefit developing countries.

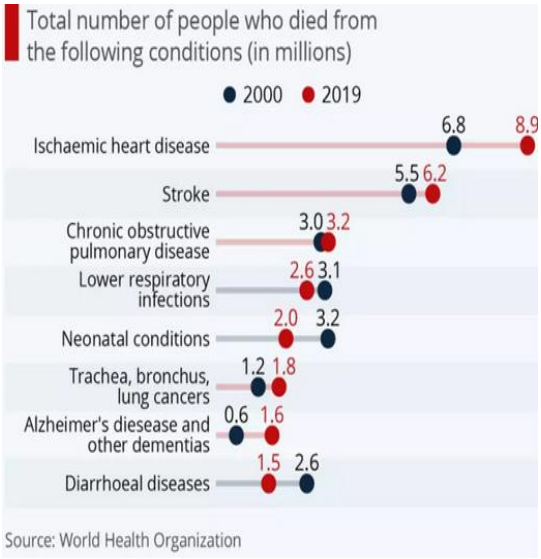
SUMMARY TABLE for FUTURE MORTALITY - CHAPTER 4 - INEQUALITY			
Sub-Driver	**Near-Term (1-5 years) Impact**	**Longer-Term Future Impact**	**Comments**
Overall			Inequality between socioecnomic groups increasing: decreasing mortality for more privileged groups with resources, knowledge, opportunities and better access to related drivers (health care, diet, education, etc.); increasing mortality for less privileged faster growing lower groups
Poverty			Increasing mortality for less privileged is growing because of affordability of related drivers (health care, diet, education, etc.)
Geographical Locality			Within and between countries, increasing mortality for more deprived areas through related drivers (like health care, diet, education, etc.)
Health care			The deprived have less access to and poorer quality health care
Diet			The deprived typically consume poorer quality food
Physical Activity			The deprived are more likely to be employed in manual labor, which is stressful to the body. The sedentary lifestyle (i.e., with reduced physical activity) that is more common among the privieged classes increases their mortality risk.
Education			Education has been found to be negatively correlated with mortality, and thus negatively affects the deprived groups with limited access to quality and higher education
Note: The evaluations reflect the authors' opinion, rather than a scientifically measurable comparison.			
Mortality Legend:	**Increasing: high**  **low**  **;**	**Decreasing: high**  **low**  **;**	**or** 

5. Diseases

Figure 5.1 presents the current leading maladies causing death around the world, according to the 2019 World Health Organization.[81] The top four causes of death in 2019 were the same for men and women, but the fifth most common cause for men was lung cancers and other trachea or bronchus-related ailments, whereas Alzheimer's disease and other dementias were fifth for women. Alzheimer's remains a growing problem that affects more women than men. COVID-19 may be disrupting immunization against diseases such as measles, cholera and polio, which could potentially cause more deaths from these diseases after being controlled for many years. HIV/AIDS and preterm birth complications have since 2000 dropped off the "top 10" and have been replaced by dementia and diabetes. Note that this is a global perspective, and important differences exist between countries; for example, diarrheal diseases are mostly a problem of the developing world. Nonetheless, disease is a major driver of mortality.

Figure 5.1

WORLD LEADING MALADIES CAUSING DEATHS



Average global life expectancy rose from 66.8 years in 2000 to 73.4 in 2019, whereas healthy life expectancy has increased only from 58.3 years in 2000 to 63.7 in 2019.[82] This indicates there is a time of life, currently lasting almost 10 years, at which health and possibly quality of life, start to diminish. Diabetes has the largest impact on Disability Adjusted Life Years[83] (DALYs), increasing by 80% between 2000 and 2019, whereas Alzheimer's and dementia DALYs have almost doubled.

[81] World Economic Forum, "These Are the Top 10 Global Causes of Death—But Two Diseases Are in Decline" (based on WHO 2019 report), 2022, https://www.weforum.org/agenda/2021/02/top-10-global-causes-death/.
[82] World Health Organization, "Life Expectancy and Healthy Life Expectancy," 2022, https://www.who.int/data/gho/data/themes/topics/indicator-groups/indicator-group-details/GHO/life-expectancy-and-healthy-life-expectancy.
[83] DALY combines years of life lost due to premature mortality (YLL) and years of life lost due to time lived in states of less than full health, or years of healthy life lost due to disability (YLD).

Although we all may intuitively conceptualize a disease,[84] Scully notes that it is not easy to articulate what a disease is, and defining disability is even more problematic.[85] We cannot always recognize one when we see it, and we may be unable to distinguish between a real disease and a disturbing behavior. Further, what counts as a disease (such as osteoporosis) may change over time. Even the definition of a disease may be confusing, as demonstrated by the following definitions, taken from dictionaries and through a Google search:

- Illness or sickness characterized by specific signs and symptoms;
- Any harmful deviation from normal structural or functional state of an organism;
- An abnormal condition affecting a living organism that involves a pathological process associated with a specific set of symptoms;
- A disorder of structure or function of a human, animal or plant that produces specific signs or symptoms or affects a specific location and is not a direct result of physical injury.

In humans, a disease often refers to any physical or mental condition that causes pain, dysfunction, distress, social problem or death to the afflicted person or to those in contact with this person. A disease often alters the affected person's perspective on life.

Diseases are often classified in various ways (which may overlap). Different categories may require different solution approaches. For example, mental illnesses may require societal actions such as confinement for the severely ill, but more communal activities for the mildly ill who may be homeless and/or employment deficient. Physiological effects are usually treated with traditional health care facilities and medicinal activities. The major categorizations of diseases include the following:

- According to physiological effects, such as autoimmune, genetic, bacterial or viral, blood, cancer, digestive, heart, nerve (or neurodegenerative), sexually transmitted, communicable or noncommunicable, and whether they are chronic (i.e., continually present and may present symptoms during a long duration).
- According to the mechanism of action: infectious diseases, deficiency diseases, hereditary diseases (including both genetic and nongenetic diseases) and physiological diseases.
- Mental illness is a disease that mostly affects a person's thinking, behavior and feelings, rather than the physiology, and alters the ability to function "normally" or relate to other people. The major categories of mental illnesses include anxiety, mood disorders, schizophrenia, psychotic disorders, eating disorders and dementia (including Alzheimer's).
- Vector-borne diseases, often infectious, which are caused by pathogens such as parasites, fungi, viruses and bacteria, and are transmitted by mosquitoes, sandflies and similar animal vectors. The major vector-borne diseases, together, account for around 17% of all infectious diseases, lead annually to more than 700,000 deaths (where malaria alone accounts for more than 400,000), and put more than 3.9 billion people in 128 countries at risk.[86]
- Alternative medicine, which is based on non-western medicine. In homeopathy, for instance, diseases are classified into indisposition, surgical (diseases due to mechanical or external sources),

[84] For the various terms associated with diseases, such as malady, illness and disorder, the reader is referred to the Wikipedia's "Disease" article. https://en.wikipedia.org/wiki/Disease

[85] J. L. Scully, "What Is a Disease?" *European Molecular Biology Organization Reports* 5, no. 7 (2004), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1299105/pdf/5-7400195.pdf.

[86] World Health Organization, "Vector-Borne Diseases," March 2020, https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases.

acute and chronic.[87] Chinese medicine, for example tries to balance the body and looks for connections within the body to treat.

Disease may be prevented or avoided using various strategies, including proper sanitation, proper nutrition, frequent exercise, diet and vaccination. Treatments for diseases and their symptoms and pains range from medications—chemical- and genetic-based—to medical devices, surgery, physical and mental exercise, palliative care, to self-care. Some diseases may be cured simply by time, whereas others require a set of treatments to reverse the disease processes or end the root medical problem permanently. Other diseases may remain uncured for a short or chronically long time.

Each disease has a case fatality rate (CFR), or mortality rate, which is the proportion of people diagnosed with the disease who die during the course of the disease. To illustrate, transmissible spongiform encephalopathies (e.g., Creutzfeldt-Jakob disease and Kuru) have a CFR of 100%, and untreated rabies, with manifested symptoms, has a CFR of 99%, but can be treated with a vaccine, which is unique in being *given after* exposure, and has approximately 0% CFR if quickly treated. Wikipedia presents a list of more than 60 such diseases, with treatment notes, CFRs and full references.[88]

The WHO maintains for its "Mortality Burden of Disease"[89] project a central source of metadata of health-related indicators used by them and other organizations. It includes data sources, indicator definitions and methods of estimations. It has a data repository, country statistics updated to 2019, about 20 reports on various health issues (such as alcohol, child health and HIV/AIDS), a map gallery and detailed standards.

The Lancet has an ongoing project, "Global Burden of Disease" (GBD), which is "the most comprehensive worldwide observational epidemiological study to date," with annual update articles that in 2019 included 369 diseases, 204 countries and 87 risk factors.[90] The GBD "describes mortality and morbidity from major diseases, injuries, and risk factors to health at global, national and regional levels. Examining trends from 1990 to the present and making comparisons across populations, enables understanding of the changing health challenges facing people across the world in the 21st century."

5.1 INFECTIOUS DISEASES

Infectious diseases, which are traditionally more common in developing countries than in developed countries, have been receiving much attention in the last few decades. As Holmes et al. note, "infectious diseases were responsible until the end of the 20th century for the largest global burden of premature death and disability."[91] In the past, global pandemics of infectious diseases, such as smallpox, cholera and influenza, periodically threatened the survival of entire populations.[92] The late 1800s led to improved living conditions (such as better sanitation and piped water supplies, following the 1854 discovery by John Snow of the link between contaminated water and cholera), particularly in high-income countries, and began to drive down the infectious disease burden. By the mid-20th century, safe, effective and affordable vaccines

[87] National Health Portal India, "Classification of Diseases," 2016.
[88] "List of Human Disease Case Fatality Rates," https://en.wikipedia.org/wiki/List_of_human_disease_case_fatality_rates.
[89] World Health Organization, "Global Health Observatory (GHO) Data," 2019, https://www.who.int/gho/mortality_burden_disease/en/.
[90] https://www.thelancet.com/gbd.
[91] "Major Infectious Diseases," 3rd ed., chapter 1, edited by K. K. Holmes, S. Bertozzi and B. R. Bloom (Washington, DC: International Bank for Reconstruction and Development and the World Bank, 2017), https://www.ncbi.nlm.nih.gov/books/NBK525197/.
[92] See, for example, L. Shaw-Taylor, "An Introduction to the History of Infectious Diseases, Epidemics and the Early Phases of the Long-Run Decline in Mortality," *Economic History Review* 73, no. 3 (August 2020), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7404362/, or J. Piret and G. Boivin, "Pandemics throughout History," *Frontiers in Microbiology*, January 2021, Frontiers | Pandemics Throughout History (frontiersin.org)

and antibiotics had further reduced the toll of infectious diseases in these countries. In the second half of the 20th century, large-scale efforts began to better control infectious diseases in low- and middle-income countries. These included a global commitment to immunize the world's children against the major infections for which vaccines were available, global campaigns to control malaria and diarrheal disease, and an accord among 196 countries (the World Health Assembly 2005) to implement metrics and measures to detect and control outbreaks of infectious diseases and to prevent pandemics.[93]

Spectacular progress has been made in reducing mortality from most infectious diseases. Specific achievement in the fight against infectious diseases, as noted by Holmes et al., includes that "global under-five mortality fell by almost two-thirds (from 14% to 5%) between 1970 and 2010.[94] In 1980 smallpox, responsible for 300–500 million deaths in the 20th century,[95] was declared the first disease to be eradicated from the planet following a global immunization campaign. Wild poliovirus has been eliminated from all but three countries and is the focus of a major eradication program. However, cases of polio in youths have surfaced in developed countries where parents may have been opposed to or lax with regard to immunizations. The number of deaths before age 70 from HIV/AIDS, tuberculosis and malaria in low-income countries fell by 46%, 35% and 36%, respectively, from 2000 to 2010.

At the same time, emerging pandemic viral infections remain a constant threat. Many zoonotic diseases enter the human population from contact with animals, including the 2002-2004 SARS-CoV-1 (Severe Acute Respiratory Syndrome), MERS (Middle East Respiratory Syndrome), Ebola and Zika viruses,[96] as well as, perennially, influenza and chikungunya infections. If the death rates of 2010 remain static, about 5.1 million people will still die in 2030 from these conditions and other communicable diseases, many of whom reside in low- and low-middle income countries, and mortality in high-income countries from these conditions will be relatively small. SARS-CoV-2 emerged in 2020, which, for more than two years (up to March 2022),[97] has infected over 500 million people, caused over six million deaths and continues today.

The risk from infectious diseases continues to harass humanity; efforts and studies continue to search for ways to eradicate and control these diseases. In a recent study Penn reports an analysis of disease outbreaks over the past 400 years that covered specific pathogens including plague, smallpox, cholera, typhus and influenza.[98] Despite a considerable variability in the rate of the occurrence of pandemics, the study estimates that a pandemic with an impact similar to COVID-19 has a probability of about 2% per year, and the annual occurrence probability of a pandemic of magnitude equal to the Spanish Influenza pandemic of 1918–1920 is 0.3–1.9%: "The data shows the risk of intense outbreaks is growing rapidly. Based on the increasing rate at which novel pathogens such as SARS-CoV-2 have broken loose in human populations in the past 50 years, the study estimates that the probability of novel disease outbreaks will likely grow three-fold in the next few decades."

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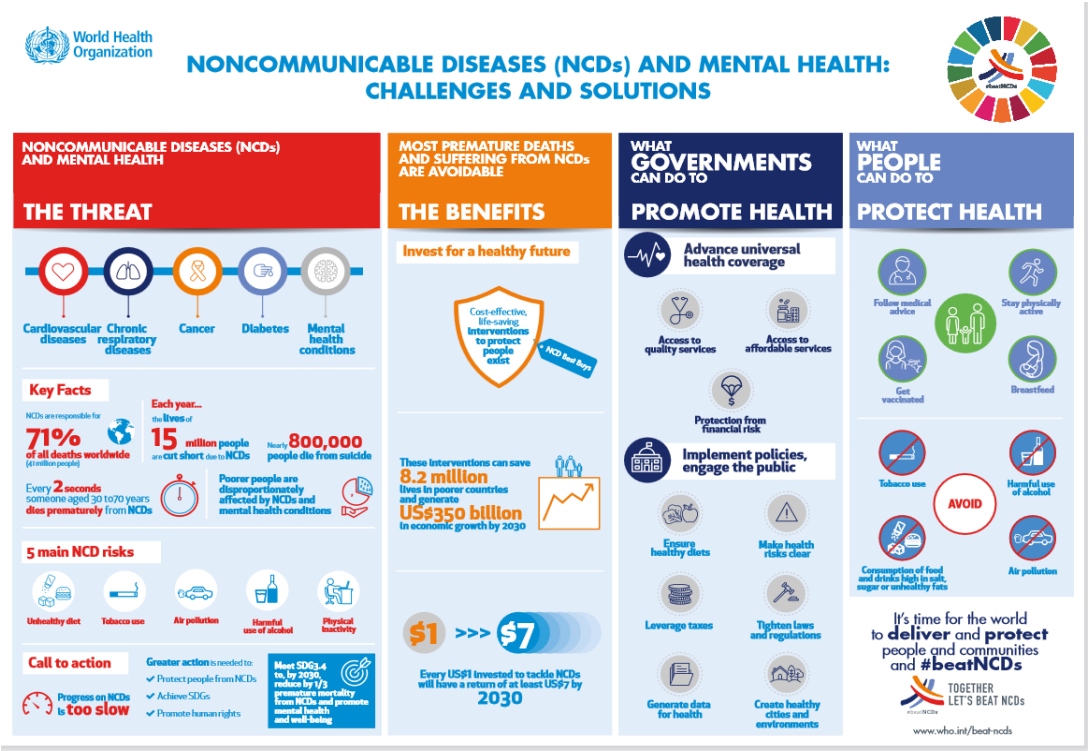
[93] World Health Assembly, *International Health Regulations* (Geneva: World Health Organization, 2005).
[94] O. Norheim, P. Jha, K. Admasu et al., "R" *The Lancet* 385, no. 9964 (2015): 39–52.
[95] Life and death of smallpox. National Library of Medicine, Pub Med, Presse Med. 2022 Sep; 51(3): 104117. doi: 10.1016/j.lpm.2022.104117. Epub 2022 Feb 7. https://pubmed.ncbi.nlm.nih.gov/35143880/
[96] N. Madhav, B. Oppenheim, M. Galivan et al., "Pandemics: Risks, Impacts, and Mitigation," in *Disease Control Priorities, Disease Control Priorities: Improving Health and Reducing Poverty*, 3rd ed., vol. 9, ed. D. T. Jamison, R. Nugent, H. Gelband et al. (Washington, DC: World Bank, 2018).
[97] "Coronavirus Disease Statistics and Deaths," updated April 1, 2022, *Our World in Data*, https://ourworldindata.org/covid-deaths
[98] M. Penn, "Statistics Say Large Pandemics Are More Likely than We Thought," Duke Global Health Institute, August 2021, https://globalhealth.duke.edu/news/statistics-say-large-pandemics-are-more-likely-we-thought.

5.2 CHRONIC NONCOMMUNICABLE DISEASES

According to the National Council of Aging, "age, family, and gender make it nearly impossible for older adults to avoid becoming chronic disease statistics."[99] Eighty percent of older adults have at least one chronic disease, and 68% have at least two. In 2021, 58% of 65+ Medicare patients were treated for hypertension, 47% for high cholesterol and about 30% for arthritis and heart diseases. In the U.K.[100] arthritis is the most common medical condition among older people.

According to the WHO,[101] 41 million people die annually of noncommunicable diseases (NCDs), of which 15 million are "premature" deaths of 30–69 years old, mostly among individuals in low- and middle-income countries. "Four groups of diseases account for over 80% of all premature NCD deaths: Cardiovascular diseases account for most NCD deaths, 17.9 million people annually, followed by cancers (9.3 million), respiratory diseases (4.1 million) and diabetes (1.5 million). Tobacco use, physical inactivity, harmful use of alcohol and unhealthy diets all increase the risk of dying from an NCD." Figure 5.2 presents the WHO's perspective on NCDs.

Figure 5.2
CHRONIC NONCOMMUNICABLE DISEASES GLOBALLY



Source: WHO, 2014, https://www.who.int/docs/default-source/infographics-pdf/ncds/ncds-and-mental-health-sdg-in-action.pdf?sfvrsn=e1633a93_

[99] Healthy Aging Team, "The Top 10 Most Common Chronic Diseases for Older Adults," National Council of Aging, April 2021, https://www.ncoa.org/article/the-top-10-most-common-chronic-conditions-in-older-adults.
[100] "20 Most Common Medical Conditions Affecting Older People," *Lifeline* 24 (January 2022), https://www.lifeline24.co.uk/medical-conditions/.
[101] World Health Organization, "Noncommunicable Diseases," 2021, https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases.

As Perlman summarizes in the introduction to "Man-made diseases,"[102] we live in a man-made environment that is materially different from the one of our ancestors, an environment that is culturally diverse, with genetically unrelated individuals, where people eat different foods and are exposed to different pathogens and toxins, and have different patterns of physical activity. These man-made changes have also led to the epidemiological transition, where death from famine and infectious diseases decreased, life expectancy increased, and there is a shift to noncommunicable chronic diseases such as heart diseases, diet-related diseases like obesity, diabetes, and hypertension and stroke, as people now live longer.

5.3 MENTAL ILLNESSES

People who are mentally healthy tend to cope well—in how they think, feel and act—with life, its subsequent stressors allowing them to relate to others and make choices. At the same time, many people, particularly older adults and especially those with illnesses or physical problems, are at risk for mental health problems, though this does not mean that mental health problems are a normal part of aging.

As the NIH notes, mental disorders do not just cause mental suffering but also make it harder to manage other health problems, particularly chronic conditions.[103] The NIH lists some of the warning signs of mental disorders (prevalent in older adults, but also viewed other age levels):

- Changes in mood or energy level;
- Changes in eating or sleeping habits;
- Withdrawing from the people and activities that one enjoys;
- Feeling unusually confused, forgetful, angry, upset, worried or scared;
- Feeling numb or like nothing matters;
- Having unexplained aches and pains;
- Feeling sadness or hopelessness;
- Smoking, drinking or using drugs more than usual;
- Anger, irritability or aggressiveness;
- Having thoughts and memories that one can't get out of their head;
- Hearing voices or believing things that are not true;
- Thinking of harming oneself or others.

Keyes and Simoes investigated whether well-being and positive mental health predicts all-cause mortality.[104] Their study population included about 3,000 midlife U.S. adults that measured as having positive mental health in 1995, and the study followed them for 10 years. They found that "the absence of positive mental health increased the probability of all-cause mortality for men and women at all ages, after adjustment for known causes of death."

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[102] R. L. Perlman, "Man-Made Diseases," Oxford Scholarship Online, 2022, https://doi.org/10.1093/acprof:oso/9780199661718.003.0011
[103] MedlinePlus, "Older Adults Mental Health," National Library of Health, National Institute of Health, 2021, https://medlineplus.gov/olderadultmentalhealth.html.
[104] C. L. M. Keyes and E. J. Simoes, "To Flourish or Not: Positive Mental Health and All-Cause Mortality," *American Journal of Public Health* 102, no. 11 (November 2012), https://ajph.aphapublications.org/doi/pdf/10.2105/AJPH.2012.300918?download=true.

5.4 NEW AND UNKNOWN DISEASES

Our world is in the middle of an exponential population explosion, from 1.6 billion in 1900 to 7.7 billion around 2020, and estimated to be 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion by 2100.[105] Population projections naturally presume that the world will continue to remain relatively stable. As actuaries, to whom predictions of the future are a necessary tool of trade, we start with the assumption that "l'histoire se repète" (history repeats itself), and thus past trends (and particularly in mortality and its drivers) are an acceptable basis for future projections. But we must also consider other plausible scenarios about currently known, as well as unknown, drivers of mortality, morbidity and other factors so as to present a more complete set of scenarios to the public and to decision makers. Moreover, not only must we make assumptions regarding individual issues and mortality drivers, a difficult task in itself, we must also quantify the combined impact of unknown combinations of many of the various advances, risks and drivers of future mortality. Is the total impact that of the largest one, overriding the impact of the others? Or is it additive, multiplicative or something else?

What future scenario (possibly including some we did not even imagine today) will unfold is not known, its timing and development are unknown, and its outcome and impacts are also not yet known. Thus, assumptions and projections may seem dubious when considering some of the issues and risks, including "shock" events that can have either a positive or negative impact, resulting in a disruptive change to the assumptions and levels of mortality and morbidity. Some events, such as past wars and pandemics, have had a temporary negative impact, whereas developments in the provision of health care, such as the development of penicillin, have had a longer positive impact. The other consideration here is not only the level of impact but also the length of the impact. Although with constant mutations of all organisms, it is difficult to predict future outcomes.

So the future is unknown, and accordingly one should be ready to act against new diseases, new variants of diseases and many other surprises to control and minimize their impact on populations. The Spanish flu of 1918–1920 and the COVID-19 of 2020–2022 are examples of such unpredicted situations. As discussed by Penn, "the risk of intense outbreaks is growing rapidly … (and) the study estimates that the probability of novel disease outbreaks will likely grow three-fold in the next few decades."[106]

[105] "Projections of Population Growth," Wikipedia. https://en.wikipedia.org/wiki/Projections_of_population_growth
[106] M. Penn, "Statistics Say Large Pandemics Are More Likely than We Thought," Duke Global Health Institute, August 2021, https://globalhealth.duke.edu/news/statistics-say-large-pandemics-are-more-likely-we-thought.

SUMMARY TABLE for FUTURE MORTALITY - CHAPTER 5 - DISEASES			
Sub-Driver	**Near-Term (1-5 years) Impact**	**Longer-Term Future Impact**	**Comments**
Overall			Improved medical technology, sanitation and living environment, and health care access reduce mortality. Aging popultion increases impact of chronic and mental diseases and dementia, while inceases in population density may lead to more zoonotic diseases and pandemics.
Infectious			Reduced mortality with improved medical technology, sanitation and living environment, and health care access
Vector-borne			Reduced mortality with improved medical technology, sanitation and living environment, and health care access
Chronic			Increase in longevity will lead to increased occurrence of chronic long-term diseases
Hereditary			Medical advances enable better identification and treatment, but this is offset by cost and availability, so they remain stable
Mental Health			Stress and aging population increase occurrence of mental diseases
Dementia and Alzheimer			The aging population increases occurrence of dementia and Alzheimer's disease
Pandemics			Unpredictable, but may have major or minor mortality impact
Medical Treatment			Medical treatment typically advances in major "jumps" (e.g., antibiotics), and then the technology improves at a slower, steady pace (e.g., robotic surgeries)
Public Infrastructure (water, sanitation, etc.)			Public infrastructure had a major impact in mortality reduction in developed countries, and is expeceted to do so in less developed countries
Note: The evaluations reflect the authors' opinion, rather than a scientifically measurable comparison.			
Mortality Legend:	**Increasing: high**  **low** **;**	**Decreasing: high**  **low** **;**	**or**

6. Health Care

A health, or health care, system[107] consists of all organizations, people, actions and resources whose primary intent is to promote, manage, deliver, maintain, restore or improve health of a target population, individuals or communities, including efforts to influence determinants of health. This includes, for example, caring for a sick child at home, hospitals and family physicians, well-being programs, prevention and control of communicable disease, health workforce planning, health insurance, rehabilitation, occupational health and safety legislation, and improving the living conditions of people.

A health care system's goals are to be responsive to population expectations, while carrying out the provision of health care services, resources management and financing. Health care systems are responsible for the stewardship of these activities to ensure that all people obtain the health services they need, while not imposing an excessive financial burden on individuals, families or communities. Many health care systems target "equality" to all members of the population served as a goal, even though experience proves that some people have more comprehensive coverage than others. Health care systems are often evaluated (by the users, regulatory bodies, and other entities) on access, quality, efficiency, acceptability,[108] dignity and equity.

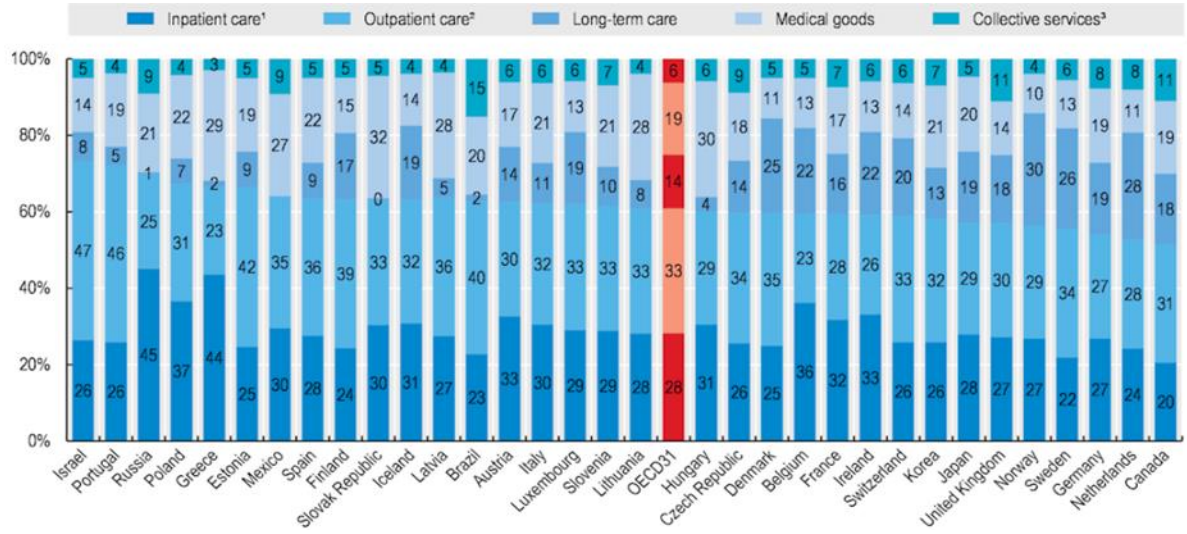
Countries design and develop health care systems in accordance with the nation's needs, priorities and resources, resulting in many organizational structures, allocation of resources to various services and financing schemes. This variety is evident in Figure 6.1, which shows different allocations of certain health expenditures in 2021 by OECD countries. To illustrate: Although most of the noted countries spend about 30% of their health expenditure on inpatient care, several countries (e.g., Russia, Estonia, Poland and Belgium) spend more than 35% on that category of service. Similarly, although 14% is the OECD average long-term-care (LTC) expenditure, some countries spend a relatively small amount (less than 5% of their health care budgets) on LTC services (e.g., Slovak Republic, Russia, Greece, Brazil and Hungary).

[107] This definition is based on the World Health Organization definitions, as given in "Healthcare Systems," Physiopedia, 2021, https://www.physio-pedia.com/Health_Care_Systems, and in "Health Systems," WHO Europe, 2022, https://www.euro.who.int/en/health-topics/Health-systems/pages/health-systems.

[108] As defined in M. Sekhon, M. Cartwright and J. J. Francis, "Acceptability of Healthcare Interventions: An Overview of Reviews and Development of a Theoretical Framework," BMC Health Services Research, 2017, https://bmchealthservres.biomedcentral.com/track/pdf/10.1186/s12913-017-2031-8.pdf, "Acceptability is a multi-faceted construct that reflects the extent to which people delivering or receiving a healthcare intervention consider it to be appropriate, based on anticipated or experienced cognitive and emotional responses to the intervention."

Figure 6.1

OECD HEALTH EXPENDITURE BY TYPE OF SERVICE, 2019 OR NEAREST YEAR



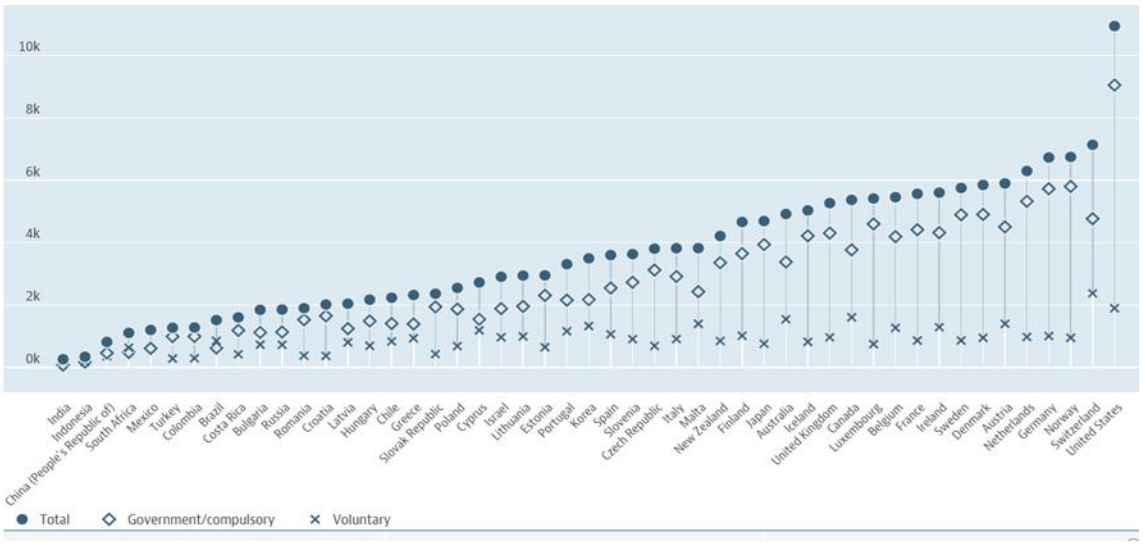
Source: OECD Health Statistics 2021, Health Expenditure by Type of Service, https://stat.link/9a68jn.

Health care systems generally impose a heavy financial and resources burden on governments and populations alike, and consequently, the financing of such systems becomes a major focus globally. Some of the resources used include public budgets (e.g., taxes), national health tax or insurance, private health insurance (e.g., corporate, individual), out-of-pocket payments, donations and limiting obligations (e.g., a ceiling on overall coverage). Various payment models for the activities of health care systems have been developed, such as fee-for-service, capitation, salaries to physicians and health practitioners, and value-based care. Figure 6.2 presents the variability in the levels of health spending per capita in various nations in 2020, as well as the spending source (voluntary versus government or compulsory).

Figure 6.2 shows that the U.S. spends much more per capita relative to all other listed countries, and most of this expense is governmental or compulsory. At the same time, although Switzerland spends overall per capita considerably less than the U.S., its voluntary per capita expense is the highest.

Figure 6.2

HEALTH SPENDING PER CAPITA, U.S.$, TOTAL, GOVERNMENT OR COMPULSORY AND VOLUNTARY, 2020 OR LATEST AVAILABLE



Source: OECD Health Spending 2021, Health Expenditure and Financing, Health Expenditure Indicators, https://data.oecd.org/healthres/health-spending.htm.

6.1 MODELS OF HEALTH CARE SYSTEMS

Health care systems are usually classified into four main types:[109]

- The *Beveridge Model*, or universal government-funded national health services, as in the National Health Service (NHS) in the U.K. The Beveridge model is a national, single-payer system, where health is a human right, available through government-funded health care to all citizens regardless of their income or employment status. Some countries may provide health care to noncitizen residents, whereas others may require them to buy private insurance. Most hospitals and physicians work for the government, although private providers do exist. All health care is paid through the government via taxes. The government as a single payer has considerable market power and controls the level of services and what pharmaceutical companies and providers can charge, thus saving money and achieving a low cost per capita. At the same time, as a single payer, the government can make patients wait for service and can ration access to services, thus creating potential for long waiting lists and service delays.
- *The Bismarck Model,* or universal public-private insurance-based social security health care system (SSH), as in Germany. This also is a national, single-payer system, where health care is provided to all citizens through private insurance companies, where premiums are paid by employer and employee payroll deductions. In some countries (such as the Netherlands and Switzerland), coverage for low-income citizens is subsidized by the government. In contrast to the NHS with its universal coverage, only people who are ineligible for private insurance are covered by the state, as everyone must be covered. It is a mixed model of public and private providers, wherein

[109] All the information related to the four types of health care is essentially taken verbatim from the article by Kate Harveston, "4 Types of Healthcare Systems," May 2018, https://ivn.us/2018/05/21/types-of-healthcare-systems. The lists of countries in each health care system type is taken from "Health care Systems by Country," https://en.wikipedia.org/wiki/Health_care_systems_by_country.

hospitals and physicians may not operate for profit, and thus the cost is comparably more affordable than in other markets where this is not the case. The SSH tends to be consumer-oriented with high accessibility, lower waiting times and often higher quality, due to the competition between the health care providers.

- *National Health Insurance Model,* or universal public insurance system, as in Japan. This also is a national, single-payer health care system, which combines aspects of the Beveridge and Bismarck models. Workers have social insurance, and patients are free to choose any doctor or hospital or other private sector providers. Usually the government withholds as premium part of the worker's wage, which is divided between employee and employer. People who do not have a legal contract of employment and/or cannot register as unemployed may be ineligible for free health care. The system is paid by higher taxation, but because it has no profit incentive and does not deny claims, it minimizes marketing costs. As a single-payer system, it enables the government to negotiate lower costs. Thus, its costs and prices are generally low.
- *The Private Nonuniversal Insurance System,* as in the U.S.: In this system, health care coverage is not provided to citizens as a right, individuals are either covered by their employers, covered by private policies they purchase themselves, or they go without coverage at all (in 2020, 28 million Americans had no health insurance coverage).[110] The state does not provide a national health care system to all its citizens (though it may provide that to certain groups, such as the aged or veterans) so as to minimize disparities in health care due to socioeconomic status, ethnicity or some other classification. Those with money (or some other "right") get access to health care, whereas others have minimal—or no—health care access. Osborn et al.[111] report that "an 11-country survey finds that adults in the U.S. are far more likely than those in other countries to go without needed care because of costs and struggle to afford basic necessities. One-third of U.S. adults went without recommended care, did not see a doctor, or failed to fill a prescription".

The cost, performance, outcomes and satisfaction of different health care systems vary significantly. Many comparisons and rankings can be found of health care systems and their outcomes, of which we present just one study with emphasis on mortality. Zee and Kroneman[112] compared the performance of the Bismarck (SSH) and Beveridge (NHS) health care systems in Europe. In Figure 6.3 the blue curves are for SSH countries, and the red curves represent the NHS countries. Some observations, based on the figure, can be made:

- Significant improvements have been seen in all the studied countries since 1970.
- Generally, the SSH countries have lower standardized death rates and infant mortality.
- Neither the SSH nor the NHS model is superior with regard to life expectancy at birth.
- SSH countries tend to spend more on health care per capita, with mixed results for expenditure as percentages of GDP, even though the extreme percentages of the SSH countries are more pronounced.
- Generally, the populations of SSH countries are more satisfied with their health care systems.

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[110] K. Keisler and L. N. Bunch, "Health Insurance Coverage in the United States: 2020," United States Census, September 2021, https://www.census.gov/library/publications/2021/demo/p60-274.html.

[111] R. Osborn, D. Squires, M.M. Doty, et al "In New Survey of 11 Countries, U.S. Adults Still Struggle with Access to and Affordability of Health Care" *Health Affairs*, published online Nov. 16, 2016. https://doi.org/10.26099/g7s0-3h12.

[112] Jouke van der Zee and Madelon W. Kroneman, "Bismarck or Beveridge: A Beauty Contest between Dinosaurs," 7 (June 2007): 94, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1934356/.

The authors cautiously concluded: “we think that our study can form a base for a policy debate on the pros and cons of the existing healthcare systems in Europe as far as health outcomes, healthcare expenditures and patient satisfaction are concerned.”

Figure 6.3

COMPARISON OF COUNTRIES WITH BISMARCK AND BEVERIDGE HEALTH CARE SYSTEMS

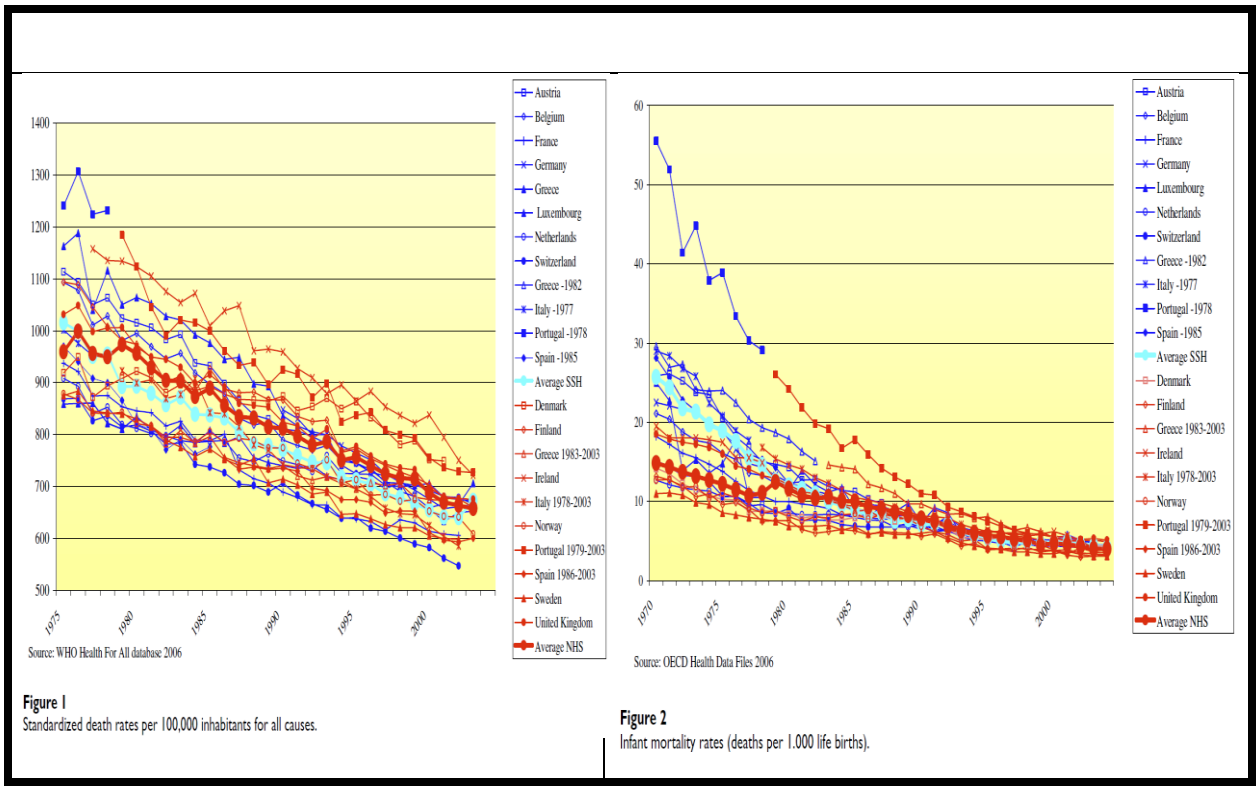
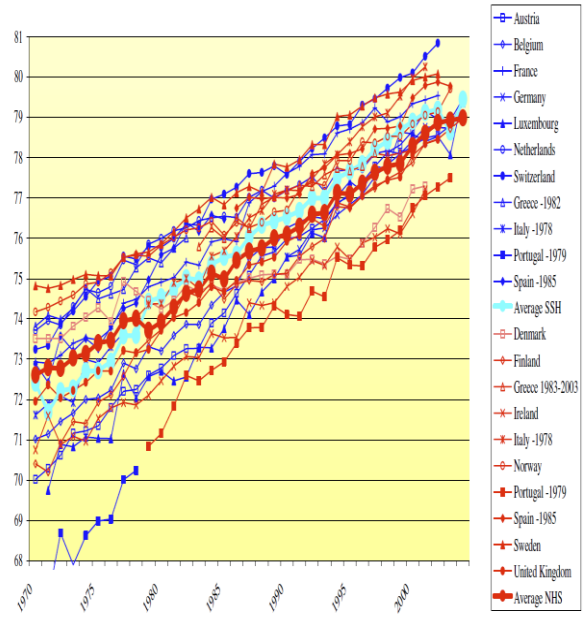


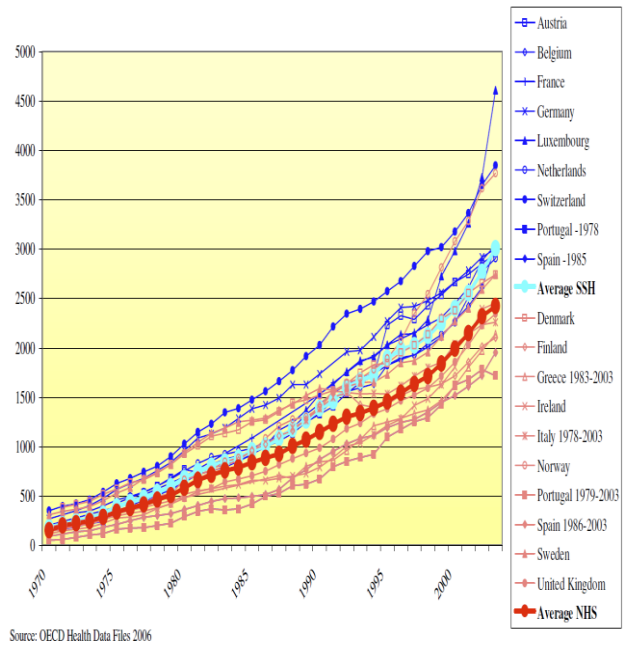
Figure 1
Standardized death rates per 100,000 inhabitants for all causes.

Figure 2
Infant mortality rates (deaths per 1.000 life births).



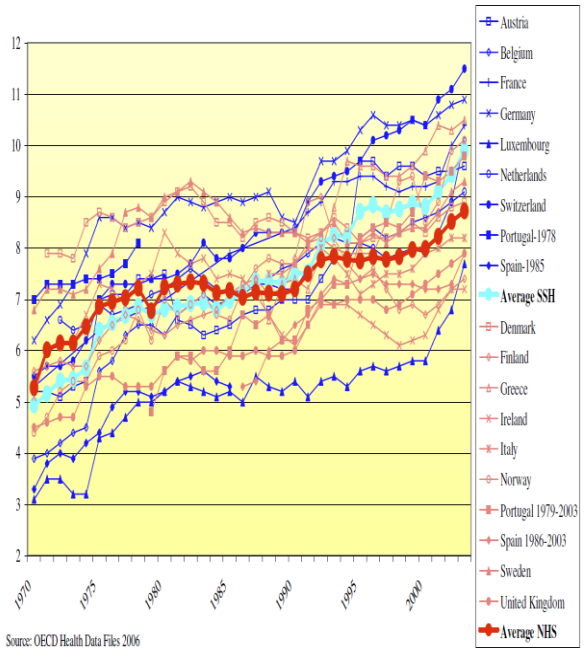
Source: WHO Health For All database 2006

Figure 3
Life expectancy at birth.



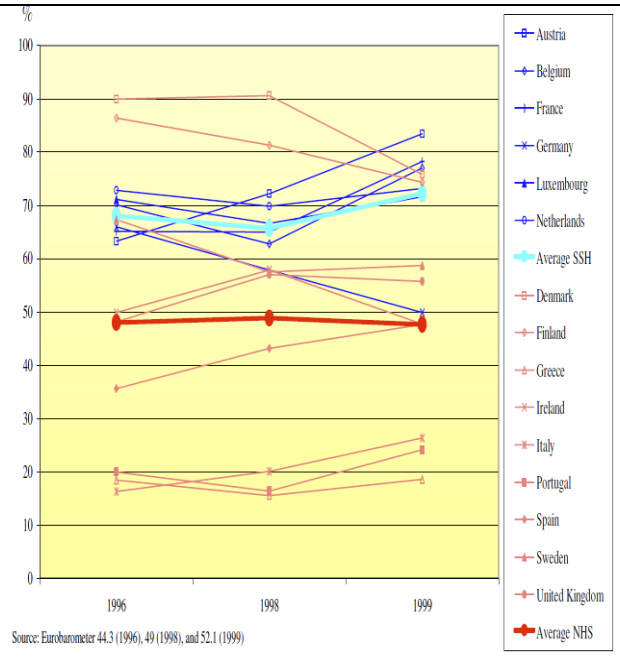
Source: OECD Health Data Files 2006

Figure 4
Total health care expenditure per capita (PPP-US$).



Source: OECD Health Data Files 2006

Figure 5
Total health care expenditure as percentage of GDP.



Source: Eurobarometer 44.3 (1996), 49 (1998), and 52.1 (1999)

Figure 6
Satisfaction with health care system (% of population very or fairly satisfied).

So how does the U.S., with the highest health care spending in the world—16.8% of GDP and $9,536 per capita in 2015—perform? A 2018 comparison of efficient health care systems found the U.S. near the bottom—55th out of 56 economies.[113] In the WHO's 2019 ranking of 190 of the world's health care systems,[114] the U.S. is ranked 37; the top five ranked were France, Italy, San Marino, Andorra and Malta, with the two most efficient in the 2018 comparison still faring quite well: Singapore ranked sixth, and Spain ranked seventh. The key to the poor ranking of the U.S. can be found in the "Health Insurance Coverage in the United States: 2017" report,[115] which presents (disappointing) statistics on health insurance coverage in the U.S. as based on several major surveys.

6.2 TREATMENTS, CURES AND PREVENTION

Humans are subject to individual injuries and diseases, as well as to group epidemics and pandemics. These disrupt normal lifestyles and often lead to long periods of limited ability, chronic diseases, reduced quality of life or even death. Screening, early detection and early treatment are a major source of potential prevention and reduction in morbidity and mortality for many of the leading causes of death. For example, hypertension treatment can greatly reduce stroke and ischemic heart disease. Lung cancer screening can greatly reduce that major cause of mortality.

When people get sick or injured, ideally they are treated and hopefully cured. Treatment may bring their body back into balance (as in Chinese medicine) and thus cure them of their problems. A (western) medical treatment may sometimes provide a "cure." Similarly, in all medical approaches, change of lifestyle may also sometimes provide a "cure." Alternatively, any of these treatments may just help with the symptoms, meaning that the afflicted may need to live with a chronic illness.

Many societal efforts—among the main responsibilities of governments—have and are devoted to fighting chronic conditions, utilizing health care systems, and including handicap and work-injuries support, as well as the establishment of many support professions and industries.

Some adverse health conditions can be cured, so that after receiving medical treatment, the patient no longer has adverse conditions. Sometimes medical and rehabilitation treatments help to lessen the symptoms and effects of a malady but cannot cure it; treatments are then used to control and manage the sickness. Often the medical treatments can extend, even for many years, the life of the patient, and even assure them of some quality of life despite their sickness. Such instances often involve chronic diseases.

Medical advances over the last century have significantly extended the longevity and quality of life. But with this great achievement have come two undesired side effects. First, the prevalence of many diseases with a long incubation period, such as cancer and cardiovascular diseases, increased significantly, and particularly among the aged. Second, the longevity and extended life of many people who would have died in the past from various causes are marked by poor quality of life due to incurable chronic diseases, discomfort and even pain. To emphasize the quality versus quantity of years lived, indicators such as Health Adjusted (or disability-free) Life Expectancy (HALE) have been developed. HALE measures are an important indicator of the relative health of a given population. The differences between the two indicators can be

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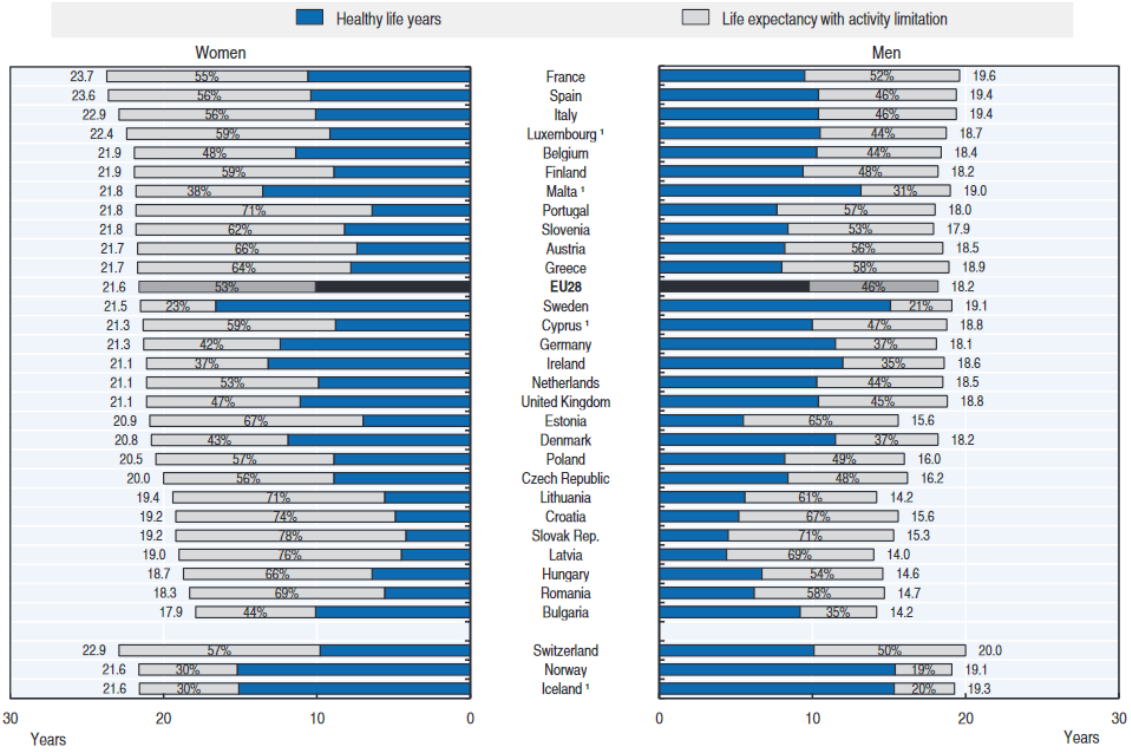
[113] "The Countries with the Most and Least Efficient Healthcare, Ranked," http://digg.com/2018/world-healthcare-system-ranking-data-viz.
[114] The World Health Organization's ranking of the world's health systems, by Rank. WHO World Health Report, 5/2019, https://photius.com/rankings/healthranks_alpha.html
[115] E. R. Berchick, E. Hood and J. C. Barnett, "Health Insurance Coverage in the United States: 2017" September 2018, Report P60–264, https://www.census.gov/library/publications/2018/demo/p60-264.html.

significant, as is evident from Figure 6.4, which compares life expectancy and healthy life expectancy at age 65 in 2016 for OECD nations, by gender.

Traditionally, western medicine concentrated its efforts on the treatment and cure of diseases, injuries and maladies rather than keeping them from happening. In contrast: "ancient Chinese doctors were paid a retainer to keep their patients healthy, and if a patient did get sick, the doctor would not be paid for this person until he or she regained their health."[116] Over the last several decades, a new medical branch has gained attention, preventive medicine, whose goal is to stop sickness before it starts, one person at a time.[117] The approach is holistic, focusing on the whole patient and the many factors affecting the patient's health and well-being, including maintaining a healthy lifestyle, the role of family and community, early detection, and more. A related health care delivery development is the move from a fee-for-service approach to a "value-based reimbursement model,[118] wherein providers are paid in an evidence-based way based on patient improved health, reduced effects and incidences of chronic diseases, and health outcomes.

Figure 6.4

LIFE EXPECTANCY AND HEALTHY LIFE YEARS AT 65, BY GENDER, 2016 OR NEAREST YEAR



Source: OECD, "Health at a Glance: Europe 2018," https://doi.org/10.1787/health_glance_eur-2018-en.

[116] M. McGowan, "What if Doctors Were Paid to Keep People Well?" T. Colin Campbell Center for Nutrition Studies, March 2021, https://nutritionstudies.org/what-if-doctors-were-paid-to-keep-people-well/.
[117] "Preventive Medicine: Prevention vs. Treatment," University of Tennessee Medical Center, 2018, https://www.utmedicalcenter.org/blog-post/preventive-medicine-prevention-vs-treatment.
[118] "What Is Value-Based Healthcare?" *NEJM Catalyst*, January 2017, https://catalyst.nejm.org/doi/full/10.1056/CAT.17.0558.

Health care and the medical profession have advanced in giant steps in the last century, and the resulting improved health and declining mortality are evident. Further advances in both can be expected, and particularly in developed countries, as the medical profession, the pharmaceutical industry and the medical research world are continually offering new treatments and cures to many diseases that in the past were considered uncurable. To name just a few examples: stem-cell medicine, nanomedicine, digitized and robotic medicine, genomic profiling and genetic medicine, personal medicine, wearable health monitors, telemedicine, and health analytics and artificial intelligence tools are now in use. These are discussed in chapters 7 and 8, which discuss medical and technological advances.

6.3 QUALITY AND ACCESS TO CARE

As a RAND study noted, "the U.S. spends on healthcare, in terms of share of the economy, about double what other OECD countries spend, but widespread variation in the quality of care heightens concerns about the value of care that patients are receiving,"[119] and this affects their morbidity and mortality outcomes. Ensuring and improving quality of care is an ongoing challenge that requires development and use of measures to determine health status and assess the quality, appropriateness and efficiency of the type of care, as well as the overall value of care. In particular, it is important to address the patient experience and ensure responsiveness to patient preferences.

According to the RAND report, "a substantial part (perhaps one-third) of care given to populations around the world is equivocal or inappropriate … U.S. adults receive recommended care about half the time. The risk of receiving poor-quality health care does not vary significantly by location, provider, race, gender or financial status."

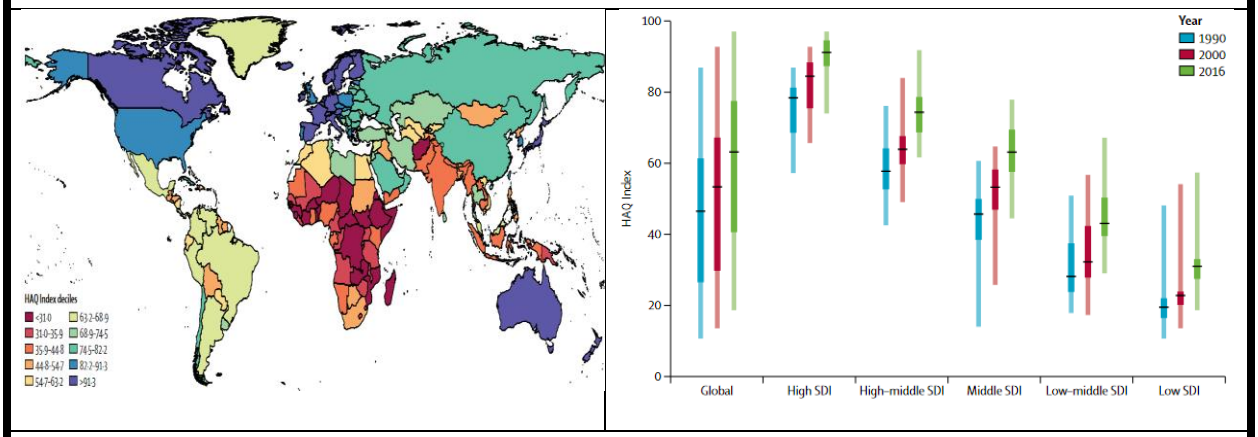
A *Lancet* study highlights the access and quality differences in 2016 among 195 countries.[120] The study used the Global Burden of Diseases (GBD), Injuries, and Risk Factors Study 2015 mortality framework—deaths from causes that should not occur in the presence of effective medical care—to approximate national levels of personal health care access and quality and develop a Healthcare Access and Quality (HAQ) Index on a 0–100 scale. Thirty-two disease causes from a range of health service areas and amenable to health care make up the HAQ Index: vaccine-preventable diseases; infectious diseases and maternal and child health; noncommunicable diseases, including cancers, cardiovascular diseases and diabetes; and gastrointestinal conditions where surgery can easily avert death. Being based on the GBD, the HAQ index also accounts for local variations in risk exposure and better isolates differences.

The global view of the HAQ is presented in Figure 6.5, providing a map of the HAQ levels in particular countries, and the global advances since 1990. It should be noted that a graph of the 2016 HAQ index values versus the logarithm of cumulative total 2010–2015 health spending in purchasing power per capita, presents almost linearly increasing HAQ values with the increases in health spending by country.

[119] RAND, "Quality of Care: In Depth," 2022, https://www.rand.org/health-care/key-topics/quality-of-care/in-depth.html.
[120] "Measuring Performance on the Healthcare Access and Quality Index for 95 Countries and Territories and Selected Subnational Locations: A Systematic Analysis from the Global Burden of Disease Study 2016," *The Lancet*, May 2018, https://www.thelancet.com/action/showPdf?pii=S0140-6736%2818%2930994-2.

Figure 6.5

MAP OF 2016 HEALTH CARE ACCESS AND QUALITY INDEX (HAQ) COUNTRY VALUES, BY DECILE, AND GLOBAL MEDIANS, INTERQUARTILE RANGES (IQR) AND RANGES OF HAQ IN 1990, 2000 AND 2016 BY SOCIODEMOGRAPHIC INDEX (SDI) QUINTILE



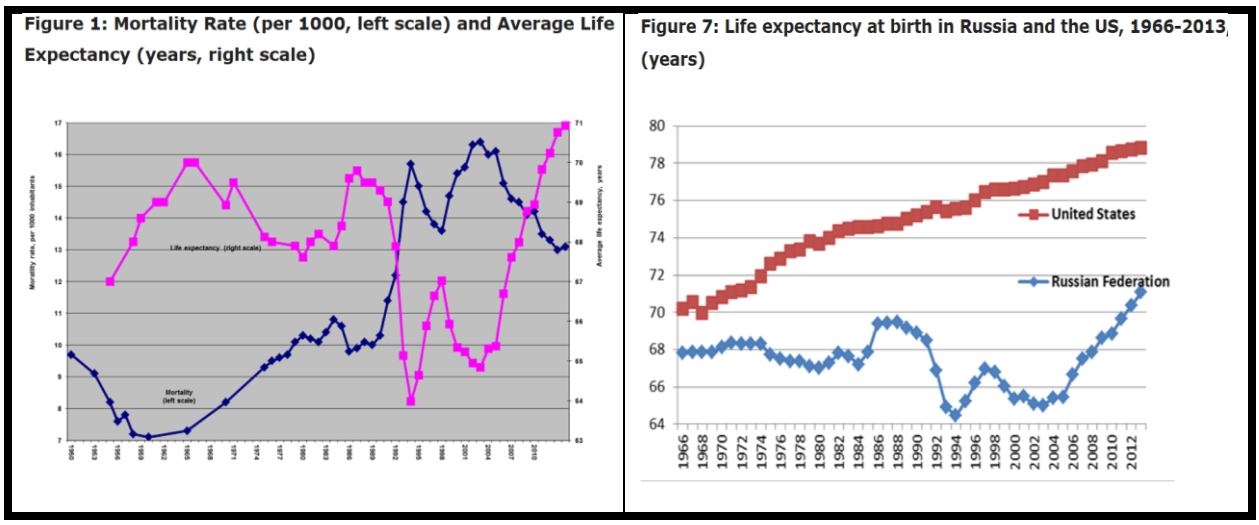
Black lines represent the median, dark-colored boxes represent the Interquartile Range (IQR) and the light-colored boxes represent the full range of values within a given group.

Source: *The Lancet,* Measuring Performance on the Healthcare Access and Quality Index for 195 Countries and Territories and Selected Subnational Locations: A Systematic Analysis from the Global Burden of Disease Study 2016, May 23, 2018, https://www.thelancet.com/action/showPdf?pii=S0140-6736%2818%2930994-2.

Despite the encouraging HAQ advances since 1990, we note that since health care systems generally reflect the strength and stability of the countries they serve, once a nation faces hard times, and particularly at times of transition, its health care system may also falter, with a resulting decline in the population health, increase in mortality and reduction in life expectancy. This was the case with the collapse of the Soviet Union in the early 1990s, which resulted in a drop of life expectancy from 70 in 1987 to 64 in 1994, as shown in Figure 6.6.

Figure 6.6

MORTALITY AND LIFE EXPECTANCY IN FORMER COMMUNIST COUNTRIES (FIGURE 1) AND LIFE EXPECTANCY OF RUSSIA AND US (FIGURE 70)



Source: V. Popov, "Mortality and Life Expectancy in Post-Communist Countries," DOC Research Institute, June 2018, https://pages.nes.ru/vpopov/documents/Mortality%20and%20life%20expectancy%20in%20post.pdf

SUMMARY TABLE for FUTURE MORTALITY - CHAPTER 6 - HEALTH CARE			
Sub-Driver	**Near-Term (1-5 years) Impact**	**Longer-Term Future Impact**	**Comments**
Overall			Health care (HC) systems are a major responsibility of governments for improving health and reducing mortality. Their current type and level of establishment imply slower future mortality improvement rate
Treatment and Cure			The maturity of current HC and advances in medical technology imply continued but slower health improvement
Prevention			Gaining traction and increased understanding due to its importance, but public acceptance can slow or impede its advance
HC Access and Quality			Access, affordability and advances in HC quality require major resources, especially in non-metropolitan areas
Note: The evaluations reflect the authors' opinion, rather than a scientifically measurable comparison.			
Mortality Legend:	**Increasing: high**	**low** ;	**Decreasing: high** **low** ; **or** ⟺

7. Medical Advances

Many amazing medical and technological advances occurred over the last century, as results of new scientific and technological innovations.[121] Many of the advances have contributed to increased longevity, improved quality of life for the aged and chronically ill, and a reduction in the burden from many diseases. At the same time, like any new technology, some advances have had undesired consequences that may take time to overcome, such as the development of drugs-resistant microbes and exposure to illnesses with a long incubation period (which has become more prevalent as longevity has increased).

Both medical (discussed in this chapter) and technological (discussed in the next chapter) advances are subject to many other considerations, such as public expectations, fear of privacy violations, quality of life issues, cost considerations, ethical concerns and societal impacts. Our discussion, though, is centered on the advances' effects as drivers of future mortality.

Despite these advances, as noted by the OECD, "U.S. improvements in life expectancy since 2011 have been slowed down and life expectancy has fallen in recent years … mortality improvements have slowed in several EU countries, Australia and Canada ... some risk factors, such as smoking, excessive alcohol consumption, drug overdose and high blood pressure continue to decline in most EU countries, while the prevalence of obesity and diabetes continues to rise … looking ahead, it is unclear whether these trends are long-term, whether the slowdown in major killers such as CVD will persist, and whether excess winter mortality seen in some years becomes a regular feature given population ageing and increasing numbers of frail, older people."[122]

Although many exciting medical and technological advances are on the horizon, as discussed in this and the next chapter, it is not known whether future advances in medicine will occur at the same pace as in the past decade; probably there will be periods of few developments as well as periods of major breakthroughs. Another consideration is the length of time that advances take to reach the vast majority of the population, as new medical advances typically are very expensive and require a long approval process. The eventual productive use of medical and technological advances may take a long time and may be stymied by lacking funding levels or similar reasons, by vested interests that may affected by advances that may supersede current offerings, by cultural fears (e.g., privacy or religious concerns) or by political realities.

7.1 MEDICAL DEVELOPMENTS AND CURES IN THE 20TH CENTURY

In this section we present a concise summary of major medical treatments and cures in the 20th century that led to significant reductions of morbidity or mortality and improvement in quality of life. To better appreciate the accelerating medical and pharmaceutical developmental pace of the 20th century, consider first the key developments prior to 1900:

- The microscope was invented in 1590;
- Medications were first administered intravenously in 1656;

[121] The distinction between medical and technological advances is blurred, as many medical advances are technology-based, and as all these advances are at the cross section of medicine, technology, cell biology, genetics and other scientific advances. We somewhat arbitrarily separated, for ease of reading, these advances into two consecutive chapters: medical and technological advances.
[122] "Trends in Life Expectancy in EU and Other OECD Countries," OECD iLibrary Health Working Papers, February 2019, https://www.oecd-ilibrary.org/social-issues-migration-health/trends-in-life-expectancy-in-eu-and-other-oecd-countries_223159ab-en.

- In 1747 lemon juice was found to prevent scurvy, and in 1797 Jenner discovered the vaccine to smallpox;
- Ether was first used as surgical anesthetic in 1842 and antiseptic was promoted by Lister in 1867;
- Germ theory was established by Pasteur and Koch in 1870;
- Cholera, anthrax and rabies vaccines appeared in 1879–1882;
- X-rays, the basis for medical imaging, were discovered by Roentgen in 1895;
- The transmission of malaria by mosquitoes was established in 1897; and
- Aspirin was developed from willow bark trees by Hoffman in 1899.

7.1.1 MEDICATIONS

Penicillin, the first antibiotic drug, was discovered in 1929 by Alexander Fleming, and this revolutionized the war against bacteria. Pharmaceutical manufacturing took off in the 1940s, when U.S. drug companies started mass production, and by 1960 it was the driver of a dramatic decline in death rates and serious illnesses arising from infection. Because of overprescribing of antibiotics and feeding antibiotics to animals in the meat and poultry industries, among other reasons, many bacteria became immune to these drugs, and the effectiveness of antibiotics is declining.[123] Also, because of limited profitability for bringing new antibiotics to market,[124] we could see increasing bacterial infections leading to serious illness and/or death.

Up to the 1960s, traditional drugs and antibiotics were ineffective against viruses, which are cores of genetic material surrounded by protective protein that hide and reproduce inside a person's cell. Antiviral drugs and techniques took off in the 1960s and have been successful in treating outbreaks such as HIV/AIDS, Ebola and rabies and in the inoculations fighting the current COVID-19 pandemic.

Unhealthy lifestyles and the resulting increases in cardiovascular diseases and mortality led to the U.S. commercial use approval of the first statin (cholesterol-lowering drug), lovastatin, in September 1987, followed by angiotensin-converting enzyme (ACE) inhibitors (to treat high blood pressure, heart problems and kidney disease) and beta-blockers (to reduce effects of adrenaline on the heart and treat high blood pressure, angina and other heart diseases). Their use has reduced death rates and improved quality of life for people susceptible to heart attacks, strokes and kidney failure.

An important element of alternative medicine, the non-Western holistic healing approach to diseases and the body, is use of herbal remedies, hormone therapy, vitamins and minerals, rather than chemicals as used by Western medicine. Naturally, for optimal results they should be prescribed by a professional, rather than being taken by word of mouth or information gleaned from the internet.

7.1.2 SURGICAL TECHNIQUES

Many newly developed surgical techniques have been instrumental in improving life expectancy and quality of life. These include the following:

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[123] M. D. Barton, "Antibiotic Use in Animal Feed and Its Impact on Human Health," *Nutrition Research Review* (2000), 13, https://www.researchgate.net/profile/Mary-Barton-3/publication/23668416_Antibiotic_use_in_animal_feed_and_its_impact_on_human_healt/links/0046353bc8f1060432000000/Antibiotic-use-in-animal-feed-and-its-impact-on-human-healt.pdf.

[124] World Health Organization, "Lack of Antibiotics Threatens Global Efforts to Contain Drug-Resistant Infections," January 2020, https://www.who.int/news/item/17-01-2020-lack-of-new-antibiotics-threatens-global-efforts-to-contain-drug-resistant-infections.

- Angioplasty is a surgical technique that uses a balloon inserted through a blood vessel to widen a narrowed or blocked artery in the heart, which is instrumental in helping people suffering from coronary heart diseases.
- Endoscopy uses a long, thin, flexible tube through which doctors can examine the inside of the body without need for surgery. Laparoscopic surgery is a minimally invasive surgery by which instruments are inserted through some small incisions in the skin rather than requiring full-scale surgery. Both techniques have revolutionized treatment, improved the experience for patients and improved safety.
- Kidney dialysis artificially replaces the waste and excess liquid removal functions in patients experiencing a kidney failure, which may prove fatal if not treated. Kidney dialysis is used until a kidney transplant can take place, or to maintain kidney function in those for whom a transplant is unsuitable.
- Medical implants are devices or tissues that are placed inside or on the surface of the body, either permanently or until they are no longer needed. For example, heart stents or hip implants are permanent, while repair screws for broken bones can be removed. Some implants are prosthetics replacing missing body parts, while others deliver medications, monitor body functions or provide support to organs and tissues.
- Organ transplants: The first kidney transplant in which the patient survived the operation was performed in Boston in 1954, the first lung transplant and liver transplant in 1963, the first pancreas/kidney replacement in 1966 and the first heart transplant in 1967. A hand transplant was first performed in 1998 and a full-face transplant in 2010.

7.1.3 ALTERNATIVE MEDICINE

Alternative medicine is a holistic medical approach that has been successfully used for thousands of years in countries such as China (e.g., herbs and acupuncture) and India (their ancient medical system, Ayurveda). Alternative medicine uses natural items to treat the whole body, in contrast to the chemicals used in the traditional Western treatment of particular diseases or body parts. Many people have found it to be successful, and sometimes even more beneficial than Western medicine. Some alternative procedures are the following:

- Acupuncture, a Chinese healing process for thousands of years, where needles are inserted in strategic positions to provide relief—or even cure—from illness or accident.
- Chiropractic procedures typically involve physical adjustment of the spine, or other body parts, to relieve painful or disabling symptoms and for healthier repositioning of the structure of one's body.
- Meditation, yoga and exercise (in many forms, such as gardening, stretching or tai chi) have been shown to reduce stress, improve outlook regarding mortality and be extremely healing. This is important because stress is a leading cause of heart diseases and death (as discussed above in section 3.5).
- Use of herbal remedies, hormone therapy, vitamins and minerals, rather than chemicals developed by the Western pharmacological industry.

7.1.4 PROCEDURES

A medical procedure is a course of action intended to achieve a result in the delivery of health care; for example:

- Traditional cancer treatments include medication, chemotherapy, radiation and surgery, and often have serious side effects such as hair loss, extreme nausea and even death from the toxins

involved. New approaches such as immunotherapy enhance the immune system's ability to fight cancer cells, enable more precise directing of medications to the cancer cells, use new experimental chemicals and more.

- Various medical advances reduce cardiovascular deaths and control cardiovascular diseases. These include angiograms (injecting a person with an iodine dye and using x-rays to identify artery blockages), angioplasty (a balloon is inserted into a blocked artery and inflated to open the blockage, often with the insertion of a stent to keep the artery open) and statins (controversial medications that help to prevent heart disease and arteries closure).[125]
- Chronic inflammation: This is a condition generally caused by continuous stress of some kind and involves changes in the cells at the inflammation site and often in the immune system as well in response to the healing process. Chronic inflammation can affect many body parts, and be painful, even life disrupting, leading in some cases to chronic disease or even death. Past treatments included diets, creams, lotions, ultraviolet-B light and medications. Modern treatments use biological and genetic approaches, geared to fix immune system failures and address only the affected cells.
- Tobacco control: Recognition of the adverse effects of smoking on the lungs and body, and the beneficial effects of actively reducing cigarette smoking, led to procedures, treatments and education campaigns that have significantly reduced smoking-related death and illness rates worldwide.
- Vaccinations and inoculations: The development of vaccines against a range of infectious diseases, and regulated vaccinations of young children against many diseases, have resulted in a major shift toward disease prevention and significantly reduced mortality.

7.2 GENETICS AND BIOMEDICINE

One of the most dramatic medical advances was the discovery of the structure of DNA in 1952 by James Watson and Francis Crick as well as by Rosalind Franklin. Since then, genetics, cell biology and medicine have made tremendous advances in understanding and deployment strides: of the DNA and the genome, of the use of stem cells (e.g., to treat leukemia, perform marrow transplantations and heal spinal cord injuries), and in cell-based and personalized medicine.[126] These strides even enabled the cloning of living creatures and the revival of a dead brain.[127] Genetic tools and information are used for early identification of people with high risk for cancer and other diseases, for screening and correction of genetic defects for embryos, and even in fighting crime. However, these tools raise difficult ethical, societal and regulatory issues because they can also be used to discriminate against people (such as future employees or insureds) with certain genetic biomarkers and/or enable cloning of human embryos.

CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) is a family of DNA sequences derived from viruses. Cas9 (CRISPR-associated protein 9) is an enzyme that uses CRISPR sequences to recognize and cleave specific strands of DNA, acting like a pair of molecular scissors, and thus enabling DNA editing. It is used for biological research, development of biotechnology products and medications, treatments of

[125] K. Clarissa, "Controversial New Study Reports Statins Useless," Carolina Total Wellness, July 2019, https://carolinatotalwellness.com/blog/index.php/2019/07/10/controversial-new-study-reports-statins-useless/. See also R. DuBroff and M. de Lorgeril, "Cholesterol Confusion and Statin Controversy," *World Journal of Cardiology* 7, no. 7 (July 2015), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4513492/.

[126] "Personalized Medicine," National Human Genome Research Institute, June 2022, https://www.genome.gov/genetics-glossary/Personalized-Medicine.

[127] "Scientists Are Giving Dead Brains New Life," *New York Times*, July 8, 2019, https://www.nytimes.com/2019/07/02/magazine/dead-pig-brains-reanimation.html.

diseases and genetic selection[128] of IVF embryos with specific genes of interest (e.g., for selection of "desired" embryos with no genetic defects or embryos with certain qualifications).

As Suran notes, following "recent success in sequencing the human genome's remaining gaps, an emerging frontier is proteomics: identifying and studying an entire set of expressed proteins (produced by the genome) in the human body and other organisms, called proteomes … [which] alter over time, and depict current (rather than at risk of occurring) health conditions."[129] Proteomes have medical potential, as certain proteins and proteomes are linked to disease, e.g., proteomic predictors of surviving COVID-19 patients in intensive care and the severity of COVID-19 cases, proteomic changes in the brains of Alzheimer's patients, and better understanding of cancer through proteogenomics (the integration of proteomics and genomics). As aging is regulated by cellular and molecular mechanisms and pathways and their change over time (as noted in section 2.2 above), one can expect that proteomics research will impact aging and age slowing and reversal research.

Personalized medicine uses individual-specific medical and genetic information to target medications and treatments. It is an extremely promising medical advance but currently is an extremely costly process, not yet amenable for public health care services, and it could lead to increasing health inequality within and between societies. Still, its principles are already being used for some medical treatments, such as depression.[130] As costs come down, there will be a leveling of the playing field for all to be able to use it.

Cancer, for example, tricks the immune system to accept the out-of-control growth of abnormal cells as a natural part of the body, so the immune system will not kill them. Immunotherapy counters that with drugs that make the immune system recognize the cancerous cells and thus be able to kill them, while leaving the healthy cells intact; this treatment, for example, cured former U.S. President Jimmy Carter.[131] However, there can be a downside to this treatment, as it can destabilize one's immune system, so that for some people who have been cured of cancer, the immune system continues to attack the body as if the cancer is still there.

Genetic medicine relies heavily on biochemical processes. A new experimental finding illustrates its promise. Just a few doses of an experimental drug can reverse age-related declines in memory and mental flexibility in mice, according to a new study by University of California at San Francisco scientists.[132] The drug, called ISRIB, has already been shown in laboratory studies to restore memory function months after traumatic brain injury, reverse cognitive impairments in Down's Syndrome and even enhance cognition in healthy animals. Researchers showed rapid restoration of youthful cognitive abilities in aged mice, accompanied by a rejuvenation of brain and immune cells that could help explain improvements in brain function.

The use of these genetic technologies is not limited to humans; but their use may be beneficial to humans and their health. To illustrate:

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[128] "Genetic Selection," Center for Genetics and Society, 2019, https://www.geneticsandsociety.org/topics/genetic-selection. See also H. Ledford, "CRISPR Babies: When Will the World Be Ready?" *Nature*, June 2019, https://www.nature.com/articles/d41586-019-01906-z.
[129] "After the Genome—A Brief History of Proteomics," *JAMA* online, August 31, 2022, https://jamanetwork.com.
[130] G. E. Simon and R. H. Perlis, "Personalized Medicine for Depression: Can We Match Patients with Treatments?," *American Journal of Psychiatry* 167, no. 12 (December 2010), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3723328/.
[131] "Jimmy Carter's Cancer Immunotherapy Story," Cancer Research Institute.
[132] N. Weller, "Drug Reverses Age-Related Mental Decline within Days," UCSF, December 2020, https://www.ucsf.edu/news/2020/12/419201/drug-reverses-age-related-mental-decline-within-days.

- The technology can eliminate the annual culling of billions of day-old male chickens (as the poultry industry is interested only in female young chicks).[133] CRISPR enables gene modification of the chicken genome, enabling immediate identification of laid fertilized eggs containing male chicks, and preventing them from growing into young males.
- To fight malaria, with an estimated 249 million sufferers and 608,000 deaths in 2022,[134] scientists introduced genetically modified sterile mosquitoes in Burkina Faso, a West African country that experienced some 4,000 malaria deaths in 2018.[135]
- Genetic technology is also used to enhance food production for our overpopulated and chronically undernourished world. Genetically modified foods are developed, including fruits, vegetables, beef and poultry, with increased productivity and higher resistance to disease, pathogens and drought, thus minimizing the use of pesticides in some instances.

As the technologies and medical advances improve, they will be more widely used and available, sometimes leading to cures never thought possible. How long this will take is not known, but some of the changes will be life altering, pun intended.

7.3 MEDICAL TECHNOLOGY

Technology has advanced in giant steps since the 19th century, bringing us into the revolution in information, computers, internet and networking. In particular, the miniaturization of the related chips, as well as nanotechnology, enabled development of intrabody medicine-carrying pills moving with the blood stream and controlling drugs distribution to specific body parts according to drug compliance needs, and measurements of physical activities that were inaccessible in the past. Other medical technology capabilities such as brain functional MRIs (fMRIs), brain wave sensing and interpretation, analysis of one's DNA and big data techniques that enable detailed follow-up of one's genome and lifestyle enable medical treatments and even cures that are personal and individually targeted rather than addressing a group of people with similar conditions. Most of these efforts are currently centered around cancer treatment.

Over the last couple of decades smartphones and wearable technology such as smart watches have become widely utilized by people all over the world. The current generation of these technologies includes a wide array of sensors and health applications that enable the measurement and analysis of many personal activities, including sports, exercise, sleep, electrocardiograms (EKG or ECG) and dieting, with more applications expected in the future. A natural extension of these abilities is "Telemedicine, the remote delivery of healthcare services, such as health assessments or consultations, over the telecommunications infrastructure. It allows healthcare providers to evaluate, diagnose and treat patients using common technology, such as video conferencing and smartphones, without the need for an in-person visit."[136] Telemedicine is likely to revolutionize the public health arena, as it will enable remote measurement and monitoring of patient medical condition, and remote patient-clinician contact, care, advice and education. It could be particularly important in rural areas, in regions with few central medical facilities, and/or when it is otherwise difficult to go in for a visit (e.g., during the COVID-19 pandemic).

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[133] "How CRISPR Could Save 6 Billion Chickens from the Meat Grinder," *CNET.com*, March 7, 2019, https://www.cnet.com/news/how-crispr-could-save-6-billion-chickens-from-the-meat-grinder/.
[134] "Malaria", World Health Organization, 29 March 2023, https://www.who.int/news-room/fact-sheets/detail/malaria
[135] "Country Disease Outlook: Burkina Faso" World Health Organization, August 2023, https://www.afro.who.int/sites/default/files/2023-08/Burkina%20Faso.pdf.
[136] TechTarget, Health IT, "Telemedicine," https://searchhealthit.techtarget.com/definition/telemedicine.

An extension of telemedicine, already common, is remote surgery (or telesurgery), using a robotic surgery system: "Remote surgery combines elements of robotics, cutting-edge communication technology such as high-speed data connections and elements of management information systems. Most of these robots are controlled by surgeons at the location of the surgery; still, remote surgery makes the physical distance between the surgeon and the patient less relevant. It allows specialized surgeons to be available to patients worldwide."[137]

"Stem cells are special human cells that have the ability to develop into many different cell types, from muscle cells to brain cells. In some cases, they also have the ability to repair damaged tissues."[138] A major area of medical and genetic advancement and development is the use of stem cell therapy to repair the body and replace cells and organs that have damaged genes. Scientists can modify an individual's stem cells into the type of damaged or impaired cells in question, and the stem cell can take on the function of the cell it is replacing.

Another approach to completely repairing a health problem is to modify the genome of cells using techniques such as CRISPR, which injects a new set of corrected code into the cells of an individual. This is a new technique that has seen some success (e.g., partially repairing some sight to blind individuals). The hope is to eventually fully restore sight for many. As more is understood about the genome and as CRISPR technology becomes improved, we can expect to see many conditions reversed or potentially eradicated.

Tissue engineering evolved from the field of biomaterials development and refers to the practice of combining scaffolds, cells and biologically active molecules into functional tissues that restore, maintain, and/or improve damaged tissues or whole organs. Some of an individual's cells can be used to begin the process of rebuilding a new organ for future transplantation, thus eliminating the issue of tissue rejection when organs from other donors are used. Artificial skin and cartilage are examples of engineered tissues. A new development in this direction is the creation of an exact replica of an organ from biological material, using 3D printing techniques.[139] These organs are used for transplantation, and some are already approaching medical functionality requirements. Originally small constructs such as heart valves were printed, but today research is structuring complex artificial organs such as heart, liver and kidneys.

Another medical advancement currently being worked on is the use of CBD and other non-hallucinogenic molecules of cannabis, as well as psychedelics,[140] to treat all kinds of impairments, including pain relief and autoimmune diseases.

7.4 ELECTRONIC HEALTH RECORDS (EHRS)

An electronic health record (EHR) is an electronic version of a patient's medical history, maintained by a health care provider over time. The EHR generally includes all of the important data relevant to that person's care under a particular provider, including, among other items, demographics, progress notes and problems, medications, vital signs, immunization records, laboratory results and radiology reports. The goal is that eventually all of a patient's medical history will be stored in the EHR.

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[137] "Remote Surgery," https://en.wikipedia.org/wiki/Remote_surgery.
[138] Stanford Medicine, "What Are Stem Cells," https://www.stanfordchildrens.org/en/topic/default?id=what-are-stem-cells-160-38.
[139] "Organ Printing," Wikipedia, https://en.wikipedia.org/wiki/Organ_printing.
[140] "Psychedelics Research and Psilocybin Therapy," *Johns Hopkins Medicine, Psychiatry and Behavioral Sciences*, 2022, https://www.hopkinsmedicine.org/psychiatry/research/psychedelics-research.html.

EHR, by itself, is not a driver of mortality. However, the information stored in an EHR can lead to a reduction in mortality and morbidity by mitigating the impacts of a person's existing maladies and enabling better and more effective treatments. Therefore, an EHR could be considered an indirect driver of mortality.

The EHR automates access to information and supports other care-related activities, including evidence-based decision support, quality management and outcomes reporting. The data, and the data's timeliness and availability, enable providers to make better decisions and provide better care, including reduction of medical errors and reducing duplication of tests and treatments, and keep all users—patients, medical providers and workers, insurers and regulators—better informed.

As the U.S. experience during the 20th century has demonstrated, EHR acceptance was hindered by the following:

- The complexity of the EHR and its components;
- The lack of sufficient computer resources;
- Complicated effective construction, management and use of the EHR records;
- Analyses related to the complete timeline of a patient.

Technology made it hard to disseminate all the data to the prospective users.[141] Further complicating the situation, each owner of an EHR database considered the data to be a valuable proprietary resource and was reluctant to share its data with other health providers. This issue was particularly challenging in practice because patients are often treated simultaneously by multiple providers who would each benefit from access to the patient's complete medical record. In addition, the different EHR systems often had different database structures and data definitions, making full sharing of data challenging.

To enable sharing of medical data, and eventually full medical histories of patients regardless of where they have been treated, which may in turn significantly improve health care quality and reduce costs, the U.S. Health Information Technology for Economic and Clinical Health Act (HITECH) of 2009 provided incentive payments to eligible hospitals and providers that demonstrate meaningful use of a certified EHR system, and in 2010 the Office of the National Coordinator for Health Information Technology began certifying EHR systems.

Further, the National Electronic Health Records Survey (NEHRS) tracks physician adoption of certified EHR systems across the U.S. and the extent to which physicians with certified EHR systems share patient health information. Results from the NEHRS[142] indicate that in 2021, 78% of office-based physicians and 96% of non-federal acute care hospitals had a certified EHR system, up from 67.5% of physicians in 2013.

In 2016 the Obama administration made an agreement with major hospital systems and leading EHR vendors[143] to make it easier for patients to access EHR, reduce barriers to sharing the information between health providers, and standardize technology to allow communication across the platforms. The

[141] When one of us (the authors) was hospitalized for a surgery, he saw nurses spending a long time every morning to copy the computer EHR data relating to him into paper notes. They explained that a real-time use of these data takes so long that it is effectively valueless.
[142] *National Trends in Hospital and Physician Adoption of Electronic Health Records*, HealthIT.gov, https://www.healthit.gov/data/quickstats/national-trends-hospital-and-physician-adoption-electronic-health-records
[143] *Fact Sheet: Commitments from health care industry to make electronic health records work better for patients and providers*. HHS Press Office, 29 February 2016, http://garnerhealth.com/wp-content/uploads/2014/02/Fact-Sheet_-Commitments-from-health-care-industry-to-make-electronic-health-records-work-better-for-patients-and-providers-_-HHS.pdf.

participants (representing 90% of the hospitals' EHRs, as well as EHR systems in 46 states) committed to the following:

- Helping patients "easily and securely access their electronic health information, direct it to a desired location, learn how the data can be shared and used, and be assured the data is being effectively and safely used."
- Not "blocking" information, allowing health providers to share patient records with other providers and the patients themselves, and not unreasonably interfere with such sharing.
- Working to implement federally recognized, national interoperability standards, policies and practices for EHRs.

Similar sharing is becoming common in other health care systems, such as in Canada, the U.K. and Israel. Challenges still exist, including impediments imposed by health-care-focused regulation, the potential for cyber theft of data, as well as potential mix-ups and confusion in shared information that could prove to be costly and even dangerous. Madhavan et al., who summarized the collective experience of 15 academic medical centers' EHRs to support public health response to the COVID-19 pandemic, found that "the lack of coordination between and among various entities, as well as the insufficiency of technical infrastructure, result in substantial expense, suboptimal outcomes, and missed opportunities for timely and impactful public health interventions."[144]

7.5 BARRIERS TO MEDICAL ADVANCEMENT

Science enables humanity to "play" with the basic processes of nature and life and perform wonders in the lengthening of life, improving quality of life, fighting diseases and becoming the masters of our health environment and future. These developments, though, may also have a dark side: we only partially understand the complexities of the processes we use and modify, we often do not understand or know all the consequences and side effects, we are many times surprised by interactions between various processes and we are susceptible to errors.

The over-reliance on antibiotics to fight inflammations and diseases among humans on the one hand and the overfeeding of farm animals and poultry with antibiotic-enhanced feeds to keep them healthy and speed their growth to get to market sooner on the other helped to accelerate the development of antibiotic-resistant bacteria, as well as microorganisms (such as bacteria, fungi, viruses and parasites) that developed antimicrobial resistance, often known as superbugs. As the World Health Organization notes, antibiotic and antimicrobial resistance is one of the biggest threats to global health and food security today.[145] A growing number of infections, such as pneumonia, tuberculosis, gonorrhea and salmonellosis, are becoming harder to treat, and hospital stays are becoming longer and more costly, and have an increased rate of mortality. To illustrate, the Antimicrobial Resistance Collaborators estimated that in 2019 4.95 million deaths were associated with antimicrobial resistance, of which 1.27 million were attributed to bacterial resistance.[146] The highest mortality rate was in western sub-Saharan Africa, with 27.3 deaths per 100,000. Lower respiratory infections accounted for more than 1.5 million deaths associated with

[144] S. Madhavan, L. Bastarache, J. S. Brown, et al., "Use of Electronic Health Records to Support a Public Health Response to the COVID-19 Pandemic in the United States: A Perspective from 15 Academic Medical Centers," *Journal of American Medical Informatics Association* 28, no. 2 (2021), https://academic.oup.com/jamia/article/28/2/393/5952684.
[145] World Health Organization, "Antibiotic Resistance," November 2021, https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance.
[146] Antimicrobial Resistance Collaborators, "Global Burden of Bacterial Antimicrobial Resistance in 2019: A Systematic Analysis," *The Lancet* (January 2022): 399, https://www.thelancet.com/action/showPdf?pii=S0140-6736%2821%2902724-0.

resistance. The six leading pathogens were responsible for 3.57 million out of the 4.95 million deaths associated globally with resistance in 2019.

Drug interactions and misuse are two common issues; misuse can also lead to drug overdoses. Interactions can take place when an individual is taking multiple medications, often because of being treated by multiple physicians and specialists, who prescribe medications for what they were consulted upon but without regard to potential harmful interactions with other drugs the person is taking. Another type of drug interaction can occur when an individual relies on media promotion of a drug or on the suggestions of nonmedical people, i.e., on word-of-mouth advice.

One other situation that can cause bad drug interactions or other problems is when one drug is originally used for some malady but causes a side effect of some kind. Then a second drug is added to the first one to treat the side effect. The combination of these may cause another side effect, and yet another drug is added. This can go on for some time, with continued bad reactions and likely no recovery from the first health issue. One example of this is taking a statin for heart issues. Statins can cause muscle pain or diabetes, for example. Although these certainly do not happen to all who take a statin, for those where it does happen, they are often prescribed another drug, which could have a negative interaction with the statin the patient is taking.

A related problem is the overdosing on drugs, which became a world concern in recent years, particularly overdosing on addictive opioids (as noted in section 3.4). In the case of opioids, when the users try to stop, they have severe withdrawal pain or discomfort, forcing them to take more and more to combat it. The individual often does not recognize that the pain is caused by the stoppage of taking the medicine, rather than the original real problem. Even if they do realize it, the pain is so severe that they continue to take more and more of the medicine until eventually they die from an overdose.

A related risk is overprescription of drugs and medications, due—particularly in the U.S.—to the efforts of the pharmacological industry to increase consumption of medications, often through media blitzes to naive consumers, called Direct-to-Consumer Pharmaceutical Advertising (DTCPA),[147] who are unaware of their real medical needs, and who press their physicians to overprescribe medications. The pharmaceutical companies also encourage physicians, hospitals and other medical providers, often through various monetary benefits, gifts and drug samples, to prescribe their drugs, even beyond the real need.[148] Thresholds for certain health conditions (such as hypertension and cholesterol level) have several times been reduced, identifying many formerly healthy people as "health risks" who seemingly need medication for life while often all that was needed was a change in lifestyle, and often with no consideration of the impact of the change on other personal health traits.[149] The results of overprescription were particularly onerous in the case of the opioid crisis, which was declared in 2017 as a public health emergency in the

[147] As specified by E. Epstein, "The Dangers of DTCPA: A Legal Analysis," *Columbia Undergraduate Law Review*, November 2017, https://blogs.cuit.columbia.edu/culr/2017/11/19/the-dangers-of-dtcpa-a-legal-analysis/, "DTCPA has proved to be exponentially profitable business, costing insurance companies and taxpayers ever more money and, more significantly, potentially endangering patients' health."
[148] See, for example, "Dollars for Docs: How Industry Dollars Reached Your Doctors," https://projects.propublica.org/docdollars/, which details "how industry dollars reached your doctors" and other medical providers in the years 2013–2018, with names and locations of providers and the amounts they received.
[149] A. Park, "Almost Half of Americans Have High Blood Pressure under New Guidelines," *Time.com*, November 2017, https://time.com/5022440/high-blood-pressure-guidelines/.

U.S. following more than 2 million addicted Americans in 2016 and more than 300,000 deaths in the period 2000–2017.[150]

Medical errors are the third leading cause of death in the U.S., with an "estimated 44,000 to 98,000 deaths in hospitals each year".[151] This is not only a problem in the U.S. "The WHO reported that adverse events due to unsafe patient care are among the top ten causes of death and disability worldwide". A UK study reported 11% adverse event rate, in Australia 16.6% of all admissions had preventable adverse outcomes, New-Zealand study reported 10.7%, and in Denmark the rate reported was 9%.

Immunizations help protect populations from epidemics, and childhood vaccination is important to protect children against various diseases. However, immunizations have recently become more controversial, with more people getting (or believe they are getting) adverse outcomes—supposedly even dying—from the immunization. The controversy over immunization has led to battles between health authorities, individuals and certain population groups, and was particularly bitter—including a class action suit against forced workplace vaccinations—with regard to COVID-19 vaccinations.[152] A related issue is how to improve people's health and well-being, particularly in developing countries[153] and help individuals lift themselves out of hunger and extreme poverty, and in particular reduce the cost of immunizations, and medications in general, that are targeted for developed markets.[154]

[150] The White House, "President Donald J. Trump Is Taking Action on Drug Addiction and the Opioid Crisis," https://trumpwhitehouse.archives.gov/briefings-statements/president-donald-j-trump-taking-action-drug-addiction-opioid-crisis/.
[151] NIH, "Medical Errors," May 2023, https://www.ncbi.nlm.nih.gov/books/NBK430763.
[152] M. Farber, D. R. Golder and E. R. Magnus, "COVID-19 Vaccine Mandate Litigation," *National Law Review* 12, no. 107 (April 17, 2022), https://www.natlawreview.com/article/jackson-lewis-class-action-trends-report-2022-covid-19-vaccine-mandate-litigation.
[153] The Bill & Melinda Gates Foundation, https://www.gatesfoundation.org/.
[154] "Vaccine Ingredients and Manufacturer Information," http://vaccines.procon.org/view.resource.php?resourceID=005206.

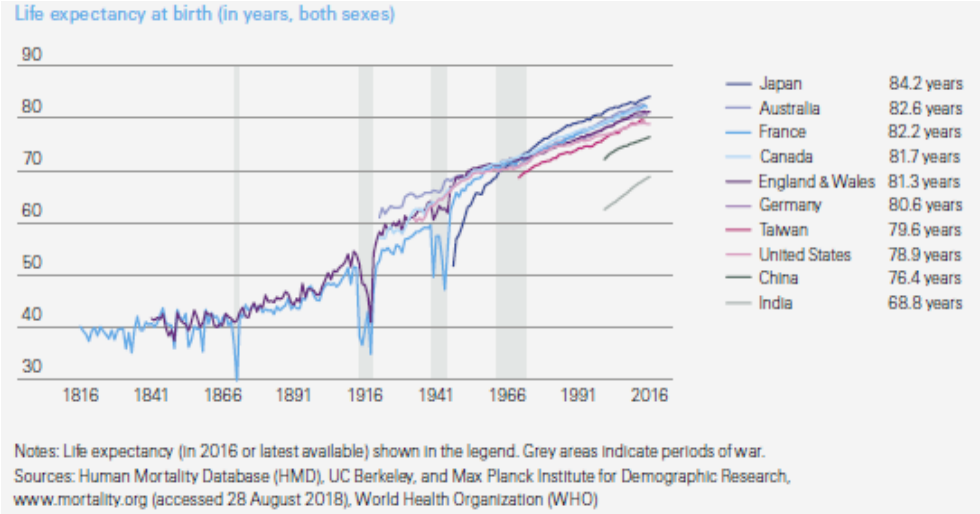
SUMMARY TABLE for FUTURE MORTALITY - CHAPTER 7 - MEDICAL ADVANCES			
Sub-Driver	**Near-Term (1-5 years) Impact**	**Longer-Term Future Impact**	**Comments**
Overall	↓	↓	Medical advances are based on research into new and existing maladies, and are characterized by unpredicatable achievements and outcomes
Medications	↓	↓	It is hard to predict (as for all medical advances) if future advances will continue at the current pace and level of accessibility
Surgery	↓	↓	The increasing use of robotics, non-invasive technologies, implants, remote surgery, and other advances will probably continue
Alternative Medicine	↓	↓	This holistic approach is gaining in developed countries
Telemedicine	↓	↓	Connectivity advances will speed up diagnosing, treatments and improve outcomes
Medical Technology	↓	↓	Further advances will be driven by scientifical and technological developments
Biomedicine	↓	↓	Understanding of genetics, biomedicine, and other medical breakthroughs, is expeected to continue
Electronic Health Records	↓	↓	Quality, access, and sharing of medical history from many sources will continue to grow, enhancing and improving the scope and knowledge of health care
Medical Developments	⟺	⟺	Many medical developments rely on new science, with many unknowns; thus they are unpredictable
Note: The evaluations reflect the authors' opinion, rather than a scientifically measurable comparison.			
Mortality Legend:	**Increasing: high** ⇈ **low** ↑ ;	**Decreasing: high** ⇊ **low** ↓ ;	**or** ⟺

8. Technological Advances

The explosion of new and revolutionary technologies over the last few decades has changed our lifestyle, social and societal conventions, the economic and job markets and more. These changes, among others, have led to global migration between countries and mass migration from rural to metropolitan areas, where societal services, including education, health care delivery, population health, general safety and standards of living, often are much better.[155] All of these have resulted in improved population health, increase in longevity, and decrease in mortality, as evident in Figure 8.1.

Figure 8.1

LIFE EXPECTANCY AT BIRTH, SELECTED COUNTRIES, 1816 TO 2016



Source: Sigma, Swiss Re Institute, "Mortality Improvement: Understanding the Past and Framing the Future," June 2018.

These technologies, by themselves, are not drivers of mortality. At the same time, technologies such as artificial intelligence have the potential for speeding up the development and effectiveness of new medications, drugs and treatments, and our better understanding of concepts we did not have the computing power in the past to contemplate. Wearable electronics can improve monitoring of patients and reduce the pretreatment response time. These and many other examples, such as EHRs, indicate technologies that are indirect drivers of mortality and worthy of discussion in this paper. This is especially true because the new technologies could allow for significant breakthroughs in understanding and possibly slowing or reversing mortality.

Interestingly, with the COVID-19 pandemic, there was a movement in the opposite direction, urban to rural, as many individuals desired to isolate themselves and have less exposure to others who might have the virus. It is not known at this time if this trend will continue or reverse itself.

[155] See, for example, "Exploring Migration Causes—Why People Migrate," *News European Parliament*, October 2020, https://www.europarl.europa.eu/news/en/headlines/world/20200624STO81906/exploring-migration-causes-why-people-migrate, or KPG, "International Migration: 10 Reasons People Embark on a Journey," 2019, https://www.kylinprime.com/news/107/International-Migration-10-reasons-people-embark-on-a-journey.html.

8.1 THE INTERCONNECTED WORLD

One of the most important technological revolutions of the 20th century was the development and adoption communications and networking technology over the internet, which later expanded into cloud computing. The internet started in late 1960 with ARPANET and the adoption of the TCP/IP networking protocol in 1983. The year 1989 ushered in the World Wide Web "network-of-networks," what we consider the modern internet. The first web browser was Nexus in 1991. Mosaic became popular in 1993, and since then, browsers have become the ad hoc means of addressing the internet information and communication resources available today on computers, smartphones and tablets. Cloud computing enhances the computing capabilities of users by moving the storage of data and programs to "cloud" farms of servers that are accessible from all places at all times.

The upcoming advance of the interconnected world is the Internet of Things (IoT), which integrates the networking capability of the internet, the everywhere-accessibility of essentially all electronic devices and facilities, and the power of cloud computing. The IoT connects any device and its components to the internet, and thus also to all other devices. Thus, it enables access, connection and control of status and activity of everything from personal cellphones, watches and wearables to home devices such as smart speakers, lamps, refrigerators, air conditioners and cars to other national and institutional entities and facilities. This technology, for example, enables a refrigerator to monitor its contents and send a message to a smartphone at the time of a person's leaving work, requesting the owner to stop at the store and pick up the missing eggs and milk that the refrigerator just ordered. From a health standpoint, a wearable could immediately notify the person's physician if a certain health-related reading was triggered.

These technologies have major impacts for health care delivery and can result in decreased mortality and improved quality of life, as outlined in the "Medical Technology" and "Electronic Health Records" sections in the last chapter. Beyond advances in medicine, genetics, biology and other areas, these technologies enable the benefits of digital transformations, providing for enhanced communication, automation, decision making and data-driven innovations, including cooperative use and sharing of data and processing by many users.

In particular, these technologies can improve the communications between medical personnel and patients, support patients in understanding and managing their medical conditions and needs, and enable artificial intelligence algorithms to review and better manage a patient's history. Medical results, with "big data" sources, are available in the ever-increasing body of scientific, public and private data sources to help manage each individual's current and future health status.

As Rodriguez et al. noted, "with digital health tools becoming prominent components of care delivery, the barriers to digital inclusion have grown increasingly apparent, where digital inclusion refers to 'the activities necessary to ensure that all individuals and communities, including the most disadvantaged, have access to and use of digital tools.'"156 For example, more than 100 studies revealed portal use disparities and digital redlining based on age, gender, race, socioeconomic status, language proficiency and other factors. This digital redlining "entails discrimination by internet service providers in the deployment, maintenance, upgrades, and service deliveries—and the communities affected by it are generally the ones with poor health outcomes."

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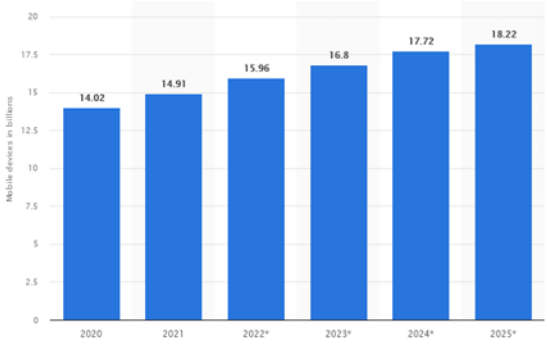
[156] J. A. Rodriguez, Carmel Shachar and D. W. Bates, "Digital Inclusion as Health Care—Supporting Health Care Equity with Digital-Infrastructure Initiatives," Perspective, *New England Journal of Medicine*, 386 (12) 1101–1103, March 2022, https://doi.org/10.1056/nejmp2115646.

8.2 WEARABLE AND PERSONAL ELECTRONICS

The first phone call on a mobile device was made by Motorola's Martin Cooper in 1973, but the first true mobile phone available to consumers was Nokia's 1982 Mobira Senator phone.[157] The evolution of the technology was astonishing, moving from analog to digital mobile phones, and from there to the current smartphones, which are as powerful as a supercomputer of a decade ago. As seen in Figure 8.2, in 2020 there were 14 billion mobile devices, almost 15 billion in 2021 and about 16 billion forecast by 2022 and 18.2 by 2025. Further, as of December 2019, there were 104.32 mobile phone connections per 100 citizens.[158]

Figure 8.2

FORECAST NUMBER OF MOBILE DEVICES 2020 TO 2025, BILLIONS



Source: Statista, April 2021, https://www.statista.com/statistics/245501/multiple-mobile-device-ownership-worldwide/#professional.

Today's generation likely cannot imagine a world without smartphones, as they have been integrated into all parts of life. This is because of the benefits of these phones: continuous communications with individuals and groups everywhere through texting, voice calls and video calls; personal management of all daily activities; online real-time entertainment eliminating the need for all other devices; information source for searches, shopping, learning, research, travel, health and more; monitoring health, sleep, exercising, diet and other daily activities; and safety and emergency facilities.

New approaches to delivering care include wearables and smartphones that monitor the health status of patients,[159] telemedicine that reduces the need for an in-person physician consultation, and remote surgery that provides access to remote medical expert advice. For example, remote monitoring of intensive care units led to more than a 20% decrease in mortality and a reduction in length of hospital stay.[160]

It is safe to project that the use of these devices, as well as other futuristic technologies, such as brain-computer interface and DNA-based storage and quantum computing devices and networks, will only increase and become the de facto way of life.

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[157] "The Evolution of Mobile Phones: 1973 to 2019," *Flaunt Digital*, November 2018, https://flauntdigital.com/blog/evolution-mobile-phones/.
[158] "List of Countries by Number of Mobile Phones in Use," https://en.wikipedia.org/wiki/List_of_countries_by_number_of_mobile_phones_in_use.
[159] "In African Villages These Phones Become Ultrasound Scanners," *New York Times*, April 15, 2019, https://www.nytimes.com/2019/04/15/health/medical-scans-butterfly-iq.html.
[160] E. J. Thomas, "Measuring the Value of Remote ICU Monitoring," University of Texas Health Science Center at Houston, Agency for Health Research and Quality, U.S. Department of Health and Human Services, https://healthit.ahrq.gov/sites/default/files/docs/publication/r01hs015234-thomas-final-report-2008.pdf.

The social and psychological burden of mobile phones cannot be ignored. The reliance on mobile and smartphones can lead to "Nomophobia," a state of fear and anxiousness related to being without a mobile phone. Cell phones have been found to lead to addiction, isolation (remember the group of youths seated around a table but not talking to each other—all are glued to their smartphone screens), depression and poor psychological and physiological health of adolescents.[161] Smartphones also lead to distractions and to a significantly increased risk of traffic accidents.[162] Cell phones can take away from the development of face-to-face communication skills.

The sharing and networking infrastructure and activities of the current and future medical and technological worlds raise—as have been seen many times—the risk of attack and penetration of the involved systems and applications with their personal and other sensitive information by unfriendly outsiders. There clearly is the question of how these outsiders will use this information and where it will migrate, with all the frightening possible outcomes. But not less frightening is the possibility of disruption of operations and activities, which may lead to catastrophic results. Imagine, for example, with all the impacts on society and on its mortality, the freezing of the entire electricity network in a city, shutting off an operations room in the middle of a surgery, releasing devastating floods through the opening of dams, stopping an electric car far from home in subzero temperatures, and much more. The resulting potential cyber war is therefore liable to become a major concern for all countries, and it seems that it will be very difficult to contain this risk.

8.3 BIOELECTRONICS, NANOTECHNOLOGY AND ROBOTICS

Several new technologies contribute significantly to medicine and population health, with considerable expected impacts on future mortality and quality of life. "Bioelectronic medicine is an exciting new field at the intersection of molecular medicine, neuroscience and bioengineering. It has the potential to revolutionize the way we treat disease through the development of nerve-stimulating devices that interact with the central and peripheral nervous systems."[163] As demonstrated by the journal *Bioelectronics in Medicine,* topics such as neural pathways affecting organs, functions and disease states, stimulation techniques, and miniaturization of bioelectronic devices and biosensors are becoming more mainstream.

Bioelectronics became feasible, among other reasons, because of nanotechnology: "the science and practice of understanding, shaping and combining matter at the atomic and molecular level. Nanotechnology encompasses science, medicine, engineering, computing and robotics at this scale, called the nanoscale. Nanotechnology offers the potential for new and faster kinds of computers, more efficient power sources and life-saving medical treatments."[164]

In addition to the use of nanotechnology for biotechnology applications, it can help with the creation of smart drugs and measurement devices that can move in the bloodstream and be directly applied to specific body locations for tissue regeneration, bone repair, clearing blocked arteries, immunity and damaged gene repairs, killing cancer cells and the like. This may cure people faster and without side effects of traditional drugs. Nanotechnology could be used to refine drug production, tailor drugs at a molecular

[161] S. Shoukat, "Cell Phone Addiction and Psychological and Physiological Health in Adolescents," *EXCLI Journal* 18 (February 4, 2019): : 47–50, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6449671/pdf/EXCLI-18-47.pdf.
[162] Ryan Gorman, One in Four Car Accidents Caused by Cell Phone Use While Driving…but Only Five Per Cent Blamed on Texting, *The Daily Mail*, March 2014, http://www.dailymail.co.uk/news/article-2591148/. See also E. Muehlegger and D. Shoag, "Cell Phones and Motor Vehicle Fatalities," https://scholar.harvard.edu/files/shoag/files/cell_phones_and_motor_vehicle_fatalities.pdf.
[163] "Future Medicine" 2022, https://www.futuremedicine.com/.
[164] S. S. Verma, "Nanotechnology: Advantages and Disadvantages," *Scientific India*, May 23, 2018, Nanotechnology--Advantages-and-Disadvantages (scind.org).

level to be attached to and impact biological targets only such as cancer cells, make them more effective and reduce side effects. Nanoparticle coating of prosthetics with carbon-based particles can prevent rejection and extend the life of the prosthetics. Nanomedicine thus has enormous potential to enhance traditional health care procedures and particularly diagnostic and regenerative medicine and make obsolete the often-inefficient diagnostic and treatment plans.

Nanotechnology is still young, and many of its side effects are still unknown. Nanotechnology may affect health and even lead to poisoning; it may increase air and water nanopollution.[165] Because of their size, nanoparticles can be very dangerous to living organisms (e.g., breathing in the nanoparticles through the air). In some cases nanoparticles may added to foods and when absorbed by the body may move through the blood stream, posing a risk to internal structures and potentially increasing the likelihood of certain illnesses, such as cancer.

Another technology that may significantly affect mortality and quality of life is robotics. The impact of robotics on the workforce has been widely discussed and has led to the full or partial disappearance of many professions. This impact in turn may change the level of workplace hazards, require retraining of workers and generate much more free time and lifestyle changes—all of which may affect population health. Robots also affect medicine: they increase surgical precision and support remote surgeries and enable better monitoring and control of patients' treatments, which, in some instances, can relieve the pressures on health care professionals. Robotics can be used for telemedicine monitoring, control and treatment, can manage the distribution and daily use of drugs to patients, and can provide exoskeletons to paraplegics.

The elderly will be among those who benefit most from the use of robots, for instance:

- Making sure they keep their doctors and other appointments, and take medications on time;
- Keeping the elderly company and enhancing their social life and health through conversation and music;
- Picking them up after a fall;
- Contacting others in the case of an emergency.

A recent advancement in robotics is the addition of artificial intelligence, allowing robots to "think" and solve problems on their own. This enhances many of the uses of robots, just described, from the workplace to assisting the elderly.

8.4 BIG DATA, PREDICTIVE ANALYTICS AND ARTIFICIAL INTELLIGENCE

The advanced computing and network technologies adopted over the last decades resulted in the digitization of all forms of data and information, and extremely large amounts of digitized data—referred to as Big Data.[166] In the last century, much of the computing effort concentrated on the construction and management of structured data (e.g., data structures and databases), but this becomes infeasible in a big

[165] "Nanotechnologies," EUROPA/DG Health and Consumer Protection/Public Health, SCENIHR (2006) and GreenFacts (2007), https://ec.europa.eu/health/scientific_committees/opinions_layman/en/nanotechnologies/l-2/6-health-effects-nanoparticles.htm. See also World Health Organization, "Nanotechnology and Human Health: Scientific Evidence and Risk Governance," December 2012, http://apps.who.int/iris/bitstream/handle/10665/108626/e96927.pdf;jsessionid=5225010A55B76E537BFF704393ED3AE1?sequence=1.

[166] For an actuarial perspective on these emerging technologies, see N. Cervi, A. da Silva, P. Downes, et al., "Emerging Technologies and their Impact on Actuarial Science," SOA Research Institute, October 2021, https://www.soa.org/resources/research-reports/2021/emerging-technologies-and-their-impact-on-actuarial-science/.

data world, where information may come from all conceivable resources, in all forms and formats, and be voluminous. Examples of big data types include physicians' visits, credit cards, air travel, internet browsing, photos and videos, and songs. Consequently, much of the effort today is on sifting through the data, identifying related items, and combining them to provide meaningful information for analysis and decision making. Stated differently, if before we concentrated on constructing the "needle," now the task is one of identification, that is, "finding the needle in the haystack."

To illustrate: in the last decades of the 20th century, because of limited computer power, medical data concentrated on individual treatment encounters (such as physician visits, surgeries or drug prescriptions) and thus missed much of the knowledge available on the history or lifestyle of a patient or region. In the linked big data information world of today, all of these items of information are available, but data science tools, such as predictive analytics and artificial intelligence, are needed to extract and associate the relevant data, analyze the data and help the user reach the appropriate decisions. This data-driven approach enables early detection of warning signs,[167] promotion of preventive medicine and early treatment of diseases such as cancer and diabetes, personalized medicine as described in section 7.2, and improved public health management of population segments, geographical regions and epidemics.

Artificial Intelligence and deep learning tools attempt to replicate, and even surpass, human abilities of cognition and decision making, through elimination of human limitations of time and power. They use the technology and statistical tools of predictive analytics to search through the big data, apply advanced artificial intelligence algorithms to identify patterns and use these to predict outcomes, and help reach appropriate decisions.[168] Illustrations of the use of big data and these techniques to health care include the following:[169]

- Predictions for improved staffing;
- Real-time alerting;
- Enhanced patient engagement;
- Identifying patterns to prevent drug—and particularly opioid—addiction and abuse;
- Using health data for informed patient strategic planning;
- Better prediction of health outcomes for one or more treatment strategies;
- Curing diseases through analysis of large amounts of data and experience;
- Support data-driven information and decisions by physicians;
- Reduction of fraud and enhancing security;
- Integrating big data with medical imaging;
- Reducing unnecessary emergency room visits.

There are, however, serious issues of privacy rights and patient confidentiality that have to be addressed, such as psychiatric treatment or use of illegal drugs. Further, multinational organizations may be subjected

[167] See, for example, A. Bonde, K. Varadarajan, N. Bonde, et al, "Assessing the Utility of Deep Neural Networks in Predicting Postoperative Surgical Complications: A Retrospective Study," D. Lin, J. Xiong, C. Liu, et al, "Application of Comprehensive Artificial Intelligence Retinal Expert System: A National Real-World Evidence Study," and J. C. Y. Seah, C. H. M. Tang, Q. D. Buchlak, et al, "Effect of a Comprehensive Deep-Learning Model on the Accuracy of Chest X-Ray Interpretation by Radiologists: A Retrospective, Multireader Multicase Study," *Lancet Digital Health*, 3, no. 8 (August 2021).

[168] A short summary of predictive analysis and artificial intelligence use in health care, with benefits and obstacles, can be found in "AI and Predictive Analytics Lead to Improved Delivery of Healthcare Services," *Healthcare Business and Technology*, January 2019.

[169] M. Labied, "12 Examples of Big Data Analytics in Healthcare That Can Save People," *Business Intelligence*, July 2018, https://www.datapine.com/blog/big-data-examples-in-healthcare/.

to different regulations in different countries; to illustrate, anyone subject to the U.K. General Data Protection Regulation (GPDR) has to follow its set of rules, which differ, for example, from U.S. regulations.

SUMMARY TABLE for FUTURE MORTALITY - CHAPTER 8 - TECHNOLOGICAL ADVANCES			
Sub-Driver	**Near-Term (1-5 years) Impact**	**Longer-Term Future Impact**	**Comments**
Overall			Technological advances impact society and expectations with spurts of innovation; hard to predict the rate and directions of advances
Connectivity			Advances in connectivity, via the internet, storage and processing "clouds", will enhance Electronic Health Records, medical data sharing, telemedicine, improved health care, and better utilization of resources
Wearable and Personal Technology			Supports personal medicine, telemonitoring, and overview and reporting of personal health
Bioelectronics			New medical opportunities, such as "personally tailored" sensors and medical controllers; hard to predict when will become widely available
Nanotechnology			Enables medicine at the cell and molecular level, but hard to predict when will be widely available
Robotics			Used for new advances in surgery, as well as in handicapped and elderly support
Predictive Analytics (PA)			PA and artificial intelligence will replace or improve many medical advancements and decisions, utilization of resources, and quality of health care
Note: The evaluations reflect the authors' opinion, rather than a scientifically measurable comparison.			
Mortality Legend:	**Increasing: high**  **low**  **;**	**Decreasing: high**  **low**  **;**	**or** 

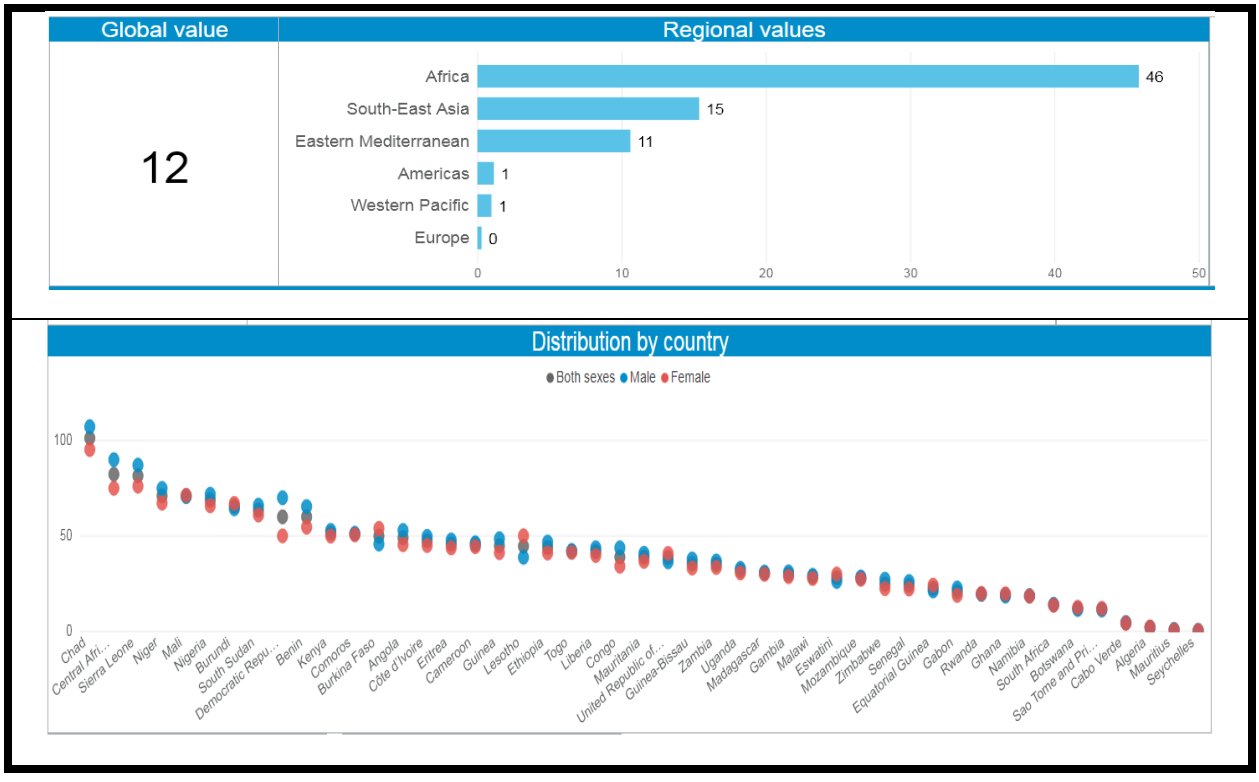
9. Environment

Our livelihood, food supply, living conditions, health and well-being—all with impacts on mortality—are heavily dependent on, and affected by, the environment we live in. According to the WHO, 91% of the world's populations live in places where air pollution levels exceed WHO guideline limits , 24% of all estimated global deaths are linked to the environment, and 3.8 million deaths annually are the result of exposure to indoor polluted environment by smoke from cooking fuels.[170]

Figure 9.1 graphically demonstrates the impact of the environmental pollution—namely, due to unsafe water, sanitation and hygiene services—on mortality rates per 100,000 population, based on the WHO 2022 information.[171] Whereas in the developed world the mortality rate is less than 1 per 100,000 (top chart in Figure 9.1), it reaches 40 per 100,000 population, with 12 being the world average. The bottom chart shows the distribution by country, with the country most affected, Chad, at the 100 level—all attributed to pollution.

Figure 9.1

MORTALITY RATES DUE TO EXPOSURE TO UNSAFE WATER, SANITATION AND HYGIENE (WASH) SERVICES, PER 100,000 POPULATION



Source: World Health Organization, "SDG Target 3.9 Mortality from Environment Pollution," 2022, https://www.who.int/data/gho/data/themes/topics/sdg-target-3_9-mortality-from-environmental-pollution.

[170] World Health Organization, "SDG Target 3.9 Mortality from Environment Pollution," 2022, https://www.who.int/data/gho/data/themes/topics/sdg-target-3_9-mortality-from-environmental-pollution.
[171] Ibid.

The WHO states that a "healthier environment could prevent almost one quarter of the global burden of disease ... Clean air, stable climate, adequate water, sanitation and hygiene, safe use of chemicals, protection from radiation, healthy and safe workplaces, sound agricultural practices, health-supportive cities and built environments, and a preserved nature are all prerequisites for good health … Local and national governments need to introduce policies and make investments that support cleaner transport, energy-efficient housing, power generation, industry and better municipal waste management."

This section looks at some of the environmental factors likely to influence the future level and distribution of mortality, either directly (e.g., impact of a poisonous chemicals) or indirectly (for example, a degraded environment may lead to a more volatile supply or lower quality of food). Therefore, "environmental factors" in this section include chemicals, drugs, pesticides, hormones, air and water pollution, and climate change.[172]

9.1 POLLUTION

All pollutants, whether air, water, earth, food or manufactured products, affect—usually adversely—human and animal health and mortality. According to another World Health Organization report,[173] air pollution kills an estimated 7 million people annually, 4.2 million deaths occur as a result of exposure to ambient outdoor pollution, and 99% of the world's population breathe air that exceeds WHO air quality guideline limits pertaining to pollutants.[174]

Many pollutants are natural, like volcanic ash, pollen and arsenic, which is found in relatively high quantities in rice. At the same time, human activities over generations, and particularly since the industrial revolution with its large use of chemical compounds, consumer products and processes largely added to the natural pollution. Still, the U.S. Environmental Protection Agency (EPA) has mandated safety testing for only a small percentage of the 85,000 industrial chemicals used today, even though the impacts of many—if not the majority—of these pollutants are not yet sufficiently assessed and understood. For example, the link between the use of pesticides and chemicals on the one hand and cancer and many other diseases is often difficult to establish and subject to ongoing debate. Despite many pollution-fighting efforts worldwide, industrial financial interests and intense lobbying efforts mean that we are far from eradicating most man-made pollution.

9.2 MEDICATIONS, DRUGS, CHEMICALS AND PESTICIDES

Medications and drugs have proven effective in the treatment and cure of many diseases. At the same time, overprescription of certain drugs can cause adverse impacts to quality of life and mortality, including drug interactions, addiction, overprescription, superbugs and pollution of the food chain with antibiotics and genetically modified foods. Beyond these risks, there is the issue of drug and pharmaceutical pollution of the environment with the metabolites and the remains of drugs and pesticides that reach the aquatic

[172] Some scientists claim that our climate goes through short and long cycles and there is nothing we can do about influencing it on any kind of scale that would make a difference. There is no doubt that the global weather goes through significant changes (e.g., such as arctic ice melting, longer and wider droughts, and increasing temperatures in various regions), regardless of the source of these changes or our actions. These are generally known as "climate change," and we just use this name. On the other hand, this phenomenon affects mortality, and for that reason it is included herein.
[173] The World Health Organization never explained the differences between the data in this section and the former section.
[174] World Health Organization, "Air Pollution," 2022, https://www.who.int/health-topics/air-pollution#tab=tab_1.

environment (e.g., groundwater, rivers, lakes and seas) through wastewater and agricultural runoff.[175] Hospitals, which tend to flush unused and expired drugs, are a major source of this pollution.[176]

Manufacturing plants often pollute the land and the aquatic environment with their chemical sewage. Indeed, antidepressants have been found in the U.S. Great Lakes, and toxic chemicals (such as mercury) have been found in fish and the oceans' food chain.

A particularly onerous source of pollution, with many health risks and a significant chemical burden on natural ecosystems, is the industrialization of the agricultural sector, the use of pesticides, as well as the pollution generated during agricultural activities, as seen in Figure 9.2. As Gibbens reports, "16,000 U.S. deaths (per annum) are the result of air polluted by growing and raising food, and 80% of these result from producing animal products like meat, poultry, milk and eggs. Additional deaths are attributable to byproducts, with total deaths from agricultural air pollution reaching 17,900 annually."[177]

In particular, pesticides are agrochemicals used in agricultural lands, public health programs (such as spraying for mosquitoes) and urban green areas to protect plants, animals and humans from various diseases and to promote growth and enhanced production.[178] But because of their known ability to cause a large number of negative health and environmental effects, their side effects can be a significant environmental health risk factor arising from absorption through the skin, ingestion, inhalation or transfer through edible agricultural products. Thus, the use of certain pesticides has been banned.[179]

Figure 9.2
TRACTOR PLOUGHING A FIELD

Source: David Bacon, Report Digital-REA/Redux, *National Geographic*, May 2021, https://www.nationalgeographic.com/environment/article/meat-production-leads-to-thousands-of-air-quality-related-deaths-annually.

9.3 CLIMATE CHANGE: FLOODS, HEATWAVES, DROUGHTS AND FAMINE

Climate change has been accelerating since the industrial revolution. It alters every aspect of the natural environment and increases the intensity and frequency of natural phenomena and disasters. If climate change continues unabated, the human environment as we know it may completely change or even be

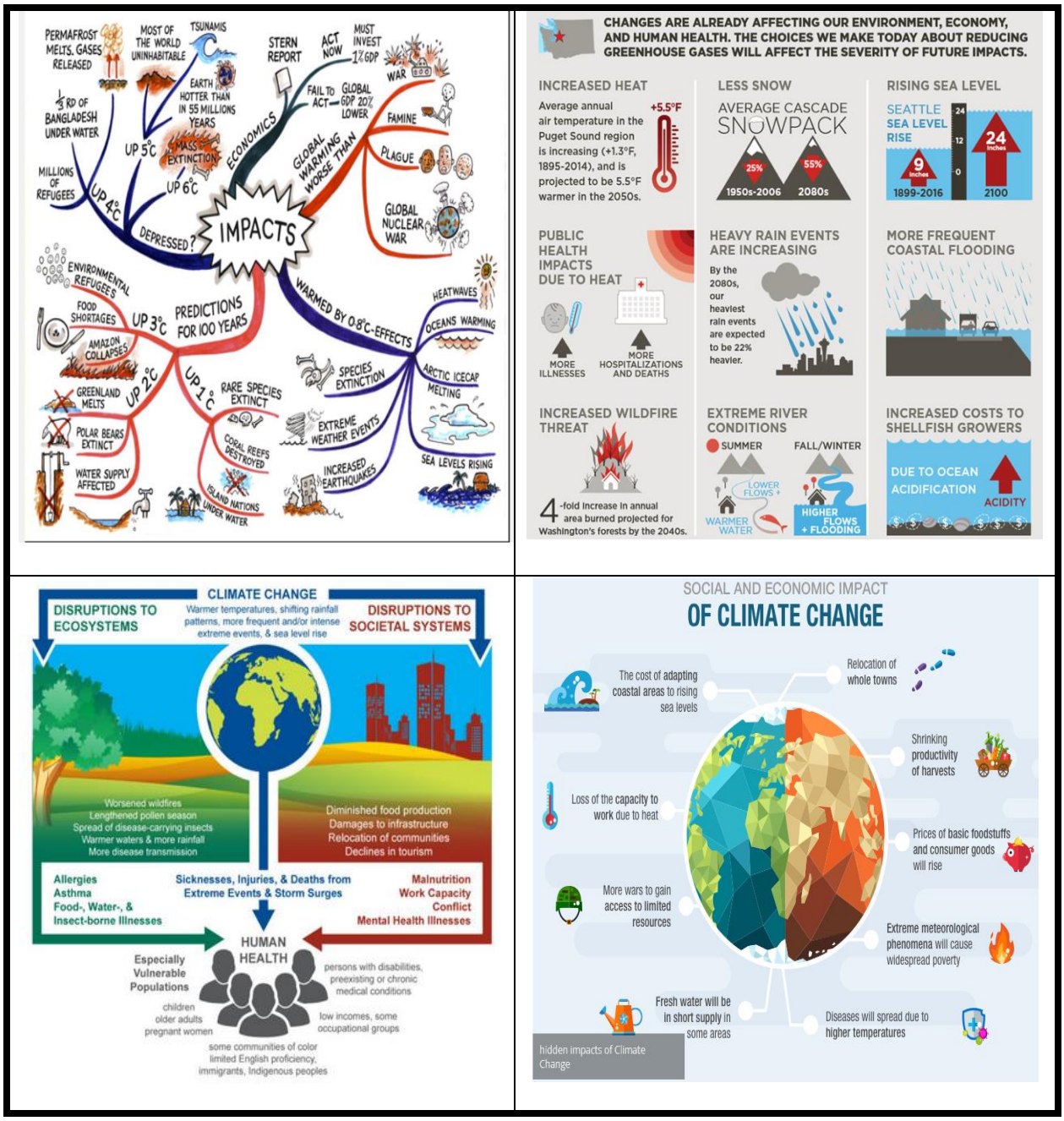
[175] "Drug Pollution," https://en.wikipedia.org/wiki/Drug_pollution
[176] "Pharmaceutical Residues in Hospital Wastewater," *Health Care without Harm Europe*, July 2021, https://noharm-europe.org/articles/news/europe/pharmaceutical-residues-hospital-wastewater.
[177] S. Gibbens, "Meat Production Leads to Thousands of Air Quality-Related Deaths Annually," *National Geographic*, May 2021, https://www.nationalgeographic.com/environment/article/meat-production-leads-to-thousands-of-air-quality-related-deaths-annually.
[178] P. Nicolopoulou-Stamati, S. Maipas, C. Kotampasi et al., "Chemical Pesticides and Human Health: The Urgent Need for a New Concept in Agriculture," *Frontiers of Public Health* 4 (2016): 148, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4947579/.
[179] N. Donley, "The USA Lags behind Other Agricultural Nations in Banning Harmful Pesticides," *Environmental Health* 18 (2019): 44, https://ehjournal.biomedcentral.com/articles/10.1186/s12940-019-0488-0.

destroyed. Some of its impacts (see Figure 9.3), which differ between various global regions, include the following:

- Increased atmospheric heat with resulting droughts and reduced ability to produce foods, scorching heatwaves with serious public health impacts, and increased risk of wildfires;
- Increased oceanic temperature, intensifying hurricanes and storms, affecting meteorological event such as El Niño and La Niña, and threatening marine life and global fishing;
- Melting polar and high mountain range glaciers, consequently raising sea and ocean levels, with disastrous results for many coastal cities and areas;
- Melting mountain snowpacks resulting in reduced annual water supplies, affecting both agricultural and metropolitan areas;
- Heavy rain and storm events, with more frequent floods, which eventually may make major parts of countries (e.g., Bangladesh) uninhabitable;
- Extreme rivers and water resource fluctuations between summer and winter.

These effects are summarized in Figure 9.3.

Figure 9.3
SOCIAL AND ECONOMIC IMPACTS OF CLIMATE CHANGE



Source: A. A. Beg, "10 Signs One Should Look around to Ascertain the Impacts of Climate Change," *The Indian Wire*, April 2021, https://www.theindianwire.com/environment/10-signs-one-should-look-around-to-ascertain-the-impacts-of-climate-change-310185/.

According to the World Health Organization, climate change is the single biggest health threat facing humanity:[180]

- It affects the social and environmental determinants of health—clean air, safe drinking water, sufficient food and secured shelter.
- Between 2030 and 2050, climate change is expected to cause approximately 250,000 additional deaths per year, ranging from malnutrition to malaria and diarrhea to heat stress.[181]
- The direct damage costs to health (i.e., excluding costs in other sectors such as agriculture, water and sanitation) is estimated to be between USD$2–4 billion per year by 2030.
- Areas with weak health infrastructure—mostly in developing countries—will be the least able to cope without assistance to prepare and respond.
- Reducing emissions of greenhouse gases through better transportation, food and energy-use choices can slow the climate change and result in improved health, particularly through reduced air pollution.

Climate change will significantly impact the distribution and extent of the environmental factors, as well as weaken the efforts of society to respond to them. Whereas it is likely that its impacts will affect countries and regions differently, the overall impact is almost certainly negative. This is especially relevant as the distribution of deaths (e.g., from air pollution, warming and droughts) varies widely by region as well, with emerging economies most affected. Indeed, as the Society of Actuaries found, "worries about climate change impacting retirement are highest among Millennials … [who believe it] will impact their health, increase likelihood of damage to property, and influence where they will live in retirement."[182] However, mitigating measures (e.g., a move from carbon-fired power stations to renewable energy, and the move from carbon-fuel driven cars to electric cars) are likely to have a positive impact on air quality and mortality.

[180] World Health Organization, "Climate Change and Health," October 2021, https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health.
[181] To illustrate: Heatwaves are among the most dangerous natural hazards, with more than 166,000 deaths from 1998 to 2017, including more than 70,000 in the 2003 European heatwave, according to the WHO: "Heatwaves," 2022, https://www.who.int/health-topics/heatwaves#tab=tab_1.
[182] Society of Actuaries, "Financial Perspectives on Aging and Retirement across the Generations," May 2021, https://www.soa.org/resources/research-reports/2021/generations-survey/.

SUMMARY TABLE for FUTURE MORTALITY - CHAPTER 9 - ENVIRONMENT			
Sub-Driver	**Near-Term (1-5 years) Impact**	**Longer-Term Future Impact**	**Comments**
Overall			Environmental quality is deteriorating with economical and natural resource shortages and hardships, and it seems extremely difficult to reverse (or even slow) this trend
Pollution			The industrial world is fast polluting the environment, over-consumption may lead to the ruin of the earth's resources and mountains of trash. Metropolitan areas are particularly polluted and hard to clean.
Chemicals			Outcomes of modern industrial activities, coupled by over-consumption of medications, plastics, pesticides, etc.
Climate Change			This is potentially an ecological disaster, with heatwaves, droughts, famines, floods, and more, which may make some of the earth inhabitable and destroy much of the food supply
Note: The evaluations reflect the authors' opinion, rather than a scientifically measurable comparison.			
Mortality Legend:	**Increasing: high**  **low**  **;**	**Decreasing: high**  **low**  **;**	**or** 

10. Catastrophes

A catastrophe is an unusually severe widespread natural, biological or man-made disaster, often large and sudden, and usually affecting a large group of individuals.[183] It can consist of a singular event or a series of events, which may create damage of immense proportions that is often accompanied by destruction of assets and/or loss of life. A catastrophic event could be either momentary or of lasting duration; it could be predictable (e.g., due to repeated occurrences in certain geographic zones or when certain weather patterns develop) or unpredictable (e.g., an explosion of a building that contains poisonous substances that are released into the environment). It could be limited to a specific geographical area or covering wide regions, affecting (relatively) small or large groups of people. Examples of catastrophes include hurricanes, floods, earthquakes and terrorist attacks. Catastrophes affect mortality, either as a momentary spike in mortality (such as a tornado) or as a longer-term impact on the overall trend of mortality (such as the contamination of living areas leading to increased deaths over time).

All people are subjected to the health and mortality risks of catastrophes, but for obvious reasons the aged and frail are particularly vulnerable (living alone, isolated, unable to seek safety or move). As Mutter and Brand note, after hurricane Katrina "fully 64 percent of deceased victims … were over 65 years old in a population in which that age group represented only about 15 percent … Mortality rates for those over 75 were even higher."[184]

10.1 NATURAL CATASTROPHES

World history is filled with natural catastrophes. These may be local storms or earthquakes with a few sporadic cases of death and with little impacts on mortality. However, from time to time large cataclysms (such as Indonesia's 2004 Banda Aceh tsunami) occur, causing death for large numbers of people in a short time (though usually mortality returns to normal after the catastrophe passes). Also, there are natural cataclysms such as the Yucatan's asteroid impact 66 million years ago, which is likely to have led to the extinction of the dinosaurs, or colossal volcanic eruptions capable of causing a mega-catastrophe, with global environmental effects (which in the worst case could make the world uninhabitable).

Individual natural catastrophes can also be recurrent, for example, floods or tornadoes that regularly or annually hit an area. In these cases, annual mortality can be calculated, and a trend analysis may reveal the effects on the long-term total mortality of such an event, for example, that the impact of natural phenomena becomes stronger with time.

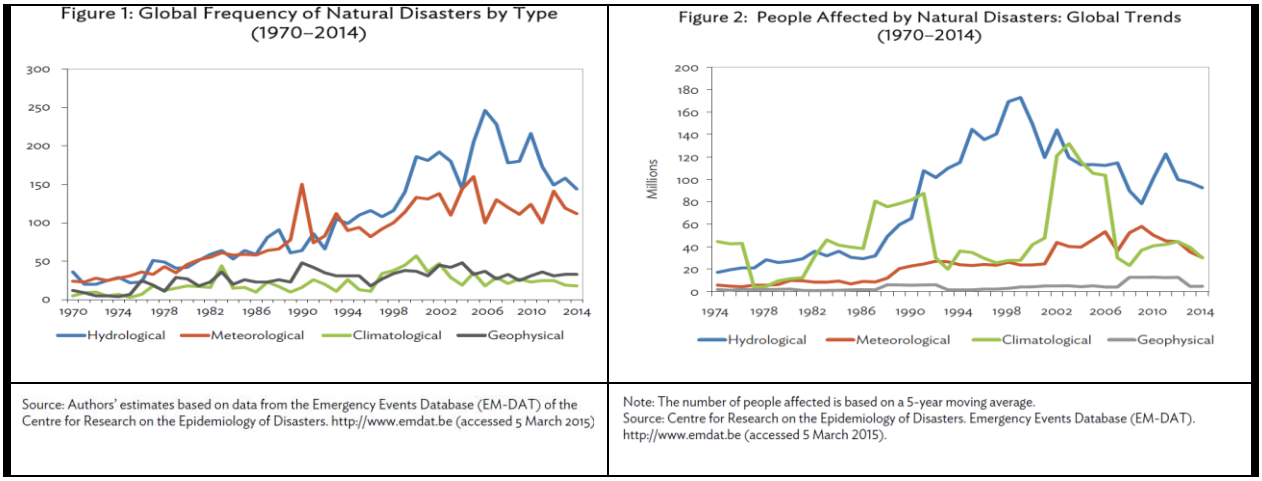
Thomas and Lopez reported in 2015 that in the last four decades the frequency of natural disasters increased almost threefold, from more than 1,300 events in 1975–1984 to more than 3,900 in 2005–2014. (Figure 10.1).[185] The number of hydrological and meteorological events increased sharply, with the annual number of Category 5 hurricanes tripling between 1980 and 2008. Since 2000, more than 1 million people worldwide have died from natural disasters, with the cost of damage estimated at more than $1.7 trillion. From 1970 to 2008, over 95% of deaths from natural disasters occurred in developing countries. However,

[183] This definition is a conglomerate of several definitions provided by a Google search.
[184] John C. Mutter and Kyle Mesa Bernard, "Climate Change, Evolution of Disasters and Inequality," in *Human Rights and Climate Change*, ed. Stephen Humphreys (International Council of Human Rights, 2010), p. 281.
[185] V. Thomas and R. Lopez, "Global Increase in Climate-Related Disasters," Asian Development Bank Economics Working Paper Series No. 466, 11/2-15, https://www.adb.org/sites/default/files/publication/176899/ewp-466.pdf.

clear trends should not be expected in natural disaster impacts, as one extreme weather event such as the Category 3 hurricane Sandy can muddle trends and break existing records for damage and destruction.

Figure 10.1

GLOBAL FREQUENCY AND NUMBER OF PEOPLE AFFECTED BY NATURAL DISASTERS, 1970–2014



Source: V. Thomas and R. López, "Global Increase in Climate-Related Disasters," Asian Development Bank Economics Working Paper Series No. 466, November 2015, https://www.adb.org/sites/default/files/publication/176899/ewp-466.pdf.

In the rest of this section, some major types of natural disasters are more succinctly described.

10.1.1 TORNADOES AND HURRICANES

Tornadoes[186] are short-duration vertical funnels of rapidly spinning air, born in thunderstorms, with top winds of up to 250 miles (400 km) per hour and pathways of up to a mile (1.6 km) wide and 50 miles (80 km) long. They occur around the world, but the most powerful and destructive occur in the Tornado Alley[187] in the central U.S., with an average annual death toll of 60, though the U.S. deaths per million have declined over the years 1875–2012.[188] Tornadoes can be forecast fairly easily with precise weather observation equipment, thus usually preventing large numbers of casualties; however, this is not always the case. Large tornadoes can create massive destruction in a widespread area, especially when combined with flooding (as has happened in China and Bangladesh).

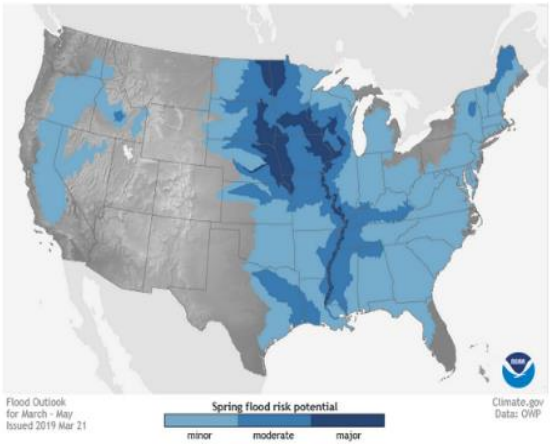
Large storms with a diameter of hundreds of miles are often generated in tropical ocean regions, with their high evaporation rates and water temperatures. These are called hurricanes in the Atlantic Ocean, cyclones in the South Pacific and Indian Oceans, and typhoons in the northwest Pacific Ocean. Their large area of coverage and their relatively slow motion (with duration measured in days) makes them a major hazard with significant economic and mortality losses.

[186] "About Tornadoes," National Weather Service, NOAA, April 2022, https://www.weather.gov/ffc/torntext.
[187] Tornado Alley, https://en.wikipedia.org/wiki/Tornado_Alley.
[188] "US Annual Tornado Death Tools, 1875–Present," NOAA, May 2013, https://blog.nssl.noaa.gov/nsslnews/2009/03/us-annual-tornado-death-tolls-1875-present/.

10.1.2 FLOODS AND MUDSLIDES

Flooding is caused by rising water level due to storms and heavy rain, snow melt, rising level of sea water, tsunamis or other causes. During the rainy season flood plains can be created and affect very large areas of land and populations, as seen in the NOAA March–May 2019 Flood Prediction Map for the U.S. (Figure 10.2). Floods may also be highly deadly, a happened in China, with 1–4 million deaths in 1931, 1–2 million in 1887, and 500,000–800,000 in 1938.

Figure 10.2
U.S. 2019 FLOOD PREDICTION MAP



Source: "NOAA: 2019 Flood Prediction Map for United States," https://unofficialnetworks.com/2019/03/22/2019-flooding-prediction/.

Floods and heavy rain often cause landslides[189] when masses of rock, earth, or debris move down a slope. Mudslides (mostly fast-moving debris flowing in channels) are due to disturbances in the natural stability of a slope; they may be generated by floods, heavy rain, earthquakes and/or volcanic eruptions. Areas with reduced vegetation due to wildfires or human modifications such as deforestation are particularly vulnerable. Floods and slides can pollute waterways and water planes, destroy infrastructure and threaten the health of the population through food shortages and traumas. In the U.S. floods and landslides result in 25–50 deaths annually.

10.1.3 DROUGHTS AND WILDFIRES

A drought is a natural disaster due to the shortage of water in a region, due to below-average precipitation, lack of surface water (e.g., low rivers or insufficient melting snow), lack of ground water, or lack of water because of human-directed diversion to other uses or regions. A drought may last months or years. Droughts cause water and food crises or even famine, and create natural, agricultural and economic disruptions. Overall, droughts have been known to lead to population migration and/or armed conflict. These conditions naturally affect the health of the population and increase the mortality rate. As the World Meteorological Organization reported, "from 1970 to 2012 droughts caused almost 680,000 deaths, due to severe African droughts of 1975, 1983 and 1984."[190]

[189] Centers for Disease Control and Prevention, "Landslides and Mudslides Fact Sheet," January 2018, https://www.cdc.gov/disasters/landslides.html.
[190] Water Meteorological Organization, "Drought," 2022, https://public.wmo.int/en/our-mandate/water/drought.

A major negative outcome of droughts is the increase in the number and intensity of wildfires. Over the last decades, the western U.S. has faced severe drought conditions, which raised average temperatures on the one hand and led to very dry vegetation and forests on the other. As a result, the annual area burned in the U.S. between 1991 and 2020 increased roughly by 192,000 acres per year, and the annual area burned in the western U.S. between 1970 and 2000 in large forest fires grew by about 1,200%.[191] In 2020 more than 33,000 eastern U.S. fires burned approximately 700,000 acres, while almost 26,000 western U.S. fires burned approximately 9.5 million acres.

10.1.4 VOLCANIC ERUPTIONS

A volcano is a location from where molten and gaseous substances from underground reservoirs connected to a crater, vent or fissure can be released. A volcanic eruption could vary from relatively low-risk lava flow (like many Hawaiian eruptions) to more high-risk eruptions where pyroclastic ejecta fly high into the air and destroy towns, the mountain where they are coming from, and even islands (e.g., the 79 AD destruction of Pompeii and the 1883 Krakatoa eruption).

Volcanoes also affect mortality through earthquakes that occur before, during and after the eruption, which can modify the geography with resulting flooding and destroy infrastructures as well as communities. The hot lava flow can burn forests and meadows, as well as human habitats and infrastructures, and melt snow and glaciers, which results in mudslides and floods. The hot, fast-moving (100 to 700 kilometers/hour) pyroclastic volcanic gases post-eruption are lethal, as the destruction of Pompeii proves. Further, large eruptions can have large-scale effects, blocking the sun and cooling the atmosphere, potentially globally, and can lead to crop failures and famines, thus threatening survival.

The earth has about 4,000 volcanoes, of which 450 have erupted in recorded history. Most volcanoes are located in tectonic plate junctions and are especially prevalent in the Pacific "ring of fire." The largest fatal volcanic eruption was Mount Tambora in 1815, the "year without a summer," with deaths estimated from 71,000 to 250,000. Three eruptions since 1883 claimed 20–30,000 deaths each, and all other recorded eruptions had a much smaller number of fatalities.[192]

10.1.5 EARTHQUAKES AND TSUNAMIS

Historically, floods, droughts and epidemics dominated disaster deaths, but earthquakes had their share as seen in Figure 10.3.[193]

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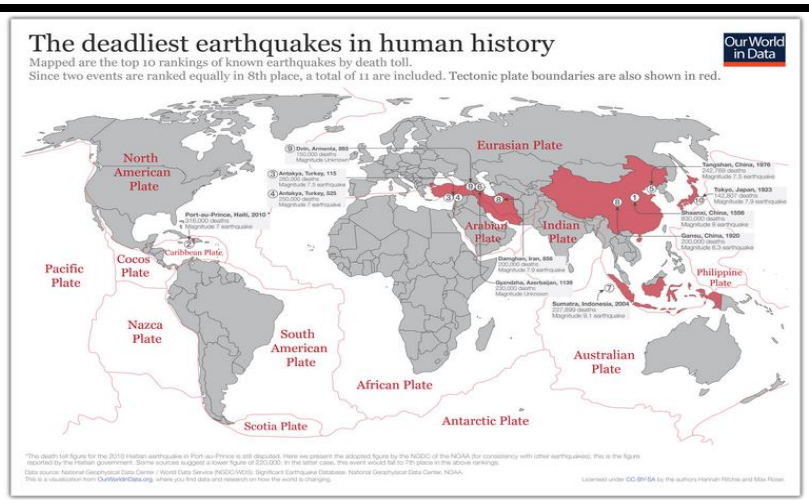
[191] M. Wibbenmeyer and A. McDarris, "Wildfires in the United States 101: Context and Consequences," *Resources for the Future* 70 (July 2021), https://www.rff.org/publications/explainers/wildfires-in-the-united-states-101-context-and-consequences/.
[192] "List of Volcanic Eruptions by Death Toll," https://en.wikipedia.org/wiki/List_of_volcanic_eruptions_by_death_toll.
[193] H. Ritchie, "What Were the World's Deadliest Earthquakes?," *Our World in Data*, October 2018, https://ourworldindata.org/the-worlds-deadliest-earthquakes.

Figure 10.3
DEADLIEST EARTHQUAKES IN HUMAN HISTORY



Ranking	Location	Year	Estimated death toll	Earthquake magnitude
1	Shaanxi, China	1556	830,000	8
2	Port-au-Prince, Haiti	2010	316,000	7
3	Antakya, Turkey	115	260,000	7.5
4	Antakya, Turkey	525	250,000	7
5	Tangshan, China	1976	242,769	7.5
6	Gyzndzha, Azerbaijan	1139	230,000	Unknown
7	Sumatra, Indonesia	2004	227,899	9.1
8	Damghan, Iran	856	200,000	7.9
8	Gansu, China	1920	200,000	8.3
9	Dvin, Armenia	893	150,000	Unknown
10	Tokyo, Japan	1923	142,807	7.9

Source: H. Ritchie, "What Were the World's Deadliest Earthquakes?" October 5, 2018, *Our World in Data,* https://ourworldindata.org/the-worlds-deadliest-earthquakes.

An earthquake is an intense shaking and vibration of the earth's crust, generated by a sudden slip of two tectonic plates. The plates try to move against each other, but they are usually restrained by friction at their edges, which is called a fault. When the stress on the fault overcomes the friction, the earthquake releases seismic waves of energy through the earth's crust that causes the shaking that can be felt. The Global Seismic Hazard Map overlaps the "ring of fire" noted above, as well as major young mountain ranges (e.g., the Himalayas), as the weak points in the earth's lithosphere where the faults exist.[194] These are the same locations where it is easier for volcanic magma to flow out from inside the earth.

A tsunami, or a seismic sea wave, is caused by a displacement of a large volume of water by an underwater disruption (e.g., an earthquake, volcanic eruption, landslide, glacier calving, meteorite impact or man-made explosion). On the open sea a tsunami wave travels at 300 to 600 miles per hour, at a height of usually less than three feet. When the wave reaches shallow water near the coast, it might rise to a 160-feet-high wall of water that rushes inland and then rushes back to sea, pulling with it everything it encounters. The latest large tsunami, Indonesia's Banda Aceh tsunami,[195] occurred in the Indian Ocean on December 26, 2004, and was caused by an undersea 9.1–9.3 magnitude earthquake. It wrecked large areas of southeast Asian shores, killed more than 225,000 people in 14 countries, and forced millions to abandon their homes.

10.1.6 ELECTROMAGNETIC PULSE

An electromagnetic pulse (EMP) is a transient electromagnetic wave similar to radio waves, resulting from secondary reactions occurring when nuclear gamma radiation is absorbed in the air or the ground (e.g., following a nuclear explosion or a solar storm). It might produce an electric field of thousands of volts, much higher than that of a radio signal, which usually produces a thousandth of a volt or less in a receiving antenna. At the same time, it is a single pulse of energy that disappears completely in a fraction of a

[194] A. Alden, "The World's Major Earthquake Zones," October 2018, https://www.thoughtco.com/seismic-hazard-maps-of-the-world-1441205.
[195] "Indian Ocean Tsunami of 2004," *Britannica*, https://www.britannica.com/event/Indian-Ocean-tsunami-of-2004.

second, similar to the electric signal from lightning, though its rise in voltage is typically a hundred times faster. Consequently, most lightning protection equipment acts too slowly to be effective against an EMP, and the EMP's interference can disrupt and damage communications and electronic equipment, and even collapse and destroy the functionality of a country's electrical, electronic and communication systems.

10.1.7 METEORITES

Thousands of small meteoroids, or rock fragments, enter the atmosphere every year, but usually they burn up there and cause no destruction. Larger meteors reach and impact the earth's surface with a frequency of about once every thousand years, with effects discernible from long distances. The 1908 Tunguska meteor, the largest in recorded history, exploded in the atmosphere with an estimated impact of 10–20 megatons of TNT and flattened 80 million trees in the Siberian forests. The 2013 Chelyabinsk meteor injured 1,700 people in the southern Ural region when it exploded about 30 kilometers above the earth with the power of 400–500 kilotons of TNT. Historically, the 150 kilometer-wide Chicxulub impact crater in the Yucatan Peninsula in Mexico was created about 66 million years ago by an 11 to 80 kilometer-wide asteroid or comet, and is thought to have affected the global climate as well as caused the extinction of most of the life on earth including the dinosaurs.

NASA, aware of the risks posed by asteroids and meteors, started a Near-Earth Object (NEO) Observation Program.[196] Its goal is to find, track and characterize at least 90% of the space rocks that are 140 meters and larger in size and thought to pose a risk of major devastation to Earth.

10.2 MAN-MADE CATASTROPHES

Nature undoubtedly has the most frightening and disturbing catastrophes, but humans can also create catastrophes, such as genocides or intentional famine (e.g., Stalin's in Ukraine in the early 1930s). Note that in World War I, between 25 and 40 million people died, in World War II between 70 and 85 million people died (the estimates vary widely), and the number of injured and displaced is countless. The September 11, 2001, terrorist attack in the U.S. was the costliest man-made disaster in history, resulting in almost 3,000 direct and 1,000 indirect fatalities, with an estimated cost of $33–36 billion.[197]

According to L. Coleman, who studied the frequency, nature and changes in man-made disasters in industrialized countries during the past century, as shown in Figure 10.4, the analysis shows an exponential growth in disaster frequency, largely due to traditional hazards (such as fires).[198] At the same time, the average severity has declined, and recent disaster fatalities are at least an order of magnitude lower than those occurring in the early part of the 20th century. The study also demonstrated that regulatory oversight and internal governance processes were inadequate to ensure effective management of modern industrial risks.

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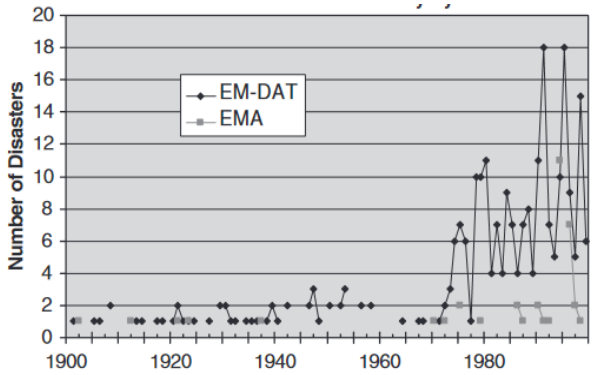
[196] NASA, "Near-Earth Object Observations Program," NASA Planetary Defense, November 2021, https://www.nasa.gov/planetarydefense/neoo.

[197] J. Bram, J. Orr and C. Rapaport, "Measuring the Effects of the September 11 Attack on New York City," Federal Reserve Bank of New York, 2002, https://www.newyorkfed.org/research/epr/02v08n2/0211rapa/0211rapa.html.

[198] L. Coleman, "Frequency of Man-Made Disasters in the 20th Century," *Journal of Contingencies and Crisis Management* 14, no. 1 (March 2006), http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.476.3458&rep=rep1&type=pdf.

Figure 10.4

MAN-MADE DISASTERS IN THE 20TH CENTURY



EM-DAT: a global emergency disasters database compiled by the Center for Research on the Epidemiology of Disasters (CRED) at Universite´ Catholique de Louvain in Brussel.
EMA: a national register of disasters maintained by Emergency Management Australia
Source: L. Coleman, "Frequency of Man-Made Disasters in the 20th Century," *Journal of Contingencies and Crisis Management* 14, no. 1 (2006): 3–11, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.476.3458&rep=rep1&type=pdf.

Human-caused catastrophes and their mortality and other risks outcomes can be classified into two groups: intentionally caused catastrophes, such as a terror attack aimed at harming and killing people or destroying property, and unintentional catastrophes driven by human behavior, inattention or error. In the rest of this section, some major types of man-made disasters are succinctly described.

10.2.1 TERRORISM

Terror is the use of violence and fear to achieve a (usually) ideological aim and is generally driven by religious sentiments (e.g., Shiite versus Sunni Muslim wars over generations or Protestant and Catholic conflict in early modern Europe), ethnic motivations (as was the case in the Rwandan conflict between the Hutu and Tutsi in 1994), underdeveloped versus developed nations (as is the case with the terrorist group ISIS over the last decade) or a combination of these. It is usually directed against civilians and (relatively) unprotected organizations with the objective of frightening them and shattering their feelings of safety and security. Terror activity and its impact have increased with the recent flourishing of "immediate" media coverage and the social networks.

Fighting terror is difficult and often involves a reduction in personal rights and disruption of civil order, as individual acts of terror can be unpredictable, and methods used by terrorists are difficult to anticipate. Furthermore, technical advancements have made society, individuals, infrastructure facilities and even governments (as evident by recent elections in the U.S. and the EU) more dependent on technological solutions, thus creating a new vulnerability—cyberattacks—that can be exploited for malicious purposes. Indeed, cyberterrorism and cyberwar (by organized armies) are on the rise.

10.2.2 WAR AND GENOCIDE

War is a disaster created by humans and driven by many reasons. Among them are disagreements between countries, the desire to gain territories or resources, animosity between nations and the ego of leaders. War often reduces or removes ethical and human constraints, brings out the worst in the combatants, ruins societies and their habitats, and is by itself one of the deadliest threats to human survival and existence. The number of fatalities injured and displaced in wars in the 20th century, the number of people killed in the Hiroshima and Nagasaki nuclear attacks, the fire storms created by indiscriminate bombing of

cities such as Dresden, and the deforestation and cancer brought pm by the use of Agent Orange in the Vietnam War are a few of the testimonies to the deadliness of wars.

10.2.3 POLICY AND GREED

Many catastrophes are the outcomes of beliefs, "good deeds" and the greed of people who were put in positions with insufficient considerations of the possible future outcomes of these actions and without considering the costs to other segments of the population (or the victims). These actions all can (or did) result in additional mortality, whether or not that was the intended outcome. Some examples are the following:

- History and politics are filled with projects conceived with short-term objectives that "blew up" several years later. A good example is asbestos: That "has been used for thousands of years, but only at a large industrial scale for about 100–150 years."[199] Then it was linked to asbestosis and later found to be a strong carcinogen, with an "estimated global annual number of 255,000 deaths."
- Industrial and commercial institutions operate legally to increase the wealth of the stockholders, regardless of the costs to society at large and the population. History and the media are filled with stories about the government-capital-power (political) connections, and the outcomes to the economy, the population and its well-being. The carbon-energy (i.e., gas and oil) industry, and its continuing funding of carbon-energy projects and economy, are a good illustration of that phenomenon.
- Egypt's 1960 Aswan High Dam on the Nile was built to control flooding, provide increased water storage for irrigation and generate hydroelectricity, but eventually it impeded the flow of nutrient- and mineral-rich water to the floodplain and delta of the lower Nile, becoming a long-term threat to the Egyptian crops, agriculture and economy.
- Similarly, the Aral Sea, formerly the fourth largest lake in the world, began shrinking in the 1960s and completely dried up by 2009, after the rivers that fed it had been diverted by Soviet irrigation projects.
- Last but not least, the industrialization of the world over the last several centuries brings us to recent global climate change and global warming, with their mortality and health costs, that have been extensively discussed in section 9.3.

10.2.4 OVERPOPULATION AND OVERUSE OF LIMITED RESOURCES

The world population is increasing quickly, and if this trend continues, the earth's resources will not be sufficient to meet the needs of the growing population. Overpopulation could make living conditions untenable, may result in famine and declining water supplies and resources, and cause conflicts between population groups and migrants from poor countries and regions.

[199] S. Furuya, O. Chimed-Ochir, K. Takajashi et al., "Global Asbestos Disaster," *International Journal of Environmental Research and Public Health* 15, no. 5 (May 16 2018): 1000, https://pubmed.ncbi.nlm.nih.gov/29772681/.

10.2.5 ACCIDENTS

Many environmental disasters and catastrophes are man-made, due to either inattention to possible outcomes or to intentional disastrous activities as noted above. Real accidents are usually due to design, operational or procedural errors; some notorious ones are the following:[200]

- Nuclear power plant accidents: Most notable is the Chernobyl, Ukraine, plant explosion in April 1986, which resulted in more than 4,000 cancer deaths, 350,000 evacuees, and the creation of an exclusion zone of about 1,000 square miles. Next is the Fukushima Daiichi accident in Japan, where the plant was shut off on March 2011 by a 15-meter tsunami, following an offshore earthquake, with about 18,500 fatalities, 170,000 evacuees waiting to return home, and plant decommission of 30–40 years. Last but not least is the Three Mile Island accident in Pennsylvania, on March 1979, which resulted in more than $1 billion in clean-up costs over 14 years.
- In December 1984, a Union Carbide pesticide plant in Bhopal, India, accidently released a deadly chemical fog of isocyanate gas that killed more than 5,000 people, forced more than 50,000 people to need treatment, and exposed more than 500,000 people to the gas. There are claims that since the accident an additional 20,000 lives have been lost because of the leak, making it potentially the worst industrial chemical disaster ever. Fortunately, many of these incidents have been caught on a timely basis to avoid a serious outcome, such as the ones just described.
- In the cold winter of 1952, the polluted air of London, combining nitrogen oxides, sulfur dioxide and soot pollution, covered the entire London area in a black cloud that claimed more than 12,000 fatalities.
- Collapse of dams create dangerous forces (the water that will be spilled once the dam collapses), but luckily is a rare event. In August 1975, the Banqiao Reservoir Dam in Henan Province in China collapsed, resulting in more than 170,000 fatalities and 11 million people who lost their homes.
- The 70-acre Love Canal neighborhood of Niagara Falls, New York, was used during the 1940s as a dump area for chemical dye and solvents as manufacturing byproducts. As a result, the occupants of the community that was built in 1953 suffered many health issues. In 2004 the resulting Superfund Law cleanup forced the demolition and evacuation of the community. Although this is a case—one among many—of chemical spills and dumps, we consider it an "accident," as dumping was considered "normal" in the 1940s, and the resulting health risk was an unexpected accident.
- Oil spills, from container ships, wells and oil searching platforms, or oil and gas pipes have created significant damage to marine life, coastlines and nature. Among the most notorious ones are the 1991 Gulf War Oil Spill, the April 2010 Deepwater Horizon Oil Spill in the Gulf of Mexico, the *Atlantic Empress* and the *Aegean Captain* collision in July 1979 in the Caribbean Sea, and the March 1989 *Exxon Valdez* oil spill in the Prince William Sound Bligh Reef in Alaska.

10.2.6 FUTURE THREATS

Developments during the last few centuries increased life expectancy and health, but at the same time changed the risk and catastrophe profile of the world, increasing probabilities for existing and new catastrophes. One example of this might be the ongoing development toward an automated future (self-driving cars, artificial intelligence applications etc.), which while increasing reliance on technical

[200] "Top 15 Worst Environmental Disasters Caused by Humans," *Conserve Energy Future*, 2022, https://www.conserve-energy-future.com/worst-environmental-disasters-caused-by-humans.php.

applications and infrastructure also creates new possible hazards, some of which are currently unpredictable. Some future changes that could occur include the following:

- Regional population densities have increased;
- Population growth is high and uncontrolled;
- Global travel and increased speed of travel facilitate the migration of both people and pandemics;
- The environment has changed, including changes in weather and severe pollution, leading to health issues;
- Interconnectedness has greatly increased the risk of fast-spreading cyberattacks and far-reaching computer-related accidents.

10.3 EPIDEMICS AND PANDEMICS

An epidemic is a widespread, out-of-control occurrence of a vector-borne infectious disease (such as influenza, COVID-19, AIDS, Ebola, SARS, Zika and measles) that actively spreads over a community, population or region at a particular time. A pandemic is an epidemic that spreads globally. Both an epidemic and a pandemic are "disease event" catastrophes.[201] Being "vector-borne diseases,"[202] these disease events are caused by pathogens such as parasites, fungi, viruses and bacteria, and can be transmitted by mosquitoes, sandflies and similar animal vectors, as well as humans. More than half of the infectious diseases affecting humans, including epidemics and pandemics, are zoonotic diseases that come from animals and insects. Every year there are globally more than 700,000 deaths from diseases such as malaria (more than 400,000) and other vector-borne diseases, which account for around 17% of all deaths from infectious diseases. Overall, more than 3.9 billion people in 128 countries are at risk.

Vector-borne diseases affect not only humans but also animals and plants. As Wilkinson et al. note, "animals and plant diseases pose a serious and continuing threat to food security and safety, national economies, biodiversity, and the rural environment."[203] That is, animal and plant diseases, in turn, have an impact on the human population's well-being and health, and consequently also affect mortality. Furthermore, new pathogens, as well as existing ones that mutate into a human virus strain, are discovered continuously (e.g., avian influenza), the result of which produces isolated breakouts each year.

Both epidemics and pandemics are defined by the pattern and speed of the disease's spread (i.e., the reproduction rate) and the size of the exposed or susceptible population (i.e., community size). These factors, in turn, as well as some other features of these catastrophes, determine the public health response to these diseases.[204] A complicating factor of a pandemic, as opposed to an epidemic, is the need for global cooperation of multinational health care authorities, as well as of travel and border regulators (such as airlines, airports and customs officials).

Finally, it should be noted that viral diseases cannot yet be fully prevented with medications, but their symptoms can be alleviated. For example, HIV is a fatal infection without treatment, and when it first

[201] Both epidemics and pandemics are referred here as "disease events," as a country's efforts to fight an epidemic within its borders are similar to the actions of the international community to fight a global pandemic.
[202] World Health Organization, "Vector-Borne Diseases," October 2017, https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases.
[203] K. Wilkinson, W. P. Grant, L .E. Green et al., "Infectious Diseases of Animals and Plants: An Interdisciplinary Approach," *Philosophical Transactions of the Royal Society B* 366 (2011): 1933–1942.
[204] T. Torrey, "Difference between an Epidemic and a Pandemic," April 2019, https://www.verywellhealth.com/difference-between-epidemic-and-pandemic-2615168.

appeared in the 1980s its effects were catastrophic.[205] But today, with correct medication it is more of a chronic disease. HIV is also a good example as of how a disease can strongly affect mortality in underdeveloped countries (such as in many African countries), as opposed to its impact on developed countries where treated HIV infections do not currently have a significant impact on population mortality.

SUMMARY TABLE for FUTURE MORTALITY - CHAPTER 10 - CATASTROPHES			
Sub-Driver	**Near-Term (1-5 years) Impact**	**Longer-Term Future Impact**	**Comments**
Overall	⟺	⟺	While unpredictable, humanity may be better prepared to deal with catastrophes and reduce casualty rates
Natural Catastrophes	⟺	⟺	Our increased ability to predict these, and better public preparadness, will diminsh, but not eliminate, their impacts
Man-made Catastrophes	⟺	⟺	Frequency of major wars with many casualties is decreasing, economical and political terrorism affecting societies is increasing, and chemical, biological, industrial, and other accidents are also increasing. The mortality severity of these threats is overall decreasing.
Overpopulation	↑	↑	While the developed world has below replacement fertility, the underdeveloped world is still fast growing, which can lead to reduced resources
Pandemics	⟺	⟺	Unpredictable, countered by societal and regulatory efforts and improved medical technology
Note: The evaluations reflect the authors' opinion, rather than a scientifically measurable comparison.			
Mortality Legend:	**Increasing: high** ⇈ **low** ↑ ;	**Decreasing: high** ⇊ **low** ↓ ;	**or** ⟺

[205] "History of the HIV Epidemic: Progress through Innovation and Activism," *Gilead*, September 2020, https://www.gileadhiv.com/landscape/history-of-hiv/?utm_id=iw_sa_15442187160_127739509142&utm_medium=cpc&utm_term=origin+of+hiv&gclid=EAIaIQobChMI9YS7tNuj-AIVOhTUAR2BsAtEEAAYASAAEgKqVfD_BwE&gclsrc=aw.ds.

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