

# Biost 517

## Applied Biostatistics I

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### Lecture 5: Descriptive Measures of Spread

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1

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## Lecture Outline

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- Univariate Measures of Spread
- Univariate Measures of Skewness
- Univariate Measures of Tendency to Extreme Values
- Depictions of Entire Distribution
- Example: Prognostic value of PSA

2

## Univariate Measures of Spread

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## Range

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- Definition varies:
  - Minimum, maximum values
  - Maximum - minimum is used by some people

4

## Range: Types of Variables

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- Only makes sense for ordered variables
- Not appropriate for censored time to event
  - Instead use Kaplan-Meier curves to estimate survival or censoring distributions

5

## Range: Purpose

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- Detecting errors in data collection, entry
  - Values out of range
- Materials and Methods
  - Limits of subjects in sample
- Less useful for quantifying or comparing distributions

6

## Range: Scientific Questions

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- Scientific questions
  - Not useful unless range of possible values differs across populations
    - But even then, the sampling distribution of the min and max depends quite heavily on the sample size

7

## Minimum: Sampling Distribution

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- Minimum of  $n$  independent and identically distributed random variables

$$\Pr(X_{(1)} \geq x) = (\Pr(X \geq x))^n$$

- Tends to estimate the  $1/(n+1)$ -th quantile of the distribution of  $X$ 
  - 25th %ile when  $n = 3$
  - 1st %ile when  $n = 99$

8

## Maximum: Sampling Distribution

.....

- Maximum of n independent and identically distributed random variables

$$\Pr(X_{(n)} \leq x) = (\Pr(X \leq x))^n$$

- Tends to estimate the  $n/(n+1)$ -th quantile of the distribution of X
  - 75th %ile when  $n = 3$
  - 99th %ile when  $n = 99$

9

## Interquartile Range (IQR)

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- Definition varies:
  - 25th, 75th percentiles of sample
  - Difference between quartiles is used by some people

10

## IQR: Type of Variables

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- Only makes sense for ordered variables
- Not appropriate for censored time to event
  - Estimate quantiles using Kaplan-Meier

11

## IQR: Purpose

.....

- Materials and Methods: Characterizing the sample
  - A measure of spread less sensitive to outliers
    - Central 50% of the data
- Assessing validity of assumptions
  - Check for equal spread of distributions
    - BUT: most assumptions are about variances

12

## IQR: Scientific Uses

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- Quantifying or comparing distributions
  - Sometimes we are scientifically interested in the spread of the distribution
  - The sample quartiles consistently estimate the population quartiles
    - Central tendency not based on sample size

13

## Variance

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- Definition
  - The average squared distance from the mean

$$\text{population } \sigma^2 = \frac{1}{n} \sum_{i=1}^n (X_i - E(X))^2$$

$$\text{sample } s^2 = \frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2$$

14

## Variance: Interpretation

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- Population variance has theoretical basis as second central moment of distribution
  - Squared error as a measure of spread
    - Squaring accentuates errors
    - More convenient mathematically
- Relevance to sampling distributions used in statistical inference
  - Variance is a fundamental parameter of the normal distribution
  - Sample variance is an unbiased estimator

15

## Variance: Types of Variables

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- Variance is a mean
  - Best used with numeric variables having interpretable differences
    - BUT it will be used whenever we are comparing means of distributions
  - Problematic with censored measurements
    - Times are mixture of times to event and times to censoring
    - Indicators of event are measured over varying times

16

## Variance: Purpose

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- Materials and Methods: Characterizing the spread of the distribution
  - Larger variance means more variable measurements
  - But units are squared units of observations
    - E.g., variance of age is measured in years squared
  - And sensitive to outliers
- Assessing validity of models
  - Many analysis methods rely on assumptions about within group variances

17

## Variance: Scientific Questions

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- Quantifying or comparing distributions
  - Sometimes we are scientifically interested in the spread of the distribution
  - As a mean, the sampling distribution of the variance in large samples is known
    - But it does take larger sample sizes than is required for inference about the mean

18

## Standard Deviation (SD)

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- Definition
  - The square root of the variance

population  $\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^n (X_i - E(X))^2}$

sample  $s = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2}$

19

## SD: Interpretation

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- Related to variance; same units as mean
  - Sample SD is not unbiased for population SD
- “Width” of the distribution
  - For any distribution
    - At least 89% of data within 3 SD of mean
  - For the **normal (Gaussian)** distribution
    - About 2/3 of data is within 1 SD of mean
    - About 95% of data is within 2 SD of mean
    - About 99.7% of data is within 3 SD of mean

20

## SD vs Variance: Uses

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- Variance is just the squared SD
  - Use SD descriptively
    - Units are the same as the measurements
    - Can evaluate equality of variances for assumptions
      - If SDs are equal, then so are variances
  - Use variance for inference
    - Mathematics and distributional theory is better defined for the variance
- SD used for standardization of statistics when making inference about means

21

## SD: Standardized Statistics

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- Often we measure distance of data from mean in units of SD's
  - (sometimes called “normalized”, but does not guarantee normality of data)

$$X_1, \dots, X_n \sim (\text{mean } \mu, \text{variance } \sigma^2)$$

$$Z_i = \frac{X_i - \mu}{\sigma}$$

22

## Mean Deviation

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- Definition
  - The average absolute distance from the mean

$$\frac{1}{n} \sum_{i=1}^n |X_i - \bar{X}|$$

23

## Mean Deviation: Uses

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- By types of variables
  - Mean deviation is a mean
    - Best for numeric variables having interpretable differences and measured without censoring
- By purpose of descriptive statistics
  - Possible alternative to SD / variance, however
    - Absolute values are harder to work with in calculus
    - Sampling distribution is thus harder to derive
    - Not helpful in statistical inference

24

## Univariate Measures of Skewness

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25

## Coefficient of Skewness

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- Definition
  - The average cubed distance from the mean divided by cube of the standard deviation

$$\text{sample} \quad \frac{1}{(n-1)s^3} \sum_{i=1}^n (X_i - \bar{X})^3$$

26

## Skewness: Interpretation

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- Cubing the distance from the mean
  - Accentuates outliers
  - Does allow positive outliers to cancel out negative outliers
- Symmetric distributions will have a skewness coefficient of 0

27

## Skewness: Types of variables

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- Skewness is a mean
  - Best used with numeric variables having interpretable differences
  - Not of interest with censored random variables

28

## Skewness: Purpose

.....

- Materials and Methods: Characterizing the distribution
  - Describing tendency to outliers (in one direction)
- Assessing validity of assumptions
  - Sometimes need symmetric distributions
  - Distributions with outliers generally require larger sample sizes for accurate inference
  - Outliers are sometimes too influential

29

## Other Measures of Skewness

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- I rarely (never?) compute the coefficient of skewness
  - Usually only interested in qualitatively describing tendency to large (or small) outlying values
- I just use other descriptive statistics to judge possibility of outliers
  - Mean, SD, min, p25, med, p50, max
  - Look at histogram if indicated

30

## Symmetric distributions

.....

- Properties of symmetric distributions
  - Mean is equal to the median
  - The median is midway between the minimum and maximum
  - The 25<sup>th</sup> and 75<sup>th</sup> percentiles are equidistant from the median

31

## Signs of Skewed Distributions

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- Descriptive statistics which suggest skewed distributions (especially when due to outliers)
  - The sample median is
    - markedly different from the sample mean
      - (Mean is greatly affected by outliers)
    - not midway between the minimum and maximum
    - not midway between the 25<sup>th</sup> and 75<sup>th</sup> percentiles

32



## Signs of Skewed Distributions

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- An additional criterion is based on the properties of the standard deviation
  - If about 2 standard deviations away from the mean includes impossible values, then it is often the case that large outliers exist
  - E.g., for measurements that must be positive, a standard deviation greater than one-half the mean may suggest the presence of outliers

33

## Univariate Measures of Tendency to Extreme Data

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34

## Coefficient of Kurtosis

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- Definition of kurtosis
  - The average fourth power distance from the mean divided by the square of the variance
    - Coefficient of kurtosis subtracts 3

$$\frac{1}{(n-1)s^4} \sum_{i=1}^n (X_i - \bar{X})^4 - 3$$

35

## Kurtosis: Interpretation

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- The fourth central moment will accentuate observations in the tail of the distribution
- In the normal distribution, the fourth central moment is  $3\sigma^4$ 
  - Coefficient of kurtosis is 0

36

## Kurtosis: Types of Variables

.....

- Kurtosis is a mean
  - Best used with numeric variables having interpretable differences
  - (As usual,) variables measuring censored times to events can not be described appropriately using the sample coefficient of kurtosis

37

## Coefficient of Kurtosis: Uses

.....

- By purpose of descriptive statistics
  - Characterizing the distribution
    - Describing tendency to heavy tails
  - Assessing validity of assumptions
    - The heavier the tails, the larger the sample size needed before the central limit theorem is a reasonable approximation
    - BUT, heavy symmetric tails often shows up in samples as skewness
      - I just tend to look for skewness

38

## Characterizing the Entire Distribution

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### General Comments

39

## Statistical Setting

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- Statistical analysis of a sample
  - Usually want to make inference to population
- Probability model
  - Describes variation observed in a population
  - We regard that the data were sampled from that probability model

40

## Probability Model Classification

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- The type of measurement is either
  - Discrete: a countable number of different values are possible for the measurement, or
  - Continuous: an uncountable number of different values are possible for the measurement

41

## Samples vs Populations

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- All (finite) samples are discrete
  - Descriptive measures appropriate for discrete measurements always make sense
- Often, however, we will be trying to estimate quantities that are only appropriate for continuous measurements (e.g., densities)

42

## Describing Discrete Distns

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- Typically give probability of each outcome
  - Prob mass function (pmf):  $\Pr(X = x)$  for each  $x$ 
    - Explicit numbers
      - (only possibility for unordered categorical data)
    - Formulas
      - (especially for measurements representing counts)
- Ordered variables: we can also consider the cumulative distribution function (cdf):
  - $\Pr(X \leq x)$  for every  $x$

43

## Describing Continuous Distns

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- Typically give a function that can be used to define the probability that the random variable is in some interval
  - Density (pdf)
    - Similar to  $\Pr(X = x)$ 
      - (but must be integrated over an interval)
  - Cumulative distribution function (cdf)
    - $\Pr(X \leq x)$  for every  $x$
  - Survivor function
    - $\Pr(X > x)$  for every  $x$

44

## Why Describe Entire Distribution

.....

- Assessing validity of data
  - Viewing outliers
- Quantifying distributions within groups
  - Simultaneously consider location, spread
- Assessing validity of assumptions for modeling
  - Outliers, shape of distribution
- Hypothesis generation
  - Multimodality, etc.

45

## Tabling a Distribution

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46

## Frequency Table

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- Frequency or proportion for each possible value of a discrete variable
  - Not defined for a continuous measurement in a population, but always defined for a sample
  - With unordered categorical data this is the most logical summary
  - With a sample from a continuous variable, this makes most sense when data is grouped into intervals
    - E.g., age divided into decades

47

## Frequency Table: Issues

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- Missing data
  - Must consider whether missing data should be counted as part of the denominator or not
- Order of listing categories
  - Unordered data: alphabetical versus most frequent, etc.
  - Ordered data: usually use ordering

48

## Stata Ex: Bone Scan Score

- `tabulate bss`

bss	Freq.	Percent	Cum.
1	5	10.42	10.42
2	13	27.08	37.50
3	30	62.50	100.00
Total	48	100.00	

49

## Stata Ex: Bone Scan Score

- `tabulate bss, missing`

bss	Freq.	Percent	Cum.
1	5	10.00	10.00
2	13	26.00	36.00
3	30	60.00	96.00
.	2	4.00	100.00
Total	50	100.00	

50

## Frequency Table: Issues

- Categorization of continuous data
  - Number of groups
    - Tradeoffs between finer resolution and lots of groups with zero counts
    - Based on average counts per group?
      - » log base 2 of N?
  - Width of intervals
  - Cutpoints
    - Based on scientific interest
    - Based on number of observations
      - » E.g., intervals based on quintiles

51

## Categorizing Continuous Data

- My recommendations
  - Groups based on scientific considerations
    - E.g., Age by decades rather than quintiles
  - Number of groups
    - Reasonable sample sizes for reliable estimates
    - Space constraints in tables

52

## Stata: Categorizing Data

- Categorizing continuous random variables
  - “recode var rulelist”
    - Replaces values of the variable
    - Rules of the form (for variable x)
      - $\text{min}/3=1$  (changes  $x \leq 3$  to 1)
      - $4=2$  (changes 4 to 2)
      - $5/9=3$  (changes  $5 \leq x \leq 9$  to 3)
      - $10/\text{max}=4$  (changes  $x \geq 10$  to 4)
    - Each rule contains both endpoints of range, last rule listed is used to resolve conflicts
    - Labels can be assigned using “label”

53

## Stata Ex: Age

- `tabulate age`

<u>age</u>	<u>Freq.</u>	<u>Percent</u>	<u>Cum.</u>
58	2	4.00	4.00
61	5	10.00	14.00
62	1	2.00	16.00
63	5	10.00	26.00
64	5	10.00	36.00
65	2	4.00	40.00
66	6	12.00	52.00
68	7	14.00	66.00
69	3	6.00	72.00
70	2	4.00	76.00
71	4	8.00	84.00
73	1	2.00	86.00
74	1	2.00	88.00
75	2	4.00	92.00
78	1	2.00	94.00
79	1	2.00	96.00
81	1	2.00	98.00
86	1	2.00	100.00
Total	50	100.00	

54

## Stata Ex: Categorizing Age

- `g agectg = age`
- `recode agectg min/60=1 60/70=2 70/80=3 80/max=4`
- `tabulate agectg`

<u>agectg</u>	<u>Freq.</u>	<u>Percent</u>	<u>Cum.</u>
1	2	4.00	4.00
2	34	68.00	72.00
3	12	24.00	96.00
4	2	4.00	100.00
Total	50	100.00	

55

## Graphing a Distribution

56

## Stem-leaf Plot

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- Stem-leaf plot : Intermediate to a tabular listing of the data and a histogram
  - Only appropriate for ordered quantitative data
  - Construction of the stem-leaf plot
    - Each measurement is divided into
      - a “stem” by truncating the observation in some position, e.g., tens digit
      - a “leaf” the remaining value
      - (thus the measurement is equal to the “stem”+“leaf”)

57

## Stem-leaf Plot

.....

- Construction of the stem-leaf plot (cont.)
  - The rows are the ordered “stem”s
  - In each row, the first digit of all the “leaf”s for that stem are listed (ordered or unordered)
- Advantages
  - Graphical appearance of a histogram
  - Retains more information about the individual measurements
  - Can be made “on the fly”
- Stata Command: “stem”

58

## Stata Ex: Stem-Leaf Plot of Age

.....

```
. stem age
      5. | 88
      6* | 11111
      6t | 233333
      6f | 4444455
      6s | 666666
      6. | 8888888999
      7* | 001111
      7t | 3
      7f | 455
      7s |
      7. | 89
      8* | 1
      8t |
      8f |
      8s | 6
```

59

## S-Plus: Stem-Leaf Plot of Age

.....

Decimal point is 1 place to the right of the colon

```
5 : 88
6 : 1111123333344444
6 : 55666666888888999
7 : 001111134
7 : 5589
8 : 1
```

High: 86

60

## Bar Plots

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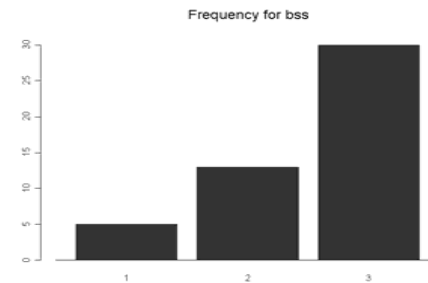
- Frequencies for categorical data
  - A separate bar for each category
  - (Not exactly the same as a histogram, which is used to estimate a density)

61

## Ex: Bone Scan Score (S-Plus)

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- Bar plot of bone scan score in PSA data



62

## Histograms

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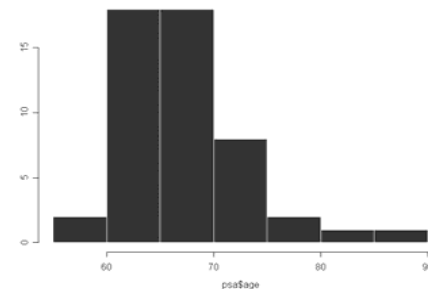
- A plot of the frequency of (categorized) continuous measurements
  - Tabulate counts of each (grouped) measurement
  - Plot bars for each group
    - Width is width of interval
    - Height such that area is proportional to the count
      - (wider intervals should decrease the height accordingly)

63

## Ex: Histogram of Age (S-Plus)

.....

- Histogram of age in PSA dataset



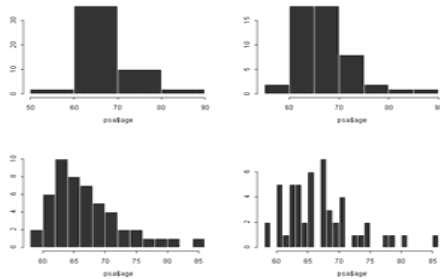
64



## Ex: Histograms of Age (S-Plus)

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- Histograms with varying number of groups can look quite different for the same data



65

## Histogram: Comments

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- Histograms are attempting to estimate a density
- The appearance of a histogram can be quite variable depending upon the selection of the groups
  - Number of groups
  - Cutpoints of groups
- Density estimation is probably better

66

## Density Estimation

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- Density estimates are essentially smoothed histograms
  - Only make sense for continuous measurements
- Smoothers can be used to provide better estimates of the density
  - In a kernel smoother, each point is “distributed” over a range of measurements
  - The “kernel” describes how many adjacent measurements are used to estimate the density and how the points are weighted

67

## Stata: Density Estimates

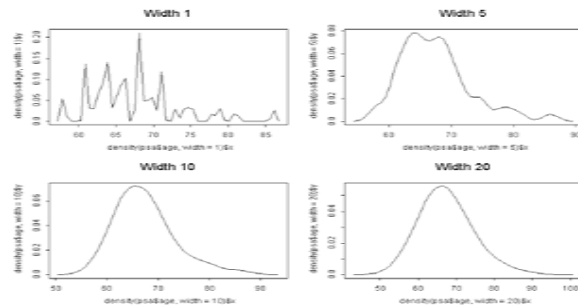
.....

- “`kdensity var, (options)`”
  - Options include
    - Shape of kernel (biweight, cosine, etc.)
    - Width of window
      - » how distant a point can influence density estimate
    - Number of points estimated
- (I tend to use default values for the options)

68

## Ex: Density Estimation

- Age from PSA data set (Gaussian window, varying widths)



69

## Cumulative Distribution, Survivor Graphs

- For ordered variables
  - Used to estimate the corresponding quantity for a population
    - These functions can sometimes be estimated (and graphed) for censored data (unlike histograms, densities, etc.)
  - We will discuss these graphs further next lecture

70

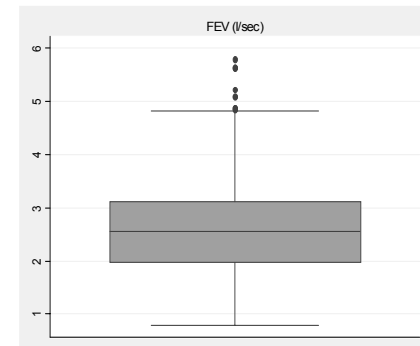
## Box Plots

- Display several summary measures simultaneously
  - A box is drawn from the lower quartile to the upper quartile, with a dividing line drawn at the median
  - Whiskers are either
    - min and max (in the absence of “outliers”), or
    - limits of “nonoutlying” data (as defined by an arbitrary criterion)
  - “Outliers” are plotted separately

71

## Box Plots: FEV

- graph box fev, t1 (“FEV(l/sec)”)



72

## Example: Use of Univariate Descriptive Statistics

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73

## Standard Univariate Description

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- Often easier to just ask for standard descriptive statistics on all variables
  - Sample size
  - Number of missing
  - Mean
  - Standard Deviation
  - Minimum
  - 25<sup>th</sup> percentile
  - Median (50<sup>th</sup> percentile)
  - 75<sup>th</sup> percentile
  - Maximum

74

## Standard Univariate Description

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- We must then consider how to use the relevant statistics (and how to ignore the irrelevant ones)
  - Scientific relevance
  
  - Descriptive measures
    - Measures of location
    - Measures of spread
    - Detecting outliers

75

## Example:

.....

- Prognostic value of PSA in hormonally treated prostate cancer
  - Usefulness of nadir PSA in predicting time in remission
  
  - Type of question?
    - Comparing distributions?
    - Predicting time in remission?

76

## Example: PSA Data Variables

- Prognostic value of PSA in hormonally treated prostate cancer
  - ptid Patient ID
  - nadir Lowest PSA following treatment
  - pretx Pre-treatment PSA
  - ps Performance status (0 – 100)
  - bss Bone scan score (1, 2, or 3)
  - grade Tumor grade (1, 2, or 3)
  - age Age (years)
  - obstime Time until relapse or end of study (months)
  - inrem In remission at obstime

77

## Ex: PSA Descriptive Statistics

	<u>n</u>	<u>ms</u>	<u>mean</u>	<u>stdev</u>	<u>min</u>	<u>25%ile</u>	<u>mdn</u>	<u>75%ile</u>	<u>max</u>
ptid	50	0	25.5	14.6	1.0	13.2	25.5	37.8	50
nadir	50	0	16.4	39.2	0.1	0.2	1.0	9.5	183
pretx	50	7	670.8	1287.6	4.8	52.0	127.0	408.0	4797
ps	50	2	80.8	11.1	50.0	80.0	80.0	90.0	100
bss	50	2	2.5	0.7	1.0	2.0	3.0	3.0	3
grade	50	9	2.2	0.8	1.0	2.0	2.0	3.0	3
age	50	0	67.4	5.8	58.0	63.2	66.0	70.0	86
obstime	50	0	28.5	18.4	1.0	12.5	28.0	42.0	75
inrem	50	0	0.3	0.4	0.0	0.0	0.0	1.0	1

78

## Example: PSA Data Variables

- Types of data
  - ptid Unordered categorical (coded as numbers)
  - nadir Continuous (ratio)
  - pretx Continuous (ratio)
  - ps Continuous (ratio) (measured discretely)
  - bss Ordered categorical
  - grade Ordered categorical
  - age Continuous (ratio)
  - obstime Censored continuous
  - inrem Binary indicator of censoring for obstime

79

## Example: PSA Data Variables

- Relevant univariate statistics
  - ptid (Mode: are observations independent?)
  - nadir Mean, SD, Min, Max, Quantiles
  - pretx Mean, SD, Min, Max, Quantiles
  - ps Mean, SD, Min, Max, Quantiles
  - bss Min, Max, Quantiles (Frequencies)
  - grade Min, Max, Quantiles (Frequencies)
  - age Mean, SD, Min, Max, Quantiles
  - obstime (Kaplan-Meier estimates needed)
  - inrem (Kaplan-Meier estimates needed, though mean of inrem does tell us proportion of uncensored observations but not time)

80

## Example: Relevant Univariate Statistics

```

      n  ms  mean  stdev  min  25%le  mdn  75%le  max
ptid 50  0
nadir 50  0  16.4   39.2  0.1   0.2   1.0   9.5   183
pretx 50  7 670.8 1287.6  4.8  52.0 127.0 408.0 4797
  ps   50  2  80.8   11.1 50.0  80.0  80.0  90.0  100
  bss  50  2           1.0  2.0  3.0  3.0    3
grade 50  9           1.0  2.0  2.0  3.0    3
  age  50  0  67.4    5.8 58.0  63.2  66.0  70.0  86
obstime 50  0
inrem  50  0

```

81

## Example: PSA Data Skewness

- Detecting skewness
  - Both nadir and pretx appear markedly skewed
    - Mean, median markedly different
    - Median not midpoint of range
    - Median not midpoint of interquartile range
    - SD greater than one-half of mean for these positive measurements
  - No evidence of skewness (that I care about) for age or pss

82

## Ex: Bone Scan Score

- tabulate bss

```

      bss |  Freq.  Percent   Cum.
-----+-----
      1 |      5    10.42   10.42
      2 |     13    27.08   37.50
      3 |     30    62.50  100.00
-----+-----
Total |     48   100.00

```

83

## Ex: Bone Scan Score

- tabulate bss, missing

```

      bss |  Freq.  Percent   Cum.
-----+-----
      1 |      5    10.00   10.00
      2 |     13    26.00   36.00
      3 |     30    60.00   96.00
      . |      2     4.00  100.00
-----+-----
Total |     50   100.00

```

84

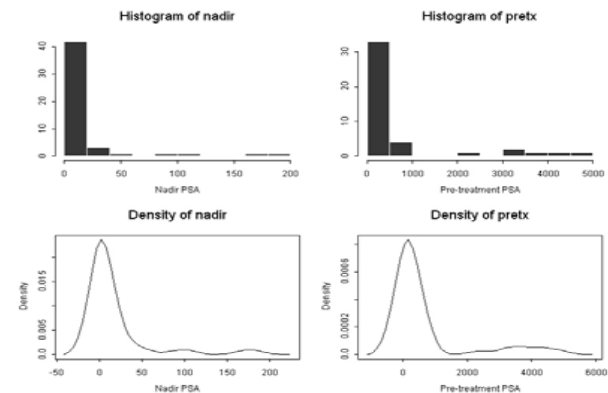
## Ex: Categorizing Age

- g agetcg = age
- recode agetcg min/60=1 60/70=2 70/80=3 80/max=4
- tabulate agetcg

agetcg	Freq.	Percent	Cum.
1	2	4.00	4.00
2	34	68.00	72.00
3	12	24.00	96.00
4	2	4.00	100.00
Total	50	100.00	

85

## Example: PSA Data Variables



86

## Example: PSA Data Variables

