Measuring Health and Disease in Populations

College of Health @ LEHIGH | Eric Delmelle February 9, 11, 23 2026

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Part 1: Comparing Health Events

Introduction

- **Definition of Health Events**: Disease outbreaks, chronic conditions, injuries, and health behaviors.
- **Importance of Comparisons**: Understanding disparities, identifying risk factors, guiding public health interventions.
- **Key Concepts**: Population health, epidemiology, and biostatistics.

Objectives of Population Health

Four Key Objectives:

1. **Describe**: Understand population-level health outcomes.
2. **Explain**: Identify determinants and drivers of health outcomes.
3. **Predict**: Anticipate future health trends and patterns.
4. **Control**: Implement interventions to improve outcomes.

Historical Context

Key Figures

- **John Snow**: Cholera outbreak mapping.
- **Ignaz Semmelweis**: Importance of handwashing.
- **Joseph Goldberger**: Nutritional causes of pellagra.

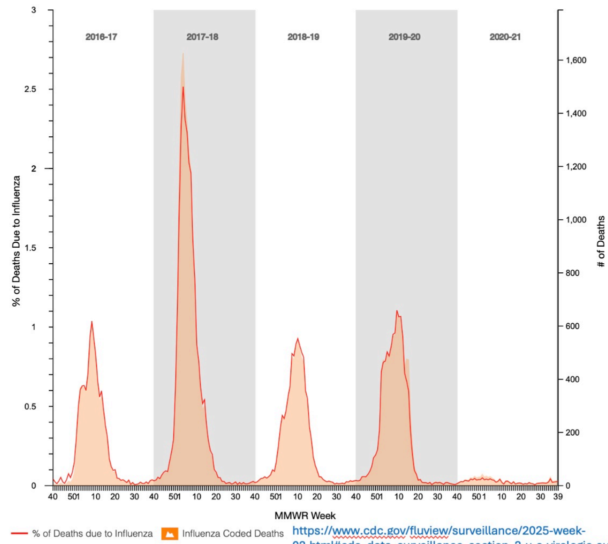
Types of Comparisons

Time-Based

Key Metrics:

- **Incidence**: New cases over time.
- **Prevalence**: Existing cases at a given time.

Pneumonia and Influenza Mortality from the National Center for Health Statistics Mortality Surveillance System

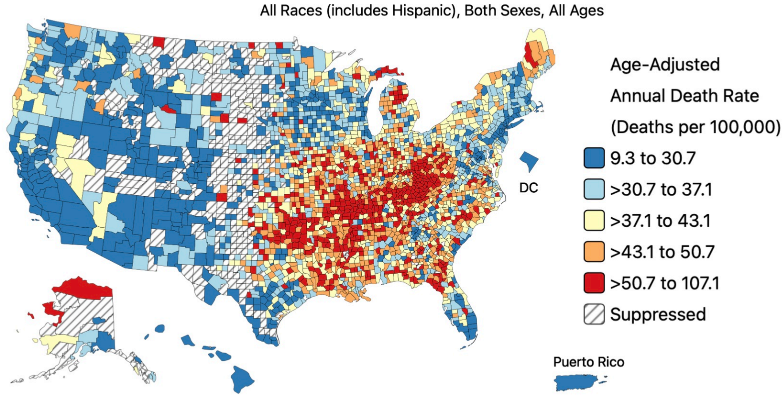


https://www.cdc.gov/fluview/surveillance/2025-week-02.html#cdc_data_surveillance_section_2-u-s-virologic-surveillance

Death Rates for United States by County

Lung & Bronchus, 2018-2022

All Races (includes Hispanic), Both Sexes, All Ages



https://statecancerprofiles.cancer.gov/

Place-Based

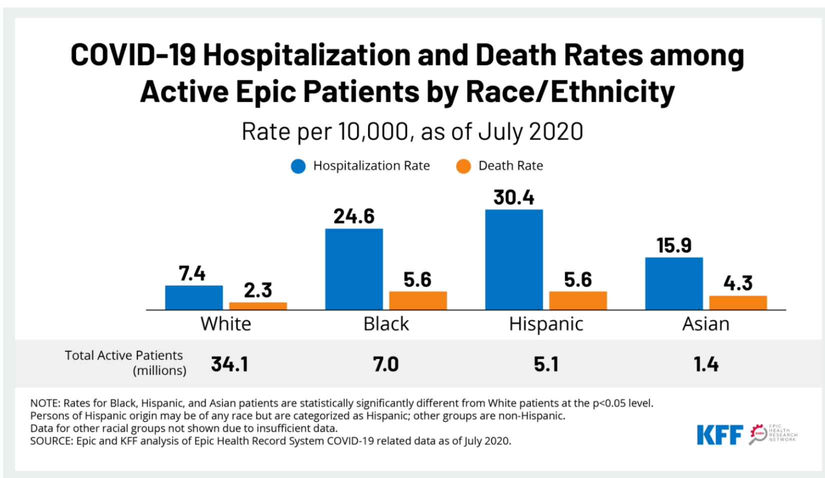
Example:

- **Urban vs. Rural Heart Disease Mortality**:
  - Urban: 50 per 100,000.
  - Rural: 75 per 100,000.

Group-Based

Example:

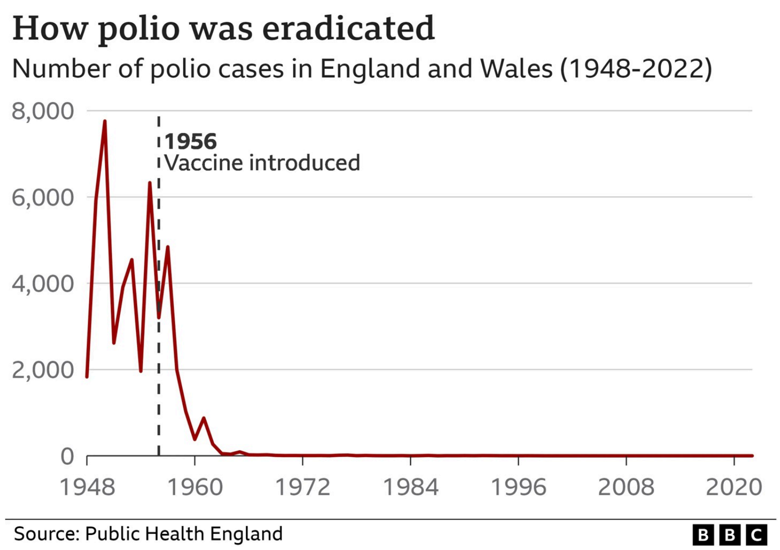
- Health disparities by race, age, and income.



Event-Based

Key Concept:

- Natural experiments: Before vs. after policy changes or interventions.



Additional Event-Based Example

Levels of Analysis

Frameworks:

- **Individual-Level**: Biostatistical and clinical trials.
- **Population-Level**: Geographic and demographic patterns.

Population vs. Community Health Assessments

Example:

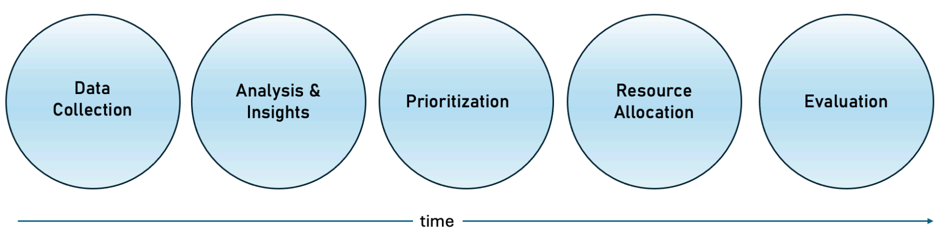
- Community: Identifying food deserts.
- Population: Obesity prevalence across counties.

Policy Implications

Using Comparisons to Drive Change:

1. **Set Priorities**: Identify at-risk groups (e.g., elderly, low-income communities).
2. **Develop Interventions**: Targeted programs (e.g., tobacco cessation).
3. **Advocate for Policy Change**: Use data for systemic reforms.

Visual:



Interactive Example

Dataset Example:

Population	Cases	Rate (per 100,000)
Urban	200	50
Rural	300	75

Prompt:

- "What does this suggest about resource allocation?"

Part 2: Measuring Health and Disease

Introduction to Measurement

Key Concepts in Measuring Health and Disease

- Definitions of incidence and prevalence.
- Importance of population health metrics.
- Ageing in the population
- Demographic transition
- Life table and life expectancy
- The importance to standardize

Incidence and Prevalence

Definitions

- **Incidence:** Number of new cases in a specified time period.
  - Formula: `(New cases during time period / Population at risk) × multiplier`.
- **Prevalence:** Total number of existing cases at a given time.
  - Formula: `(Existing cases / Total population) × multiplier`.

Differences

- Incidence: Measures risk; useful for studying causation.
- Prevalence: Measures disease burden; important for planning healthcare services.

Impact of New and Existing Cases

- **Prevalence Formula Relation:**
  - `Prevalence = Incidence × Duration of Disease`
  - check this youTube video
- **Factors affecting prevalence:**
  - **Increase:** Longer disease duration, improved survival without a cure.
  - **Decrease:** Shorter duration, high mortality rates, or prevention.

Rates, Ratios, and Proportions

- **Rate:** A measure of change per unit time (e.g., incidence density).
  - *pay attention to **rate instability***
- **Ratio:** Comparison of two numbers, unrelated (e.g., sex ratio).
- **Proportion:** A part of a whole (e.g., percentage of women in a study group).

Cumulative Incidence

- **Proportion** of an initially disease-free group of individuals who develop the disease within a specified period of observation.
  - *pay attention to* ***censoring*** (when individuals drop out or are lost to follow-up)

$$CI = \frac{\text{new cases}}{\text{number of individuals at start of the period}}$$

- Example: Start with **100 disease-free individuals**. After **one year, 10 develop the disease**.

$$CI = \frac{10}{100} = 0.10$$

- After **one year**, **10% of the population developed the disease**.

Incidence Density

- **Rate** that measures how often new cases of a disease occur while accounting for different lengths of time that people are at risk

$$ID = \frac{\text{new cases}}{\text{total person-time at risk}}$$

- Study follows **5 individuals**:
  - **Person A:** 2 years at risk
  - **Person B:** 3 years at risk
  - **Person C:** 1 year at risk
  - **Person D:** 4 years at risk
  - **Person E:** 2 years at risk
- **Total person-time at risk = 12 person-years**

Why different times?

- Developed disease
- Died (other causes)
- Lost to follow-up
- Study ended

Incidence Density

- **Total person-time at risk = 2 + 3 + 1 + 4 + 2 = 12 person-years**
- **New cases = 3**

$$ID = \frac{3}{12} = 0.25 \text{ cases per person-year}$$

- **0.25 cases per person-year** means that, on average, for every 4 people followed for a year, 1 will develop the disease.

Measures of Comparison

Key Metrics:

- **Age-Standardized Rates**: Adjusted to eliminate age structure differences.
- **Attributable Risk**: Measures the impact of specific risk factors on outcomes.

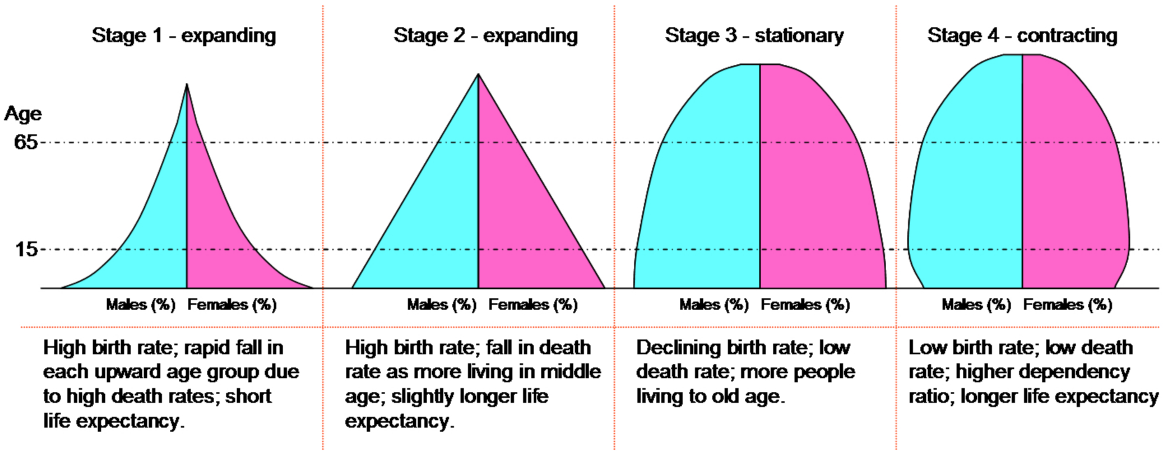
Demographic Changes and Health Metrics

- **Fertility Rate:** Key measure of reproductive behavior.
- **Mortality:** Affects life expectancy and health metrics.
- **Migration:** Alters population composition, health service demands.

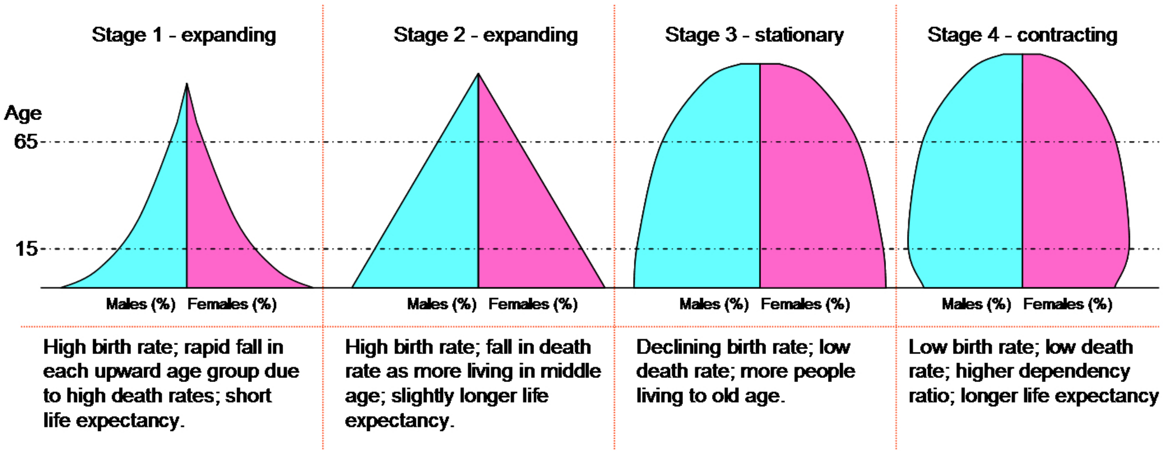
Population Structure

Age Pyramids

- Graphical representation of age and sex distribution.
- Shows aging trends, and reveals impact of demographic events like wars, migrations.



Age Pyramids

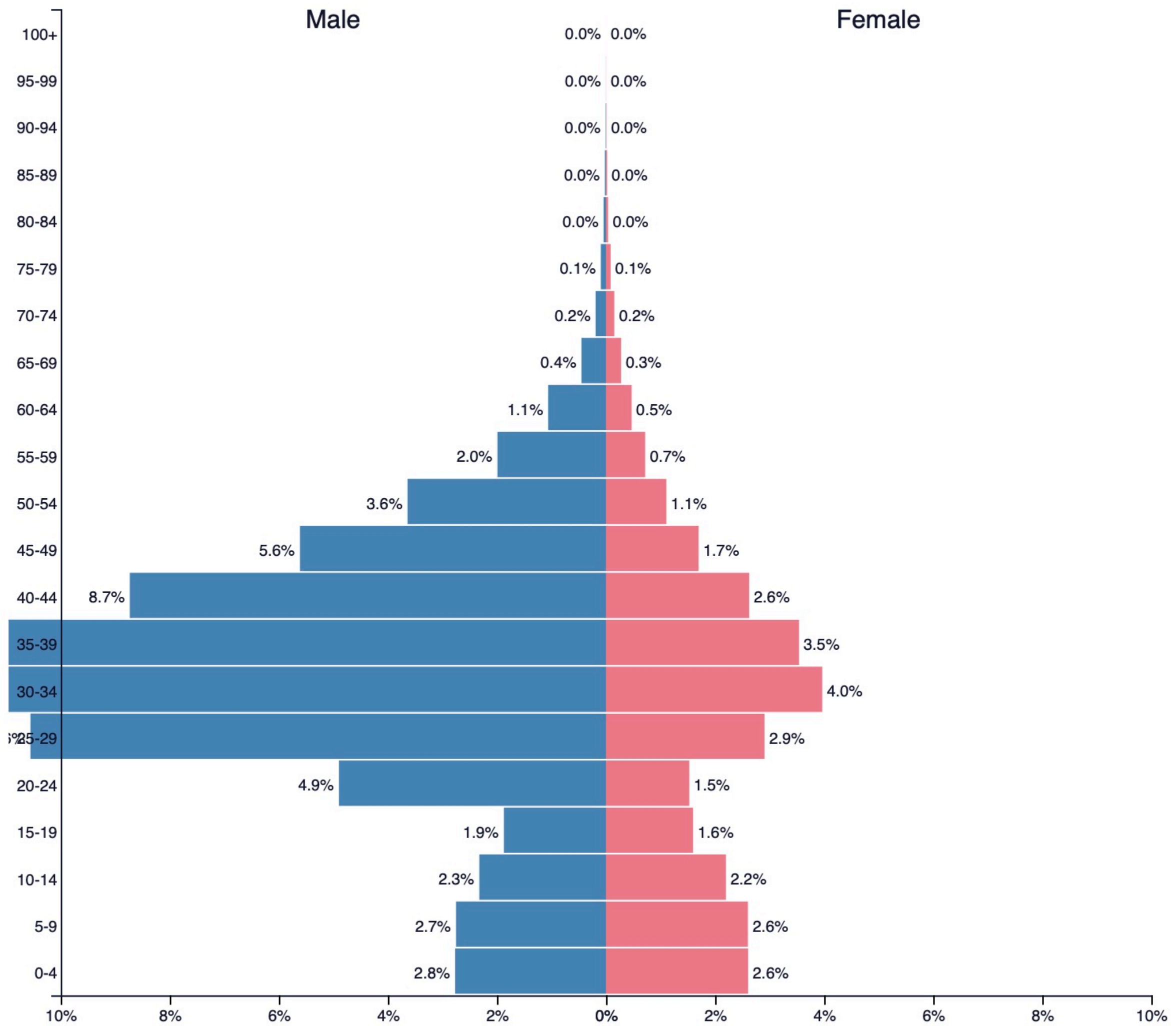


- **Developed Countries:** Narrow base, wider top (aging population).
- **Developing Countries:** Broad base, narrow top (younger population).
- Interactive pyramid.

Qatar and Japan Age Pyramids

Qatar

Japan



Male
Female
100+
95-99
90-94
85-89
80-84
75-79
70-74
65-69
60-64
55-59
50-54
45-49
40-44
35-39
30-34
25-29
20-24
15-19
10-14
5-9
0-4
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8.7%
2.6%
3.5%
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2.9%
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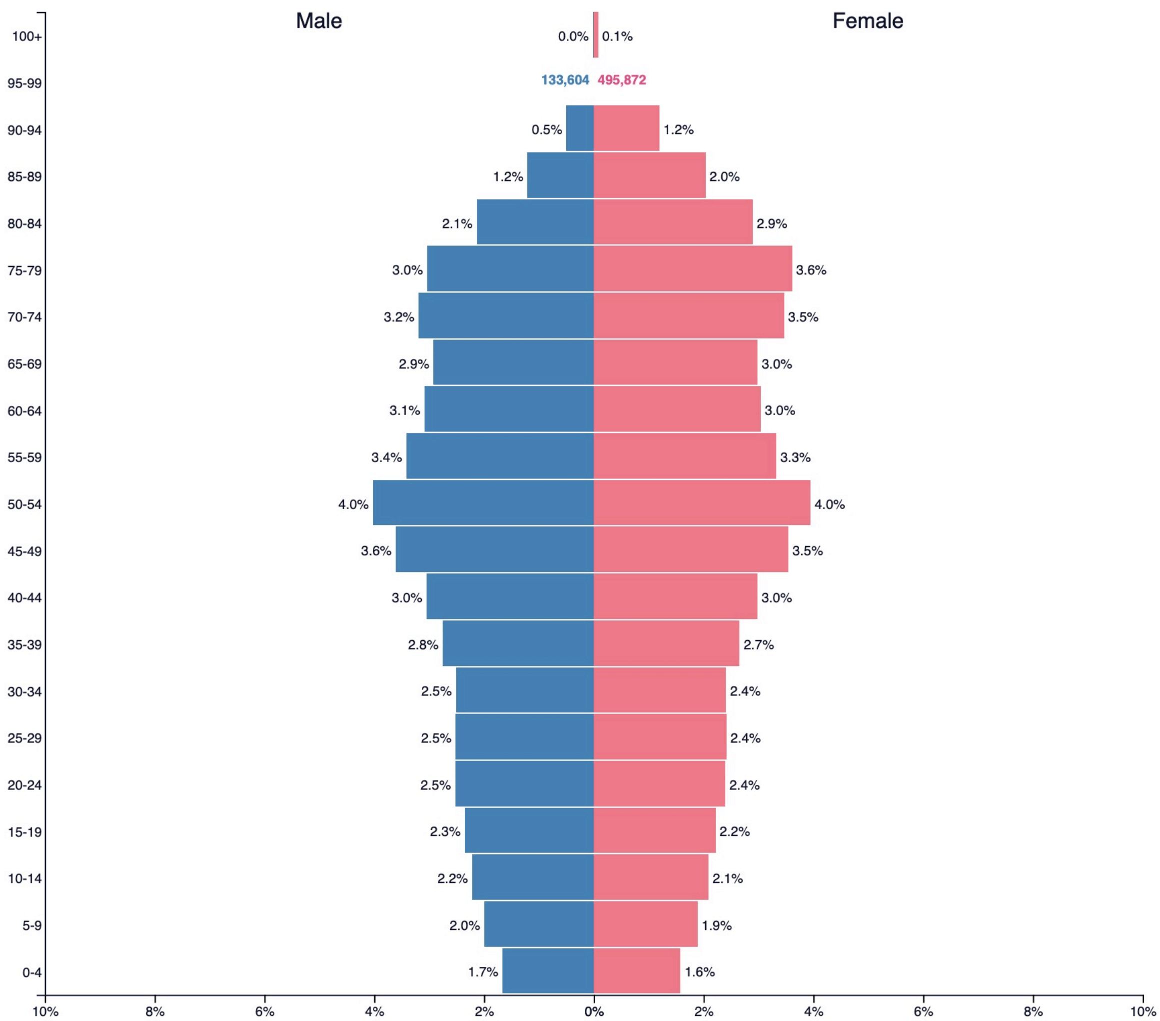
10%


Male
Female
100+
95-99
90-94
85-89
80-84
75-79
70-74
65-69
60-64
55-59
50-54
45-49
40-44
35-39
30-34
25-29
20-24
15-19
10-14
5-9
0-4
0.0%
0.1%
133,604
495,872
0.5%
1.2%
1.2%
2.0%
2.1%
2.9%
3.0%
3.6%
3.2%
3.5%
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2.1%
2.0%
1.9%
1.7%
1.6%
10%
8%
6%
4%
2%
0%
2%
4%
6%
8%
10%

Interactive Activity

Analysis Instructions

- Choose an age pyramid.
  - international pyramid.
  - local level pyramid.
- Explain to class what you see and what you expect the population to look like in 15, 30 and 50 years.

Demographic Transition

- 4 stages of transitions
- There is actually a fifth stage!

Demographic Transition

- **Stage 1**: high burden of infectious diseases, high maternal/child mortality
- **Stages 2 & 3**: transition to chronic diseases; improved health infrastructure
- **Stages 4 and 5**: dominance of Non-Communicable Diseases (NCDs), and ageing related conditions

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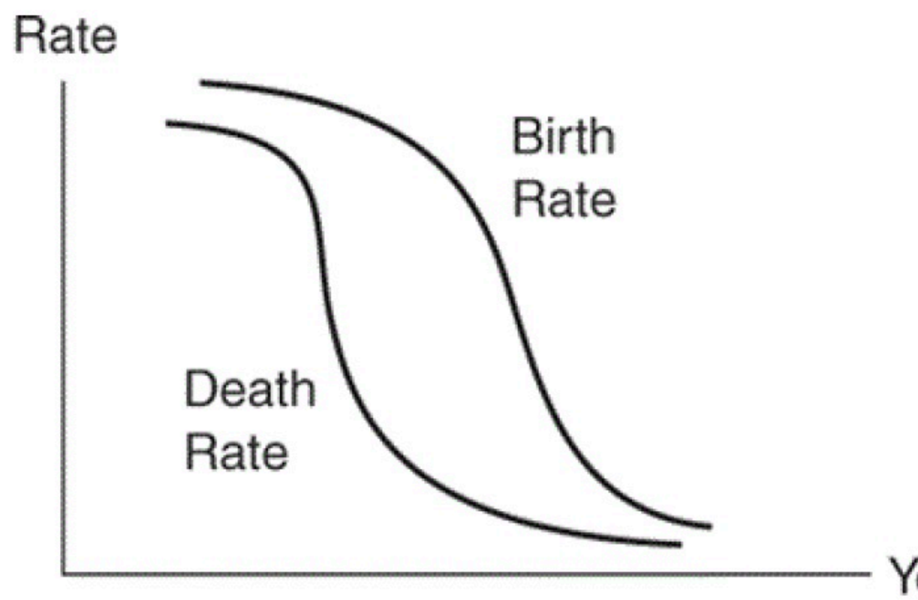
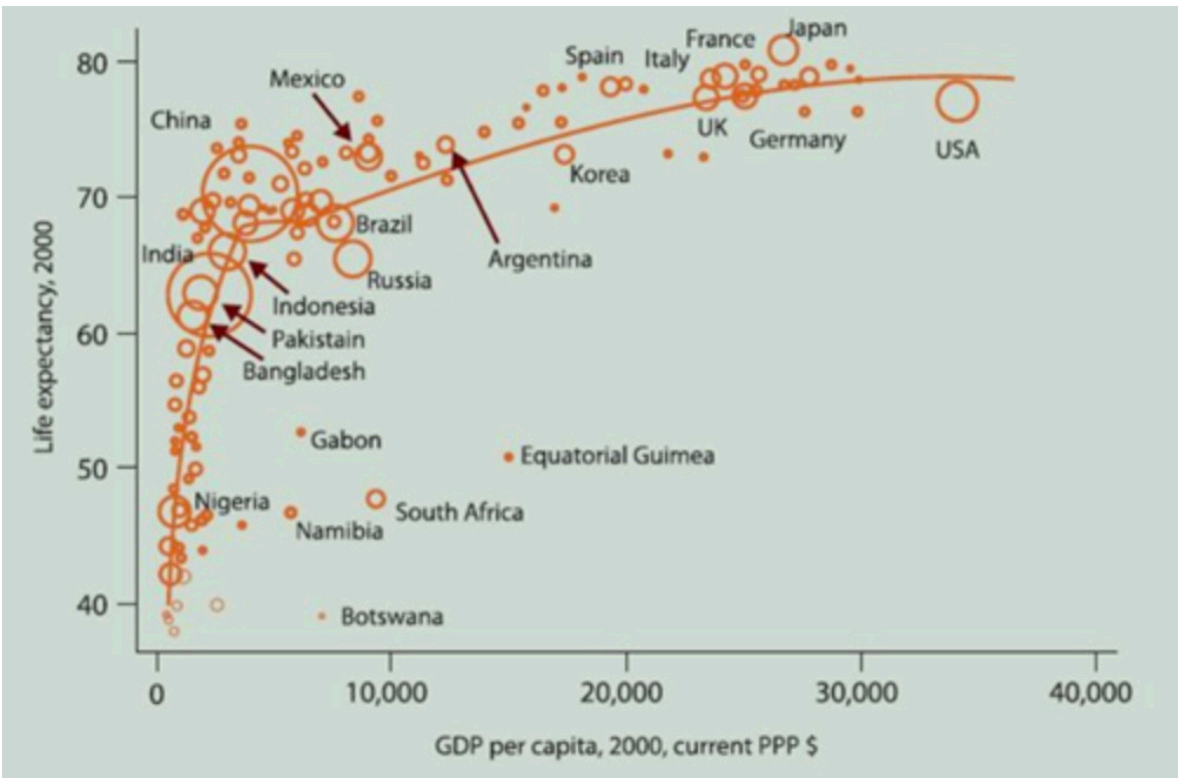
Preston Curve

GDP vs. Life Expectancy

- How do country's economic status and life expectancy relate?
  - Higher GDP often correlates with longer life expectancy.
  - Plateau effect beyond a certain GDP.



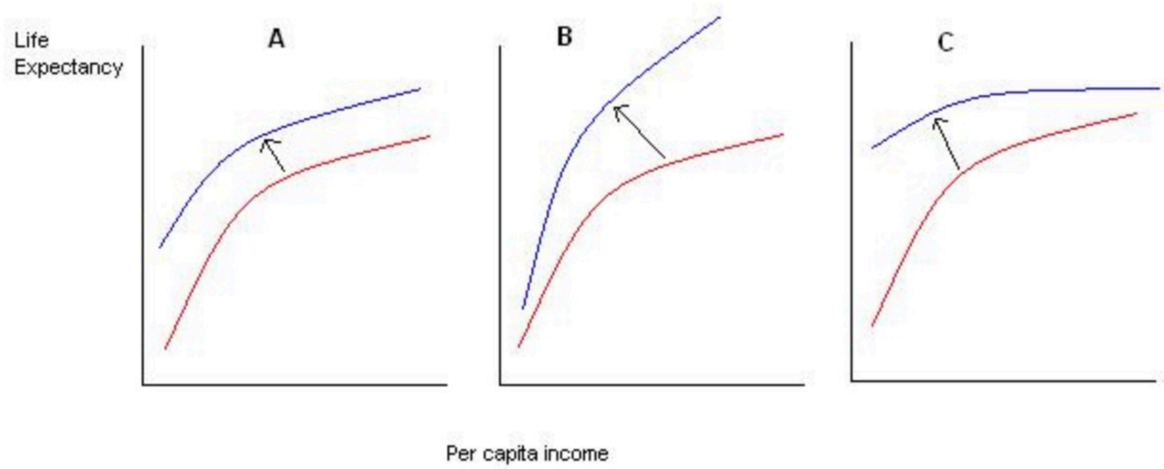
Stage	1	2	3	4
Birth Rate	High	High	⇓	Low
Death Rate	High	⇓	Low	Low



Life expectancy, 2000
GDP per capita, 2000, current PPP $
80
70
60
50
40
0
10,000
20,000
30,000
40,000
Mexico
China
India
Brazil
Russia
Argentina
Indonesia
Pakistain
Bangladesh
Gabon
Equatorial Guimea
Nigeria
Namibia
South Africa
Botswana
Spain
Italy
France
Japan
UK
Germany
Korea
USA

Preston Curve

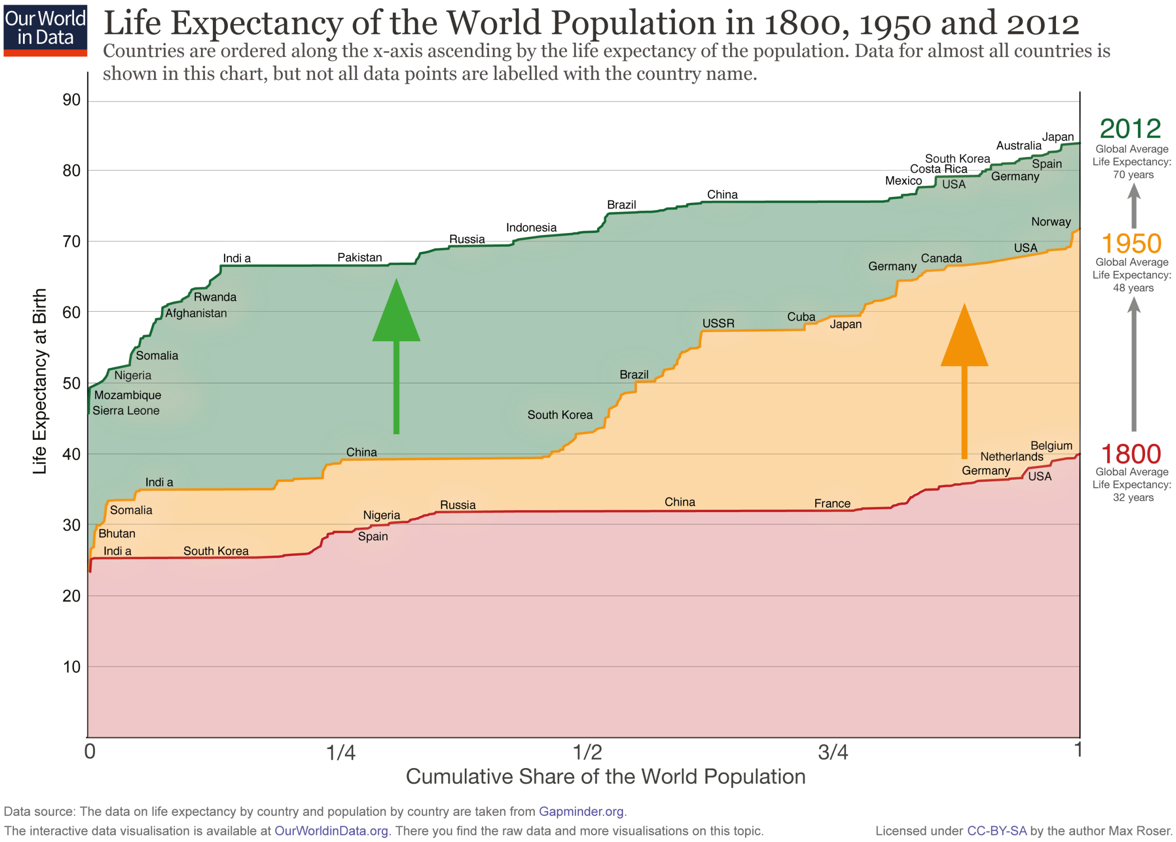
- **A**: the new technology is equally applicable in all countries regardless of their level of income.
- **B**: the new technology has a disproportionately larger effect in rich countries.
- **C**: poorer countries benefit more.

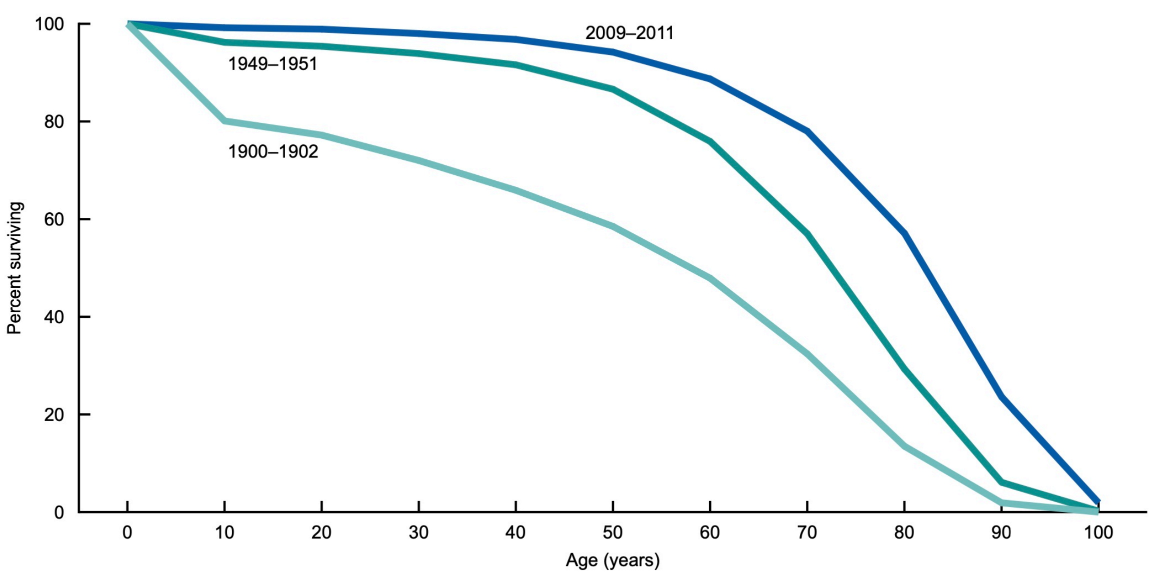


Aging Populations

- **Trends:**
  - Increasing proportion of elderly.
  - Dependency ratios rise, impacting economic and health systems.

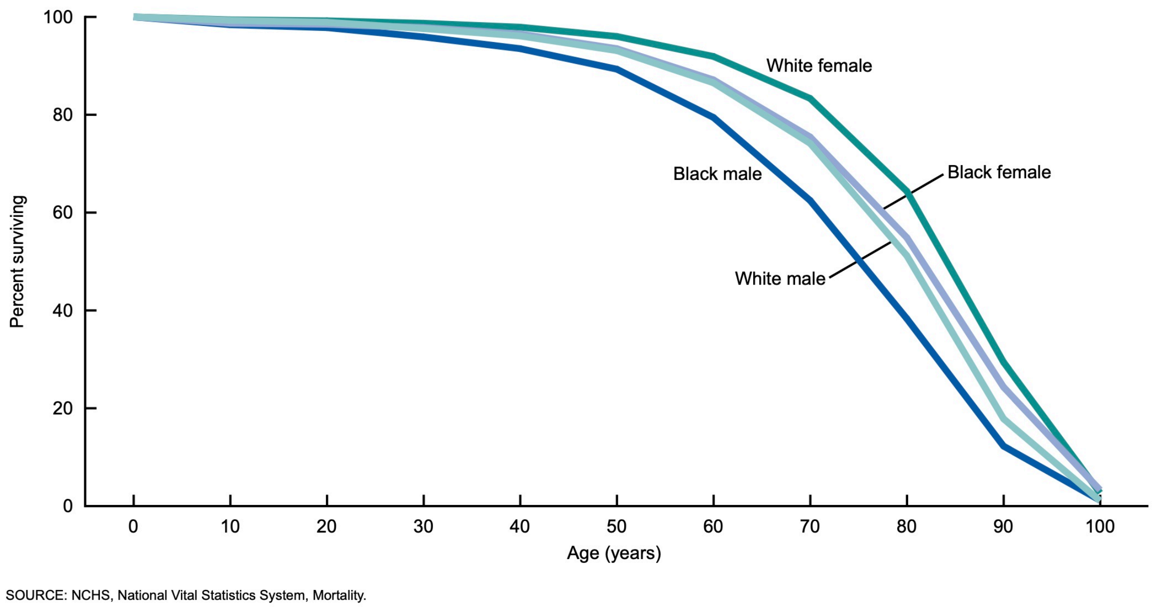
Aging Populations





SOURCE: NCHS, National Vital Statistics System, Mortality.

Aging Populations

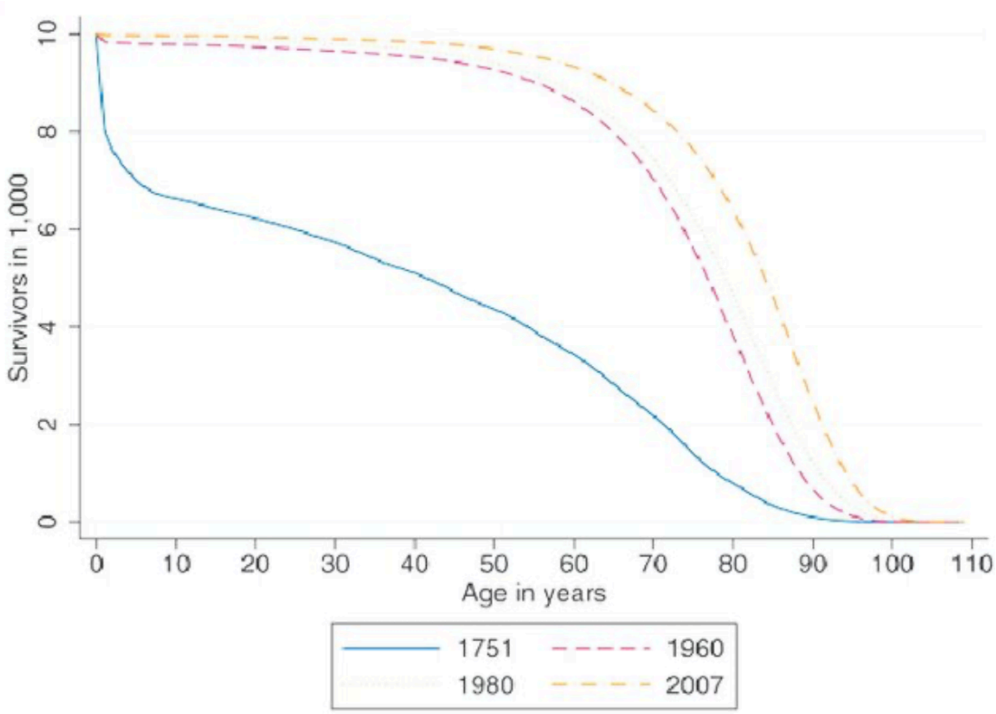


Rectangularization of Life Expectancy

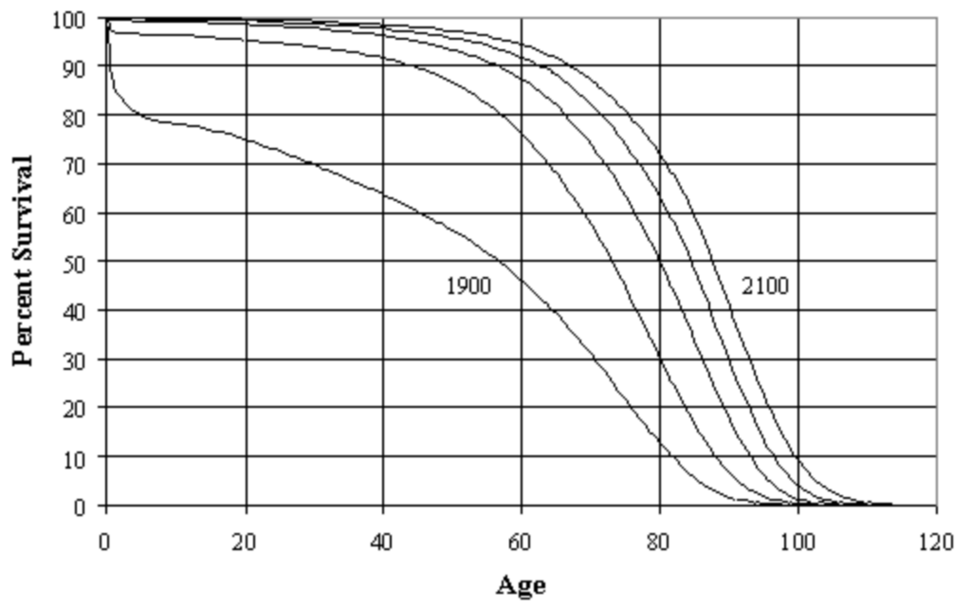
- Survival curves become more rectangular as mortality compresses toward older ages.
- **Implications:**
  - Shift to chronic diseases as leading health concerns.
  - Need for age-specific interventions.

Survival Curves in Sweden

Source: Schoder, J., & Zweifel, P. (2011). Flat-of-the-curve medicine: a new perspective on the production of health. Health Economics Review, 1, 1-10.



Survivors in 1,000
Age in years
1751
1960
1980
2007



Percent Survival
Age
1900
2100

Survival Curves in USA

Source: Bell, F. C., & Miller, M. L. (2005). Life tables for the United States social security area, 1900-2100 (No. 120). Social Security Administration, Office of the Chief Actuary.

Mortality Metrics

Crude Death Rate (CDR)

- Number of deaths per 1,000 individuals per year.
- Can be refined by breaking it down by age, sex, and socioeconomic status.
- **Example:** CDR in Mexico < CDR in the USA, but age distribution must be considered.

Case Fatality Rate (CFR)

- Proportion of individuals with a disease who die from it.
- Indicates severity and lethality of a disease.
- **Example Calculation:** CFR = (Disease deaths / Total diagnosed cases) × 100

Standardized Mortality Ratio (SMR)

- Adjusts mortality rates for different population age structures.
- **Formula:** SMR = (Observed Deaths / Expected Deaths) × 100
- **Example Calculation:**
  - Observed deaths: 93
  - Expected deaths: 70.5
  - SMR = (93 / 70.5) × 100 = **132** (indicating 32% higher mortality than expected)

Life Table Construction

Steps in Constructing a Life Table (1)

Define Age Groups

- 0-20, 21-40, 41-60, 61+

Initialize Population (l)

- Assume l = 100,000

Define Mortality Rates (q)

- 0-20: q = 0.005
- 21-40: q = 0.01
- 41-60: q = 0.15
- 61+: q = 0.50

Calculate Deaths (d)

$$d_x = l_x \times q_x$$

- **Example:**

$$d_{0-20} = 100,000 \times 0.005 = 500$$

Calculate Survivors (l)

- l_x for next group = previous $l_x - d_x$
- **Example:**

$$l_{21-40} = 100,000 - 500 = 99,500$$

Steps in Constructing a Life Table (2)

Calculate Person-Years Lived (L)

- $L_x = \frac{l_x + l_{x+1}}{2} \times n$
- Example: $L_{0-20} = \frac{100{,}000+99{,}500}{2} \times 20 = 1995000$

Calculate Total Years Remaining (T)

- T_x= Sum of all subsequent L_x values.

Derive Life Expectancy (e)

- $e_x = \frac{T_x}{l_x}$
- Represents average remaining years of life for individuals entering each age group.

```
library(knitr)
life_table <- data.frame(
  Age_Group = c("0-20", "21-40", "41-60", "61+"),
  Initial_Population = c(100000, 99500, 98550, 83767),
  Mortality_Rate = c(0.005, 0.01, 0.15, 0.50),
  Deaths = c(500, 995, 14783, 41883),
  Survivors = c(99500, 98550, 83767, 41884),
  Person_Years = c(1995000, 1980500, 1823170, 1256510),
  Total_Years_Remaining = c(7055180, 5060180, 3079680, 1256510),
  Life_Expectancy = c(70.55, 50.85, 31.25, 15.00)
)
kable(life_table)
```

```
Warning: 'xfun::attr()' is deprecated.
Use 'xfun::attr2()' instead.
See help("Deprecated")

Warning: 'xfun::attr()' is deprecated.
Use 'xfun::attr2()' instead.
See help("Deprecated")
```

Age_Group	Initial_Population	Mortality_Rate	Deaths	Survivors	Person_Years	Total_Years_Remaining	Life_Expectancy
0-20	100000	0.005	500	99500	1995000	7055180	70.55
21-40	99500	0.010	995	98550	1980500	5060180	50.85
41-60	98550	0.150	14783	83767	1823170	3079680	31.25
61+	83767	0.500	41883	41884	1256510	1256510	15.00

Years of Life Lost

- Years of Life Lost (YLL) quantifies the impact of premature mortality in a population.
- Used in public health to evaluate disease burden and prioritize interventions.

Methodology for Calculating YLL

Definition of Premature Mortality Age

- Premature mortality is defined relative to a threshold age, typically the average life expectancy.
- For this example, we use **75 years**.

Identification of Age at Death

- Essential for determining premature deaths.
- Each death's impact varies depending on age at death.

Calculation of Individual YLL

- Formula: $\text{YLL} = T - a_i$ where:
  - T is the threshold age,
  - a_i is the individual's age at death.

Summation of YLL

- Total population impact calculated as: $\text{Total YLL} = \sum \text{YLL}_i$

Example Calculation

Consider three individuals dying at **ages 25, 35, and 60**, with a threshold of **75 years**:

- **Individual 1:**
  - Age at death: 25
  - YLL = 75 - 25 = **50 years**
- **Individual 2:**
  - Age at death: 35
  - YLL = 75 - 35 = **40 years**
- **Individual 3:**
  - Age at death: 60
  - YLL = 75 - 60 = **15 years**
- **Total YLL:** $50 + 40 + 15 = 105$ years

Discussion

- The **105 years of YLL** highlight the burden of premature deaths.
- Helps health authorities prioritize interventions.
- Modifications include:
  - Discounting future years,
  - Weighting younger deaths more heavily,
  - Adjusting for epidemiological and demographic context.
- *Let's look at Box 2.5 in the book.*

Summary

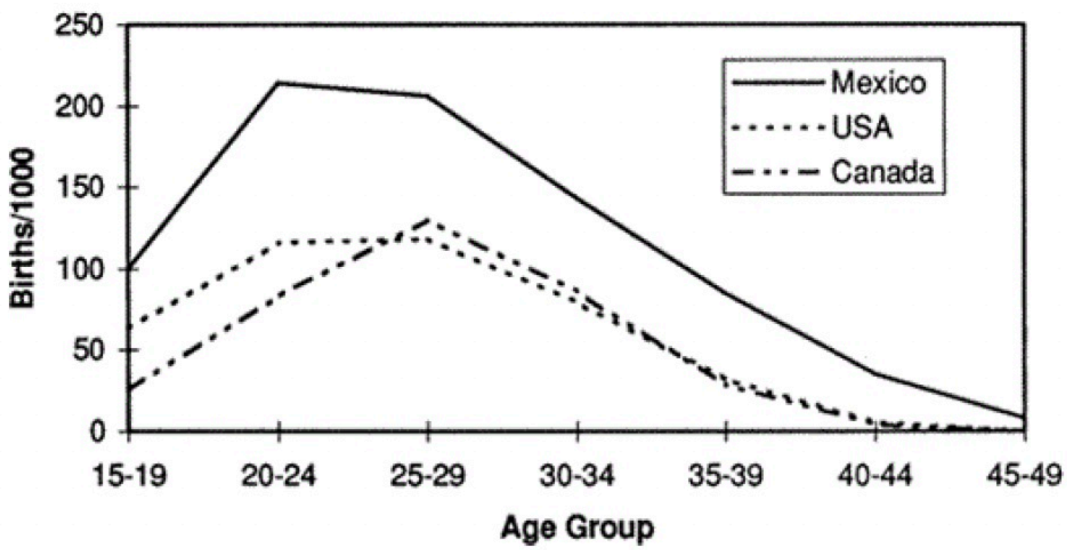
- Crude Death Rate (CDR) and Case Fatality Rate (CFR) provide baseline mortality measures.
- Standardized Mortality Ratio (SMR) adjusts for age distribution differences.
- Life tables are constructed step-by-step to estimate life expectancy at various ages.
- **Years of Life Lost (YLL)** quantifies premature mortality and is crucial for measuring disease burden.

- YLL helps prioritize public health interventions by identifying the most significant sources of early death.

Fertility

- **Some definitions**
  - *crude birth rate (CBR)*: number of births per 1,000 population per year. The denominator, however, refers to the total population, including men and boys, young girls and old women!
  - *general fertility rate (GFR)*: restricts inclusion in its denominator only to women in the reproductive age range
  - *total fertility rate (TFR)*: summing all age-specific fertility rates for women in the childbearing ages.

Birth Rates in US, Canada, Mexico



Deriving Total Fertility Rate

Age-Specific Fertility Rates (ASFRs) for the U.S. (2000)

- **15–19**: 48.5/1,000
- **20–24**: 112.3/1,000
- **25–29**: 121.4/1,000
- **30–34**: 94.1/1,000
- **35–39**: 40.4/1,000
- **40–44**: 7.9/1,000
- **45–49**: 0.5/1,000

Total: 425/1,000

Explanation

- The ASFR represents the birth rate per 1,000 women in each age group.
- Summing the ASFRs gives 425/1,000 for all age groups.
- Since each ASFR represents a five-year average, multiplying by 5 gives 2,125/1,000. This means the TFR = 2.1 births per woman, the replacement-level fertility rate typical of developed countries.
- Including ages 10–14 or 50–54 has little impact on the overall TFR.

Aging Populations

- **Policy Implications:**
  - Need for long-term care services.
  - Redesign of healthcare systems.

Book Exercise

Exercise 2.1: State of the Population

In the 2000 census, the total population of the United States was 281,423,000, with the following age-sex distribution (rounded to the nearest thousand):

Age Group	Male Population	Female Population	Total Population
0–1	1,949,000	1,857,000	3,806,000
1–4	7,862,000	7,508,000	15,370,000
5–14	21,044,000	20,034,000	41,078,000
15–44	62,647,000	61,577,000	124,224,000
45–64	30,143,000	31,810,000	61,953,000
65+	14,410,000	20,582,000	34,992,000
Total	**138,055,000**	**143,368,000**	**281,423,000**

Calculations

- (a) **Proportion of the Elderly (65+ years) in the Population**
- (b) **Proportion of the Young (0–14 years) in the Population**
- (c) **Sex Ratio in Age Group 0–14 (expressed as 100 males per females)**
- (d) **Sex Ratio in Age Group 65+ (expressed as males per 100 females)**

At Home Exercise

- Analyze an example population pyramid.
- Predict changes over 20 years based on fertility and mortality trends.
- Fertility Trend and Mortality

$$P(t) = P_0 \times \left(1 + \frac{B - D}{1000}\right)^t$$

- $P(t)$: The **population** at time t, after t years.
- P_0: The **current population** (the population at time $t = 0$).
- B: The **birth rate**, expressed as the number of **births per 1,000 people** per year.
- D: The **death rate**, expressed as the number of **deaths per 1,000 people** per year.

- t: The **number of years** into the future you are projecting (e.g., 20 years).

Summary

Key Takeaways

- Differences between incidence and prevalence.
- Importance of understanding demographic changes.
- Using tools like age pyramids to predict health trends.

Discussion Questions

- How do changes in prevalence reflect healthcare advances?
- What policies can address the challenges of aging populations?

References

- Young, T. K. (2004). *Population Health: Concepts and Methods.*
- WHO Reports on Health Metrics.
- National Center for Health Statistics.
- Preston, S. H. (1975). *The changing relation between mortality and level of economic development.* Population Studies, 29(2), 231-248.
- Omran, A. R. (1971). *The Epidemiologic Transition: A Theory of the Epidemiology of Population Change.* The Milbank Quarterly, 49(4), 509–38.
- Fries, James F. (2002). *Aging, natural death, and the compression of morbidity.*Bulletin of the World Health Organization 80, no. 3 (2002): 245-250.
- Nusselder, W.J. and Mackenbach, J.P. (1996). *Rectangularization of the survival curve in the Netherlands, 1950-1992.* The Gerontologist, 36(6), pp.773-782.