Measurement in Epidemiology

Course: Study designs and measurements

Measurement in Epidemiology

- Measures of disease frequency
- Measures of association
- Measures of potential impact

Measures of disease frequency

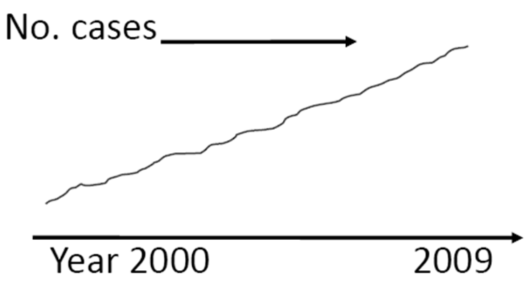
- Measures of disease frequency in mathematical quantity
  - Count
  - Fraction
    - Rate
    - Ratio
    - Proportion (percentage)
- Measures of disease frequency in epidemiology
  - Prevalence
  - Incidence

Counts

- Simplest & most basic measure – absolute number of persons who have disease or characteristic of interest.
- Useful for health planners & administrators: for allocation of resources (e.g. quantity of ORS needed by diarrheal cases)
- Count of No. cases of a disease, is used for surveillance of infectious disease for early detection of outbreaks.

Introduction > **Frequency** > Association > Impact > Conclusion

Counts



Is the situation worse?

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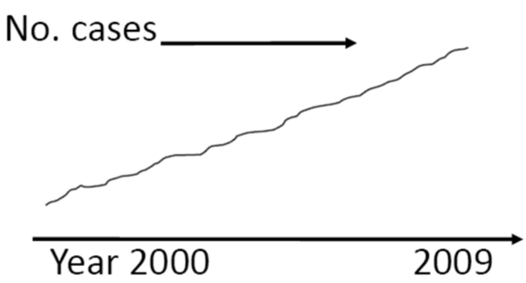
Counts



Is the situation worse?

Depends on population size,
difference in reporting method (more sensible),
definition of case !!!

Limited values of counts

- Number of persons with characteristic, e.g., cases of malaria depends on the size of the population at risk of the disease in an area.
  - The bigger this group, the higher is the expected number of cases.
- The duration of observation also affects the frequency of cases; the longer the observation period, the more cases can occur.

Count does not contain these elements !

Measurement fractions

- Rate
  - Measures the frequency of **an event in a population**.
  - **Time** and multiplier
  - Incidence
- Ratio
  - A value obtained by dividing one number by another (either related or unrelated)
  - Fraction that **numerator is not a part of denominator**
- Proportion
  - Numerator and denominator have the same units (**dimensionless**).
  - Prevalence

Rate

Definition: Frequency of events, that occur in a defined time period, divided by the average population of risk.

$$\text{Rate} = \frac{\text{Numerator}}{\text{Denominator}} \times \text{Constant multiplier}$$

$$\text{Crude death rate} = \frac{\text{Number of deaths (defined place and time period)}}{\text{Mid-period population (same place and population)}} \times 1000$$

Crude Mortality Rates

$$\frac{\text{Number of deaths in a specified year}}{\text{Number of individuals in the population in the specified year (Mid-period population)}}$$

$$\frac{\text{Number of deaths in a specified year}}{\text{Number of individuals in the population in the specified year}} \times 1000$$

Advantages

- -Actual Summary rates
- -Easy calculation for international comparisons

Disadvantages

Since population vary in composition (e.g., age)differences in crude rates difficult to interpret

Age-Specific Mortality Rate

- Provide a broader view of mortality for sub-groups stratified by age
- Numerator and denominator are limited to a specific age group
- Comparable across populations

Introduction Frequency Association Impact Conclusion

Age-Specific Mortality Rate

$$\text{Aged 0–14 years} = \frac{\text{Number of deaths among persons aged 0-14 in a given year}}{\text{Total number of persons aged 0-14 in the same year}} \times 100000$$

Age-specific Rates

Advantages

- Homogenous subgroups
- Detailed rates useful for public health and
- Epidemiological aims

Disadvantages

- Cumbersome to compare subgroups of two or more populations

Introduction > **Frequency** > Association > Impact > Conclusion

Standardization of Rates (Adjusting rates)

- Used to reduce distortion in comparisons between crude areas
- Allows comparisons of rates between populations that differ by variables that can influence the rate (e.g., age)
- Two types: Direct and Indirect

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Direct Adjustments of Rates

- Requires a **standard population**, to which the estimated age-specific rates can be applied
- Multiply standard population by age-specific rates for populations A and B to determine the **standardized rates**
- **Compare** standardized rates

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Population, Deaths, and Death Rate by Community and by Age

	Community A			Community B		
Age (year)	**Population**	**Deaths**	**Death Rate (per 1000)**	**Population**	**Deaths**	**Death Rate (per 1000)**
Under 1	**1,000**	**15**	**15.0**	**5,000**	**100**	**20.0**
1 – 14	**3,000**	**3**	**1.0**	**20,000**	**35**	**1.0**
15 – 34	**6,000**	**6**	**1.0**	**35,000**	**35**	**1.0**
35 – 54	**13,000**	**52**	**4.0**	**17,000**	**85**	**5.0**
55 – 64	**7,000**	**105**	**15.0**	**8,000**	**160**	**20.0**
Over 64	**20,000**	**1,600**	**80.0**	**15,000**	**1,350**	**90.0**
All ages	**50,000**	**1,781**	**35.6**	**100,000**	**1,740**	**17.4**

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Standard Population by Age and Age-Specific Death Rates

Age (years)	Standard population Combined				
Under 1	6,000				
1 – 14	23,000				
15 – 34	41,000				
35 – 54	30,000				
55 – 64	15,000				
Over 64	35,000				
Total	150,000				
Age – adjusted death rate (per 1000)					

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Standard Population by Age and Age-Specific Death Rates

Age (years)	Standard population Combined	Death rate in A (per 1,000)	Expected deaths at A's rate	Death rate in B (per 1,000)	Expected deaths at B's rate
Under 1	6,000	15.0	90	20.0	120
1 – 14	23,000	1.0	23	1.0	23
15 – 34	41,000	1.0	41	1.0	41
35 – 54	30,000	4.0	120	5.0	150
55 – 64	15,000	15.0	225	20.0	300
Over 64	35,000	80.0	2,800	90.0	3,150
Total	150,000	35,6	3,299	17.4	3,784
Age – adjusted death rate (per 1000)			22.0		25.0

Standard Population by Age and Age-Specific Death Rates

Age (years)	Standard population	Death rate in A (per 1,000)	Expected deaths at A's rate	Death rate in B (per 1,000)	Expected deaths at B's rate
Under 1	6,000	15.0	90	20.0	120
1 – 14	23,000	1.0	23	1.0	23
15 – 34	41,000	1.0	41	1.0	41
35 – 54	30,000	4.0	120	5.0	150
55 – 64	15,000	15.0	225	20.0	300
Over 64	35,000	80.0	2,800	90.0	3,150
Total	150,000	35,6	3,299	17.4	3,784
Age – adjusted death rate (per 1000)			22.0		25.0

Indirect Adjustments of Rates

- Indirect adjustment is used less frequently than direct adjustment
- Use when **age-specific numbers of deaths** in the study population are either **unavailable or small** in number

Indirect Adjustment of Rates

Based on applying the **age-specific rates of the standard population** to the population of interest to determine the number of **"expected"** deaths

$\Downarrow$

Standardized Mortality Ratio
SMR

Introduction | **Frequency** | Association | Impact | Conclusion

Standardized Mortality Ratio

Total **observed** deaths
in a population

____

Total **expected** deaths
in a population

Population of Community A by Age and Standard Death Rates

Age (years)	Population in A	Death rate B Standard death rate (per 1,000)	
Under 1	1,000	20.0	
1 – 14	3,000	1.0	
15 – 34	6,000	1.0	
35 – 54	13,000	5.0	
55 – 64	7,000	20.0	
Over 64	20,000	90.0	
Total	50,000	17.4	

Population and Expected Deaths of Community A by Age

Age (years)	Population in A	Death rate B Standard death rate (per 1,000)	Expected deaths in A at standard rates
Under 1	1,000	20.0	20.0
1 – 14	3,000	1.0	3.0
15 – 34	6,000	1.0	6.0
35 – 54	13,000	5.0	65.0
55 – 64	7,000	20.0	140.0
Over 64	20,000	90.0	1,800.0
Total	50,000	17.4	2,034.0

SMR_A = 1781 / 2034 = 0.876

SMR_B = 1.0

Standardized Mortality Ratio

If the SMR is greater than 1,
more deaths have occurred
than anticipated

If the SMR is less than 1,
fewer deaths have occurred
than anticipated

Ratio

- **Ratio:** A fraction in which the numerator is not part of the denominator.

$$\frac{a}{b}$$

- a and b are two mutually exclusive frequency

- Example:
- Number of hospital beds per 100,000
- Male and female dengue infection ratio = 70/35 or 2 males to one female (2 : 1)

Ratio

- A ratio is the relative magnitude of two quantities or a comparison of **any two values**.
- It is calculated by **dividing** one variable by the other.
- The **numerator and denominator need not be related**. Therefore, one could compare apples with oranges or apples with number of physician visits.

Example

EXAMPLE: Calculating a Ratio — Different Categories of Same Variable

Between 1971 and 1975, as part of the National Health and Nutrition Examination Survey (NHANES), 7,381 persons ages 40–77 years were enrolled in a follow-up study.[1] At the time of enrollment, each study participant was classified as having or not having diabetes. During 1982–1984, enrollees were documented either to have died or were still alive. The results are summarized as follows.

	Original Enrollment (1971–1975)	Dead at Follow-Up (1982–1984)
Diabetic men	189	100
Nondiabetic men	3,151	811
Diabetic women	218	72
Nondiabetic women	3,823	511

Of the men enrolled in the NHANES follow-up study, 3,151 were nondiabetic and 189 were diabetic. Calculate the ratio of non-diabetic to diabetic men.

Ratio = 3,151 / 189 x 1 = 16.7:1

Proportion (percentage, frequency)

- **Proportion:** + a included in the denominator

$$\frac{a}{a+b}$$

+ No measurement unit; > 0 to ≤ 1
+ Often expressed as %

Example: From 7,999 females aged 16 – 45 y, 2,496 use modern contraceptive methods.

The proportion of those who use modern contraceptive methods = 2,496 / 7,999 x 100 = 31.2%

Example

EXAMPLE: Calculating a Proportion

Example A: *Calculate the proportion of men in the NHANES follow-up study who were diabetics.*

Numerator = 189 diabetic men
Denominator = Total number of men = 189 + 3,151 = 3,340

Proportion = (189 / 3,340) x 100 = 5.66%

Example B: *Calculate the proportion of deaths among men.*

Numerator = deaths in men
= 100 deaths in diabetic men + 811 deaths in nondiabetic men
= 911 deaths in men

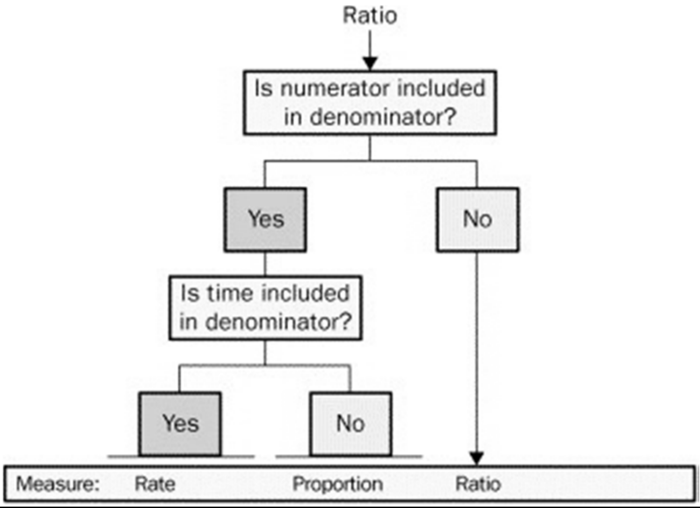
Notice that the numerator (911 deaths in men) is a subset of the denominator.

Denominator = all deaths
= 911 deaths in men + 72 deaths in diabetic women + 511 deaths in nondiabetic women
= 1,494 deaths

Proportion = 911 / 1,494 = 60.98% = 61%

Introduction | **Frequency** | Association | Impact | Conclusion

Algorithm for distinguishing rates, proportions, and ratios



Introduction | **Frequency** | Association | Impact | Conclusion

Measures of disease Frequency in epidemiology

- Incidence (I): Measures **new** cases of a disease that develop over a period of time.
    1. Cumulative incidence (incidence)
    2. Incidence rate = incidence density

- Prevalence (P): Measures **existing** cases of a disease at a particular point in time or over a period of time.
    1. Point prevalence
    2. Period prevalence

Cumulative Incidence (CI) = Incidence

$$CI = \frac{\text{No. of individuals who get the disease during a certain period}}{\text{No. of individuals in the population at the beginning of the period}}$$

- A proportion
- Has no dimension
- Varies between 0 and 1

Example of Cumulative Incidence

- The population statistic of Lab Lair District in 2001 revealed that there were 5,572 women aged 20-39 years who were sex workers. Based on the record of CHAS, among those women, 45 were HIV + ve during 2002-2005.
- What is the cumulative incidence of HIV + ve among those women during a period of 4 years?
- Cumulative incidence = 45 / 5,572 = 0.008 or 0.8%

Incidence Rate

$$IR = \frac{I}{PT}$$

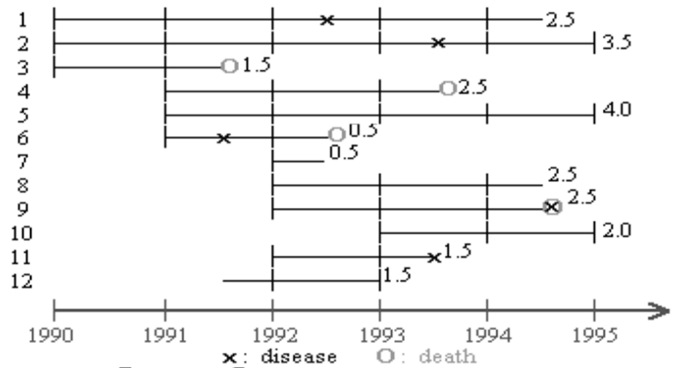
I = # of new cases during follow-up
PT = total time that disease-free individuals in the cohort are observed over the study period (time at risk).

Synonyms: hazard rate, **incidence density rate**.

Measures the **rapidity** with which new cases are occurring in a population

Example

Hypothetical cohort of 12 initially disease-free subjects followed over a 5-year period from 1990 to 1995.



$$\hat{IR} = \frac{I}{PT} = \frac{5}{25\ PY} = 0.20$$

Incidence Rate

$$\hat{IR} = \frac{I}{PT} = \frac{5}{25\,PY} = 0.20$$

$$= 20 \text{ new cases per } 100 \text{ person - years}$$

Study questions:

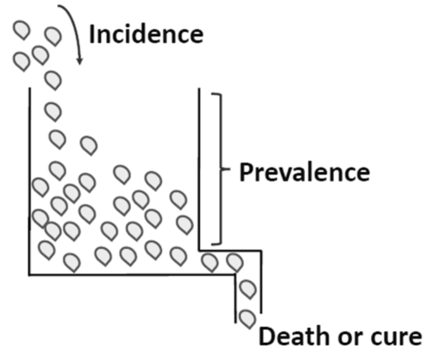
1) Is the value of 0.20 a proportion?
2) Does the value of 0.20 person-year represent the risk of developing disease?

Prevalence

$$\text{Prevalence} = \frac{\text{Number of exiting cases}}{\text{Number of population}}$$

Number of existing cases = New + preexisting cases/
Number of population during the same time period

Prevalence VS. Incidence



- Prevalence can viewed as describing a pool of disease in a population.
- Incidence describes the input flow of new cases into the pool.
- Fatality and recovery reflects the output flow from the pool.

Prevalence

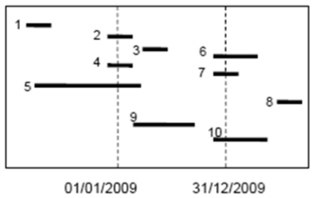
Useful for:

- Assessing the health status of a population.
- Planning health services.

Not Useful for:

- Identifying risk factors

Prevalence divided into two types:



Point prevalence

01/01/2009: case No. 2, 4, 5

31/12/2009: case No. 6, 7, 10

Period prevalence between 01/01-31/12/2009:

Case No. 2, 3, 4, 5, 6, 7, 9, 10

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Example

Suppose we followed a population of 150 persons for one year, and 25 had a disease of interest at the start of follow-up and another 15 new cases developed during the year.

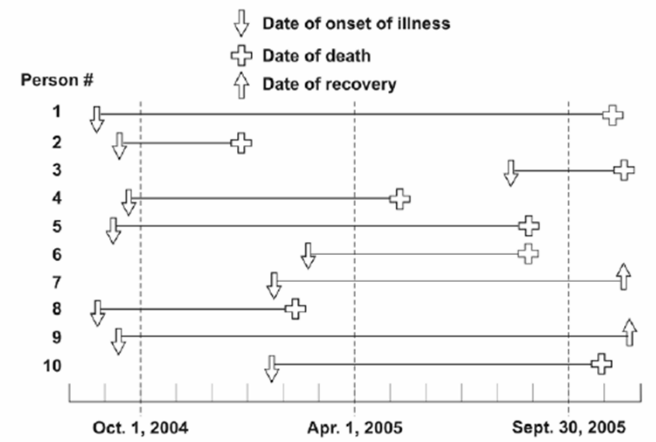
1) What is the period prevalence for the year?
2) What is the point prevalence at the start of the period?
3) What is the cumulative incidence for the one year period?

Example (Answer)

Suppose we followed a population of 150 persons for one year, and 25 had a disease of interest at the start of follow-up and another 15 new cases developed during the year.

1) What is the period prevalence for the year?
   – pp = (25+15)/150 = 0.27 or 27%
2) What is the point prevalence at the start of the period?
   – p = 25/150 = 0.17 = 17%
3) What is the cumulative incidence for the one year period?
   – CI = 15/125 = 0.12 = 12%

Represents 10 new cases of illness over about 12 months in a population of 20 persons.



- A Calculate the incidence rate from October 1, 2004, to September 30, 2005, using the midpoint population (population alive on April 1, 2005) as the denominator. Express the rate per 100 population.
- B Calculate the point prevalence on April 1, 2005.
- C Calculate the period prevalence from October 1, 2004, to September 30, 2005.

- **Example A: Calculate the incidence rate from October 1, 2004, to September 30, 2005, using the midpoint**

population (population alive on April 1, 2005) as the denominator. Express the rate per 100 population.

Incidence rate numerator = number of new cases between October 1 and September 30
= 4 (the other 6 all had onsets before October 1, and are not included)

Incidence rate denominator = April 1 population
= 18 (persons 2 and 8 died before April 1)

Incidence rate = (4 / 18) x 100 = 22 new cases per 100 population

- **Example B: Calculate the point prevalence on April 1, 2005.**

Point prevalence is the number of persons ill on the date divided by the population on that date.
On April 1, seven persons (persons 1, 4, 5, 7, 9, and 10) were ill.
Point prevalence = (7 / 18) x 100
= 38.89%

- **Example C: Calculate the period prevalence from October 1, 2004, to September 30, 2005.**

The numerator of period prevalence includes anyone who was ill any time during the period.
In Figure 3.1, the first 10 persons were all ill at some time during the period.
Period prevalence = (10 / 20) x 100
= 50%

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Measures of association

- **Absolute**
  - Risk difference, excess risk
  - Attributable risk

Exposed - unexposed

- **Relative**
  - Risk ratio, rate ratio
  - Odds ratio

Exposed /unexposed

Introduction | **Frequency** | **Association** | Impact | Conclusion

Measures of association

- **Strength (magnitude) of association**
  - **Cohort ---> Relative risk (RR)**
  - **Case control ---> Odds ratio (OR)**
  - **Cross sectional ---> Odds ratio (OR)**

Introduction | **Frequency** | **Association** | Impact | Conclusion

Strength of Association

Cohort study

E+ •——→ D+ (a) D- (b)

E- •——→ D+ (c) D- (d)

RR = {a/(a+b)}/{c/(c+d)}

RR = 1 → No effect
RR > 1 → Harmful effect of exposure
RR < 1 → Protective effect

Introduction | Frequency | **Association** | Impact | Conclusion

Measurement of association

Expression	Question	Definition
Absolute risk	**What is the incidence of disease in a group initially free of the condition?**	$I = \frac{\#\text{new case}}{\#\text{People in group}}$
Attributable risk Risk difference	**What is the incidence of disease attributable to exposure?**	AR = $I_{E^+} - I_{E^-}$
Relative risk Risk ratio	**How many times more likely are exposed persons to become disease, relative to nonexposed persons?**	RR = $\frac{I_{E^+}}{I_{E^-}}$

Relative risk or risk ratio

- Compares the risk of a heath event among one group with the risk among another group.

$$\frac{\text{Risk of disease (Cumulative incidence) in exposure group}}{\text{Risk of disease (Cumulative incidence) in non-exposure group}}$$

		Outcome CA lung Yes	No	
Risk	smoking	a	b	a+b
	non-smoking	c	d	c+d

Risks of CA in smoking (I_{E+}) = a/a+b
Risks of CA in non-smoking (I_{E-}) = c/c+d
Relative risk (risk ratio) (I_{E+})/ (I_{E-}) = $\frac{a/a+b}{c/c+d}$
Absolute risk reduction (ARR) = (I_{E+}) - (I_{E-})
Number needed to treat (NNT) = $\frac{1}{ARR}$

		Outcome CA lung Yes	No	
Risk	smoking	20	180	200
	non-smoking	5	495	500

Risks of CA in smoking (I_{E+}) =
Risks of CA in non-smoking (I_{E-}) =
Relative risk (risk ratio) (I_{E+})/ (I_{E-}) =
Absolute risk reduction (ARR) =
Number needed to treat/harm (NNT/NNH) =

Rate ratio

- Compares the incidence rates (person-time rates) of two groups

$$\frac{\text{Mortality rate for exposure group}}{\text{Mortality rate for non-exposure group}}$$

Strength of Association

Case-control study

E+ E- ← D+

(a) (c)

E+ E- ← D-

(b) (d)

O.R. (odds ratio) = $\frac{a/c}{b/d}$

Probability vs. Odds

- Probability (P)
  - The **proportion** of people in whom a particular characteristic, such as a positive test, is present.
- Odds
  - The **ratio** of two probabilities of an event to that of 1-the probability of the event
- $\text{Odds} = \frac{P}{1-P}$ or $P = \frac{\text{Odds}}{1+\text{Odds}}$

Introduction | Frequency | Association | Impact | Conclusion

Example

- Probability of win = 0.8
- Odds of win = 0.8/(1-0.8)
  = 0.8/0.2
  = 4

Example

Among 100 people at baseline, 20 develop influenza over a year.

- The risk is 1 in 5 (i.e. 20 among 100)

- The odds is 1 to 4 (i.e. 20 compared to 80)

Thus a risk is a *proportion,*
But an odds is a *ratio.*

Introduction > **Frequency** > **Association** > Impact > Conclusion

Odds ratio

- **The ratio of the odds of a condition in the exposed compared with the odds of the condition in the unexposed**
- **Usually applied to prevalence studies rather than incidence studies**

$$OR = \frac{\text{Odds of exposed among disease}}{\text{Odds of exposed among non-disease}}$$

		Outcome CA lung Yes	No
Risk	smoking	a	b
	non-smoking	c	d

Odds of smoking in CA = **a/c**

Odds of smoking in non-CA = **b/d**

Odds Ratio = $\frac{a/c}{b/d} = \frac{ad}{cb}$

		Outcome CA lung Yes	No
Risk	smoking	30	5
	non-smoking	10	35

Odds of smoking in CA = **a/c** = **30/10 = 3**

Odds of smoking in non-CA = **b/d** = **5/35 = 0.14**

Odds Ratio = $\frac{a/c}{b/d} = \frac{ad}{cb} = \frac{3}{0.14} = 21$

The odds of smoking in CA lung/the odds of smoking in control (odds of having CA lung comparing smoking and non-smoking)

Example

Assume that among the 100 people at risk, 50 are men and 50 women. If 15 men and 5 women develop influenza,

The relative risk of developing influenza in men, as compared with women, is:

Risk in men = 15/50
divided by
Risk in women = 5/50

15/50 : 5/50 = 3.0

The odds ratio is a ratio of two odds
The odds in men = 15/35
divided by
The odds in women = 5/35
5 : 5/45 = 3.9

We conclude that the odds of men getting influenza over the year are 3.9 times as high as the odds of women getting influenza.

Introduction > **Frequency** > Association > **Impact** > Conclusion

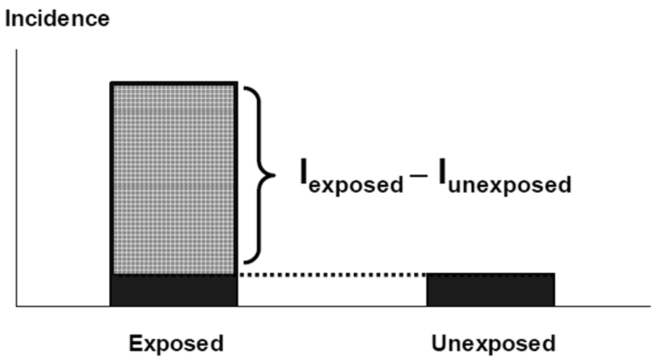
Measures of Impact

- Reflects the burden that an exposure contribute to the frequency of disease in the population
- Impact of exposure removal
- Two concepts
  - Attributable risk among exposed
  - Population attributable risk

Attributable Risk (AR)

- Quantifies disease burden in exposed group attributable to exposure.
- Provides answer to
  - What is the risk which can be attributed to the exposure?
  - What is the excess risk due to the exposure?
- Calculated as risk difference (RD)

Attributable Risk



I = Incidence

Introduction | **Frequency** | Association | **Impact** | Conclusion

Population Attributable Risk (PAR)

- Excess risk of disease in total population attributable to exposure.
- Reduction in risk which would be achieved if population entirely unexposed.
- Helps determining which exposures relevant to public health in community.
- PAR =AR*P

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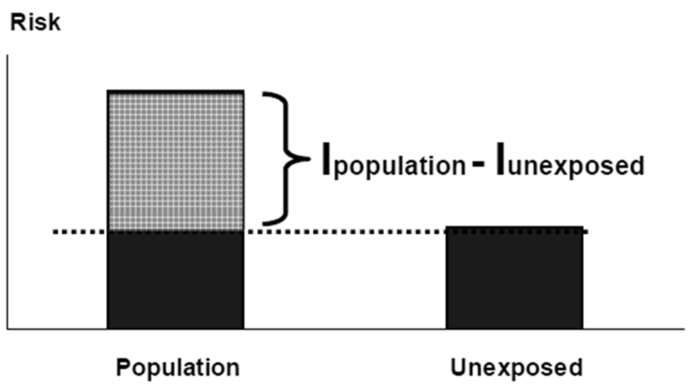
Population Attributable Risk



Attributable Risk fraction

- Attributable risk in the exposed group

$$AR\% = \frac{I_{exposed} - I_{unexposed}}{I_{exposed}}$$

- Attributable risk in the total population

$$PAR\% = \frac{I_{population} - I_{unexposed}}{I_{population}}$$

Note:

I_p can be linked to I_e and I_u if one knows the proportions of the population who are exposed (P) and unexposed (Q), (P and Q add to 1).

$$I_p = P(I_e) + Q(I_u)$$

Example

- Consider a cohort study of risk of ischemic stroke, taken in 1 year, with 500 subjects with atrial fibrillation (AF) controlled against 500 subjects without AF.
- Given the proportion of AF in general population is 30%.
- The results are summarized as follow:

	Ischemic stroke present	Ischemic stroke absent	Total
AF	2	498	500
No AF	1	499	500
	3	997	

Answer

- Attributable risk
  - I_E - I_{NonE} = 0.004-0.002 = 0.002
  - The incidence of ischemic stroke that is attributable to AF is 2 in 1000
- Attributable risk fraction
  - I_E-I_{nonE}/I_E = = 0.002/0.004 = 50%
  - If AF patient were controlled, we could expect 50% reduction in ischemic stroke.
- Population attributable risk
  - AR*P = 0.002* 0.3= 0.0006
  - The risk of ischemic stroke in the total population that is attributable to AF is 6 in 10000.
- population attributable fraction
  - PAR /[(I_E*P) +($_{InonE}$*(1-P)]
    = 0.0006/[(0.004*0.3) +(0.002*0.7)] = 0.23
  - According to these results, control AF in population would reduce the overall risk of ischemic stroke by 23%.

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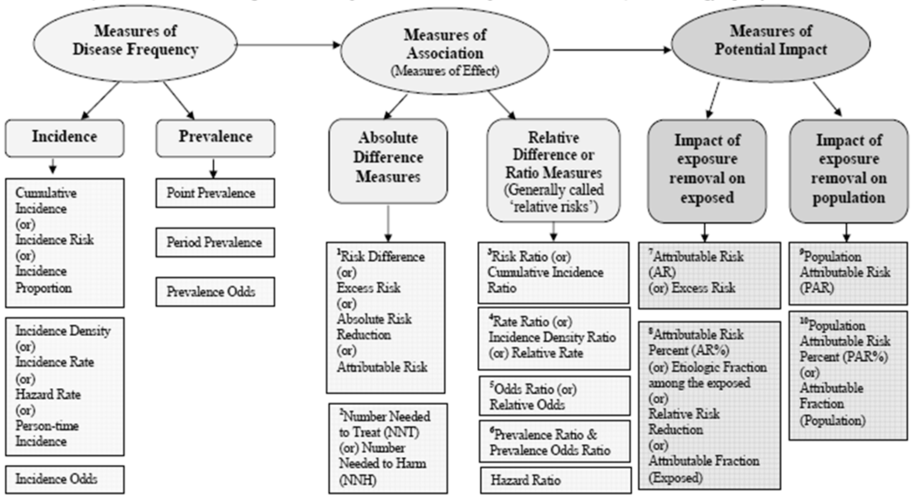
Conclusion

AN OVERVIEW OF MEASUREMENTS IN EPIDEMIOLOGY

EXPOSURES → ? → OUTCOME

Epidemiology is about identifying associations between exposures and outcomes. To identify any association, exposures and outcomes must first be measured in a quantitative manner. Then rates of occurrence of events are computed. These measures are called "*measures of disease frequency*." Once measured, the association between exposures and outcomes are then evaluated by calculating "*measures of association or effect*." Finally, the impact of removal of an exposure on the outcome is evaluated by computing "*measures of potential impact*." In general, measures of disease frequency are needed to generate measures of association, and both these are needed to get measures of impact. There is some overlap between these measures, and terminology is poorly standardized.



The superscript numbers refer to the formulae used to compute those measures (formulae shown separately in the following pages)

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Frequently used measures of morbidity

Measure	Numerator (X)	Denominator (Y)
Crude death rate	Total number of deaths during a given time interval	Mid-interval population
Cause-specific death rate	Number of deaths assigned to a specific cause during a given time interval	Mid-interval population
Attack rate	No. of new cases of a specified disease reported during an epidemic period	Population at start of the epidemic period
Secondary attack rate	No. of new cases of specified disease among contacts of known cases	Size of contact population at risk

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Other measures of mortality

Measure	Numerator (X)	Denominator (Y)
Death-to-case-ratio	No. of deaths assigned to a specific cause during a given time interval	No. of new cases of that disease reported during the same time interval
Neonatal mortality rate	No. of deaths under age 28 days during a given time interval	No. of live births during the same time interval
Postneonatal mortality rate	No. of deaths from ages 28 days to, but not including, 1 year during a given time interval	No. of live births during the same time interval
Maternal mortality rate	No. of deaths assigned to pregnancy-related causes during a given time interval	No. of live births during the same time interval