

# BIOSTATISTICS AND INFORMATICS

EVIDENCE BASED MEDICINE  
MATHEMATICAL LOGIC IN DIAGNOSTICS

MIKLÓS KELLERMAYER

Monday 7 December 15

# Biostatistics and informatics in medicine

- Overview
- Planning and conducting clinical investigations
- Medical diagnostics, differential diagnostics
- Evidence based medicine
- Computer-assisted medical decision making

Monday 7 December 15

## A posteriori overview

- Variables:
  - *Stochastic variables, Type, Distribution*
- Random variation plays important role!
- Inferences on the population are drawn from samples
- Statistical inference:
  - *Hypothesis testing, correlation, regression*
- Statistical data - information
- Information:
  - *Can be defined, Encoded, Stored, Transmitted*
- Medical knowledge, medical data:
  - *enormously large sets of information*

Monday 7 December 15

## Planning and conducting clinical investigations

So far we have dealt with **already acquired** data.

Even the most sophisticated data analysis cannot remedy an **incorrectly designed** study.

How do we obtain **clinical** data?

**Issues** to be considered:

Objectives

Methods

Sources of error

Sampling methods, sample size

Monday 7 December 15

# Objectives of clinical studies

- **Estimation**

Estimation of certain **features** of a population.

E.g., frequency of diarrheal episodes in children under 5, incidence of H1N1 infection in pregnant women, etc.

- **Associations**

Investigation of the **association** (correlation) between a factor of interest (environmental parameter) and a particular outcome (disease, death).

E.g., does smoking increase the incidence of respiratory infections, does H1N1 infection increase mortality, etc.?

- **Evaluation of intervention**

Evaluation of the **efficiency** of a drug therapy or other medical (e.g., surgical, vaccination) intervention.

E.g., does the use of sleeping nets reduce the risk of malaria, does H1N1 immunization reduce mortality/morbidity, etc.? The efficiency of a diagnostic test is evaluated the same way.

Monday 7 December 15

# Methods of studies - Vital statistics



CAPTAIN JOHN GRAUNT



**NB:** Vital statistics - data of births and deaths

Monday 7 December 15

# Methods of studies - Vital statistics



CAPTAIN JOHN GRAUNT



John Graunt, 1662  
*Natural and Political Observations upon  
the Bills of Mortality*  
First analysis of vital statistics

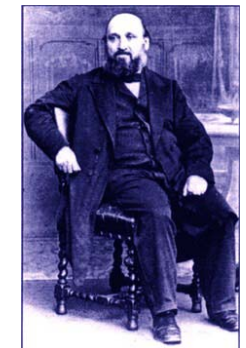
**NB:** Vital statistics - data of births and deaths

Monday 7 December 15

# Methods of studies - Vital statistics



CAPTAIN JOHN GRAUNT



John Graunt, 1662  
*Natural and Political Observations upon  
the Bills of Mortality*  
First analysis of vital statistics

Edmund Halley, 1693  
*Natural and Political Observations upon  
the Bills of Mortality*  
First survival table

**NB:** Vital statistics - data of births and deaths

Monday 7 December 15

# Methods of studies - Vital statistics



John Graunt, 1662  
*Natural and Political Observations upon the Bills of Mortality*  
First analysis of vital statistics



Edmund Halley, 1693  
*Natural and Political Observations upon the Bills of Mortality*  
First survival table



William Farr, 1807-1883  
*Registrar General, England and Wales*  
Systematic use of vital statistics

**NB:** Vital statistics - data of births and deaths

Monday 7 December 15

# Methods of clinical studies I.

## • A. Vital statistics analysis

Often provides the first clues to the association between a disease and its cause. E.g., increase in mortality from lung cancer and its possible association with increased frequency of cigarette smoking was initially noted from vital statistics data.

## • B. Observational studies

The disease is observed without actually intervening. Sampling methods are important: sample size, probability of selection into observed group.

### 1. Cross-sectional studies.

Relatively inexpensive, easily executed. Measures the prevalence but not the incidence of the disease. Therefore, associations are difficult to interpret.

**NB:**

**Prevalence** - frequency of diseased in total population at a given point in time.

**Incidence** - number of new patients in the diseased population within a time interval.

Monday 7 December 15

# Problem of cross-sectional studies

**Onchocerciasis** study: blind persons are of lower nutritional status

**Onchocerciasis:** river blindness, Robles'-disease

Pathogen: *Onchocerca volvulus* (nematode, roundworm), survives for up to 15 years as a parasite in the human body.

Transmitted to humans by the bite of a female blackfly (*Simulium yahense*).

Upon worm necrosis, the endosymbiont (*Wolbachia*, bacterium) is released, evoking tissue necrosis (e.g., in the eye).

Second leading cause of infectious blindness.



*Onchocerca volvulus* worm, as it is released from the antenna of the blackfly.



Children leading blind adults in sub-Saharan Africa.



Global distribution of onchocerciasis.

Low nutrition - defective immune response.

**But:** Blindness - interferes with nutrition.

Cause or effect? Only longitudinal (time-dependent) studies can resolve the issue.

Monday 7 December 15

# Methods of clinical studies II.

## • B. Observational studies (cont'd.)

The disease is observed without actually intervening.

### 2. Longitudinal studies

Individuals are followed as a function of time.

**Continuus:** from birth to death.

**Retrospective / prospective:** past records / present or future records.

Simplest type: periodically repeated cross-sectional studies.

Period (interval): depends on the type of disease (e.g., diarrhea repeats in short episodes).

Patient group may be **dynamic** or **fixed**.

**Dynamic group:** individuals may leave or enter the group (e.g., diarrhea in under-5-year-old children).

**Fixed group (cohort):** group remains unchanged throughout the study.

### 3. Case-control study

One group: **diseased (case group)**. The other group: **control (control group)**

E.g., does breast feeding reduce infant mortality? (Case group: infants died in first year; control group: children of identical gender living in the same area)

Highly effective in the investigation of rare diseases and large effects. Study design can be difficult.

Monday 7 December 15

# Methods of clinical studies III.

## • C. Experimental studies

Individuals are allocated *a priori* (by the investigator) into groups: control, treated.

**Considerations:** randomization, pairing, single- and double-blind studies, use of placebo, ethical issues (withholding therapy).

### 1. Clinical trials

Investigation of the efficiency of pharmaceuticals.

### 2. Vaccination trials

Investigation of the efficiency of vaccines.

### 3. Intervention trials

- Evaluation of profilactic (prevention) protocols (e.g., antimalarials).
- Evaluation of non-pharmaceutical preventive measures (e.g., sleeping nets - malaria).

Monday 7 December 15

# Clinical trials - History

- Egypt - Imhotep ( ~3000 BC, surgery, herbal medicine)
- China (~2700 BC, herbal medicine)
- Ancient Greeks and Rome (Hippocrates, 460-370 BC, Galenus, 130-200 AD)
- Middle ages - Renaissance ("Consilia", Leonardo Da Vinci - anatomy)
- Edward Jenner (1749-1823, smallpox)
- Oliver Wendel Holmes (1809-1894, anaesthesia, puerperal fever)
- **Ignatius Semmelweis (1818-1865, savior of mothers)**
- Louis Pasteur (1822-1895, fermentation, anthrax, rabies)
- Robert Koch (1843-1910, tuberculosis)
- Emil von Behring (1854-1917, diphtheria)
- Elie Mechnikov (1845-1916, phagocytosis)
- Paul Ehrlich (1854-1915, complement system)
- Florence Nightingale (1820-1910, modern nursing)
- Alexander Fleming (1928 penicillin)
- Banting and Best (1921 insulin)
- World War II - nazi human experiments, Nürenberg Code 1947
- 1953 National Institutes of Health, USA: Principles of the practice of medical experiments on humans



Semmelweis Ignác Fülöp  
(1818-1865)

Monday 7 December 15

# Poliomyelitis

*Poliomyelitis anterior acuta*, Heine-Medin disease, infantile paralysis



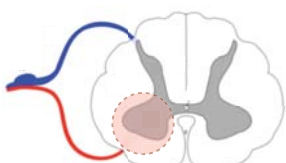
Jakob Heine,  
1840



Oskar Medin,  
1890



Flaccid paralysis of limb muscles, muscle atrophy, deformation of limbs.



Poliovirus preferably attacks the motor neurons of the anterior horn in the spinal cord.



"Iron lung" (negative-pressure ventilator)

In severe cases (in bulbospinal polio), respiratory failure occurs, requiring life-long respiratory assistance.

Monday 7 December 15

# Randomized, controlled double-blind experiments

## Polio vaccine trials



Jonas Salk, 1955  
IPV: Intravenous Polio Vaccine



Albert Sabin, 1962  
OPV: Oral Polio Vaccine ("Sabin drops")

Is the polio vaccine effective?

Consideration	Problems
The vaccine is simply provided.	Intensity of epidemic varies by itself (solution: comparative study).
Establishment of a <b>Control group</b>	Ethical concerns (reassurance: treatment also carries risks)
Comparison	Different size of control and treated groups (solution: calculate ratios)
Group selection	Lurking variable (e.g., financial background, hygiene) (solution: similar groups - <b>randomization</b> )
Selection of administration method	Effect of subconscious factors (solution: placebo)
Diagnostics	Driven diagnosis (solution: <b>double blind</b> experiment)

	Group size	Incidence
Treated group	200 000	28
Control group	200 000	71

Monday 7 December 15



# Sources of error

## Random error:

Stochastic effects. Lead to measurement uncertainty.  
Reduces precision, but does not lead to invalidity.

## Systemic error (bias):

### 1. Selection bias

Systemic, relevant differences exist between the selected and non-selected individuals. E.g., the most severe diarrhoic patients do not get selected into clinical groups in certain countries.

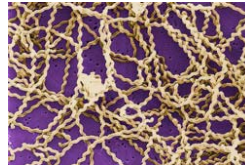
### 2. Confounding bias

Participating groups differ *a priori* in terms of the investigated parameter. E.g., prevalence of leptospirosis differs between city and village residents. However, the **gender is a confounding** parameter: leptospirosis prevalence differs according to gender, but gender composition also differs between city and village.

### 3. Information bias

Errors caused by questionnaire problems, the examiner, the responder, or instruments.

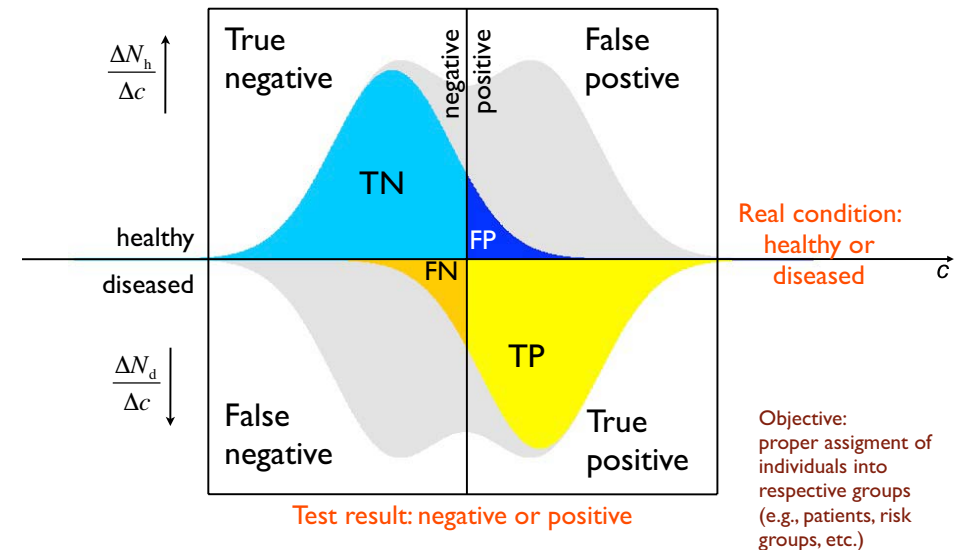
**Leptospirosis:** most frequent zoonosis (disease spreading from animals to humans). Infectious disease caused by *Leptospirae* of the *Spirochaeta* family



*Leptospira* bacteria, SEM image.

# Parameters of correct group selection

Contingency table: Confusion matrix



Monday 7 December 15

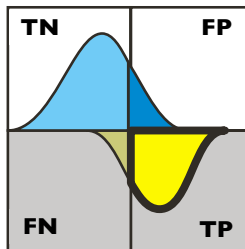
Monday 7 December 15

## Diagnostic (selection) sensitivity

-True Positive Rate (TPR)

-Hit Rate

-Recall



Probability that the test finds the diseased positive.

Positive within diseased.

$$P(\text{positive}|\text{diseased})$$

$$\frac{\text{TP}}{\text{TP} + \text{FN}} = \text{TPR} = \frac{\text{TP}}{\text{diseased}} = \frac{\text{TP}}{\text{FN} + \text{TP}}$$

Large-sensitivity tests (100%) are required in early diagnosis (screening) so that few patients remain unrecognized. E.g., in the beginning of a vaccination trial it is important to identify (and exclude) all the diseased.

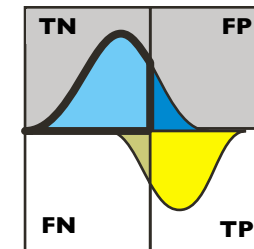
Monday 7 December 15

## Diagnostic (selection) specificity (SPC)

-True Negative Rate (TNR)

Probability that the test finds a healthy negative.

Negative among healthy



$$P(\text{negative}|\text{healthy})$$

$$\frac{\text{TN}}{\text{TN} + \text{FP}} = \text{SPC} = \frac{\text{TN}}{\text{healthy}} = \frac{\text{TN}}{\text{TN} + \text{FP}}$$

High-specificity tests (near 100 %) are important when the false positive values have severe consequences (e.g., surgery). E.g., in a post-vaccination follow-up all the healthy should be identified.

Monday 7 December 15

# Data acquisition

- Census
- Sampling
  - Simple - Sampling frame, random table
  - Complex
    - Layered (age groups, gender)
    - Multi-step (school > classes > child groups)
    - Clusters

## Size of sample?

- Ethical, financial issues
- Standard error, power


Monday 7 December 15

# Medical activity

## Series of decisions!

The logic of a research scientist and a physician are similar:

Observation	Symptoms
Consideration, hypothesis	Preliminary (target) diagnosis
Experiment	Tests (laboratory, imaging)
Theory	Diagnosis



Therapy
---------

Monday 7 December 15

# Diagnostics, differential diagnostics

The physician meets the individual, not an abstract group.

Diagnosis: identified disease of the patient.

Diagnostics: intellectual process during which the physician arrives at the diagnosis.

*dia* = apart, *gnosis* = knowledge.

Differential diagnostics: selection of correct diagnosis from many alternative choices.

Diagnosis is not a fact, but a possibility.

Steps of differential diagnosis:

1) data collection, 2) evaluation, contemplation, 3) differentiation.

Monday 7 December 15

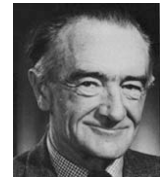
# “Evidence-based medicine”

“The sole criterion of scientific truth is the experiment.” (Richard P. Feynman)

**Application of the best available evidence gained from the scientific method in medical decision making.**

## History:

- Ancient Greeks (?)
- Ancient Chinese medicine (?)
- Avicenna (*Ibn Sīnā*) (XI. sz.): *Canon medicinae* (1025); 14 volume medical encyclopedia
- Ignatius Semmelweis (1818-1865): “savior of mothers”
- Archie Cochrane: Scottish physician epidemiologist.  
*‘Effectiveness and Efficiency: random reflections on health services’* (1972)
- Introduction of the term “Evidence-based medicine”:  
Gordon Guyatt, 1992.
- Cochrane Centers, Cochrane Collaboration, 1993.  
International network, Cochrane library, reviews.



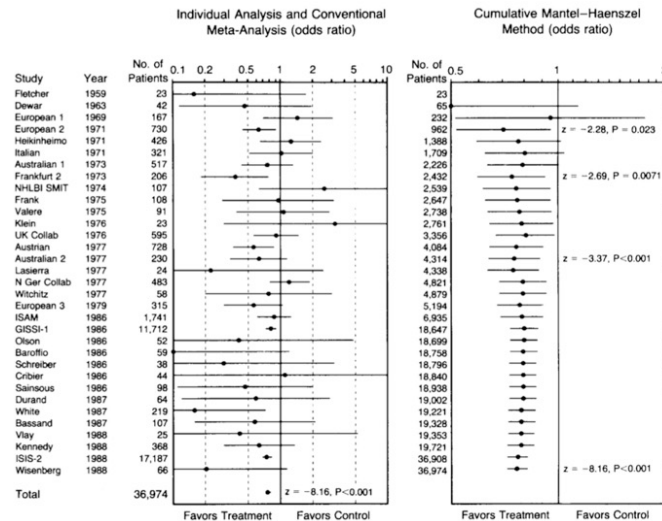
Archie Cochrane (1909-1989)



Monday 7 December 15

# “Evidence-based medicine”

## Effect of streptokinase treatment in acute myocardial infarction



### N.B.:

- **meta-analysis:** combined analysis examining several hypotheses.
- **odds ratio:** one parameter of probability. For odds = 1 the probability of the given outcome is identical in both groups.
- With a proper evaluation of clinical trial results the efficiency of streptokinase treatment could have been identified by 1973.

Monday 7 December 15

# “Evidence-based medicine”

### Practice:

1. Evidence-based guidelines - practice of evidence-based medicine at the organizational or institutional level.
2. Evidence-based individual decision making - evidence-based medicine as practiced by the individual health care provider

### Types:

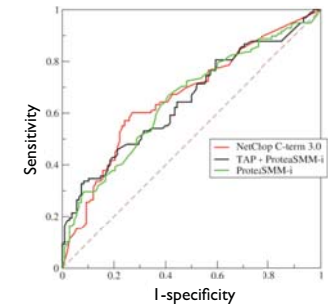
1. Application of the recommendation of original medical literature.
2. Application of the recommendation of review literature.
3. Application of the recommendations of medical organizations.

### How good is the evidence?

- I. Based on criteria of professional organizations. E.g.:
  - I. Evidence obtained in properly executed double blind randomized trial.
  - II. Evidence obtained in properly designed controlled trial (but with no randomization).
  - III. Opinions of selected authorities.

### 2. Statistical criteria.

Mathematical analysis of the efficiency of diagnostic and therapeutic methods. E.g., **AUC-ROC curve** (“area under the receiver operating characteristic curve”).



Monday 7 December 15

## Computer-aided medical decisions I.

Diagnostic steps (or therapeutic decisions) assisted by computer algorithms.

**Medical knowledge:** datasets of symptoms and formalized diseases.

**Symptoms:** sum of information characterizing the health status of the patient (anamnesis, physical signs, laboratory tests, diagnostic imaging tests)

**Formalized diseases:** diagnostic categories organized into logical order (e.g., upper respiratory diseases, malignant tumors, etc.)

Monday 7 December 15

## Computer-aided medical decisions II.

- Computer Aided Diagnosis (CAD), diagnostics supported with artificial intelligence.
- **Objectives:**
  - Simulation of specialist (medical) arguments.
  - Reduce guessing (reduce number of hypotheses or target diagnoses)
  - Consideration of pathophysiological argumentation.
- Generally employed **logical iteration:**
  1. Do the observed symptoms occur in the considered diseases?
  2. Assign weighting points to the diseases according to the number of observed symptoms.
  3. Rank the diseases according to the points.
  4. Investigate whether the observed symptoms contain ones which are not present in the most highly-ranked disease.
  5. If yes, consider the next disease in the ranking order.
  6. In case of **new symptoms** the iteration is started from the beginning (stage 1); if not, the diagnosis is established according to the ranking.
- **Problems:**
  - The **frequency** and **severity** of the symptoms are difficult to evaluate correctly.
  - New symptoms make the iteration very difficult.

Monday 7 December 15

# Computer-aided medical decisions III.

**Objectives:** set-theory associations are investigated between symptoms and diseases.

## Medical arguments:

"Runny nose is *almost always* present in common cold."

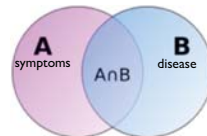
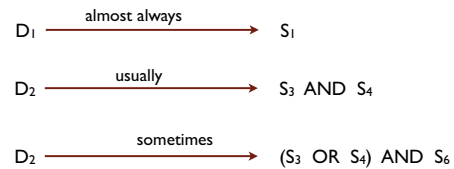
"Acute pyelonephritis is *usually* accompanied by cystitis and inflammation."

"Acute pyelonephritis is *sometimes* accompanied by fever, shiver and malaise (discomfort)."

Common cold, acute pyelonephritis: diseases ( $D_{1-2}$ )

Runny nose, cystitis, inflammation, shiver, malaise: symptoms ( $S_{1-6}$ )

"Almost always, usually, sometimes": mathematical conditional operators



## Boolean operators:

$A \text{ OR } B$ : union

$A \text{ AND } B$ : intersection

$A \text{ XOR } B$ : union-intersection

# Faith - certainty - knowledge

Is faith in our knowledge strong enough to bet our life on it?



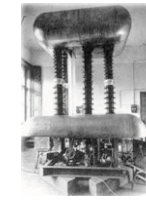
Károly Simonyi (1916-2001)



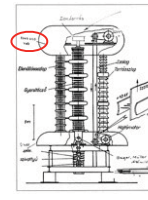
Accelerator today (ELTE)



Statistics is inherently manifested in human thinking...



Van de Graaff particle accelerator (Sopron, 1951)



Murillo: Adoration of the magi