

Analysis of categorical data

S3

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Categorical data

- One-way contingency table = frequency table

	Frequency (%)
Blue	14 (34)
Yellow	22 (54)
Green	5 (12)
Total	41 (100)

- Two-way contingency tables = cross tabs

– 2-by-2

Vital status	Exposed		
	Yes	No	
Deceased	18	4	22
Nondeceased	18	365	383
	36	369	405

– r-by-c

Age	Taste			Total
	Mild	Medium	Strong	
Young	9	14	3	26
Old	4	17	12	33
	13	31	15	59

Which test to use when?

Groups	Outcome data scale		
	Binomial	Nominal	Ordinal (Continuous)
Single sample	Binomial	χ^2 goodness of fit	
Paired samples	McNemar Sign		Wilcoxon Signed Rank One-sample T
2 independent samples	Fisher's Exact Pearson's χ^2 Cochran-Mantel-Haenszel (stratified)	Fisher's Exact Pearson's χ^2	Wilcoxon Mann Whitney Two-sample T
K independent unordered samples	Fisher's Exact Pearson's χ^2	Fisher's Exact Pearson's χ^2	ANOVA Kruskal-Wallis
K independent ordered samples	Linear-by-linear		Linear-by-linear

Anaplastic Large-Cell Lymphoma in Women With Breast Implants

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Context Recently, we identified 2 patients with anaplastic large T-cell lymphoma (ALCL) negative for tyrosine kinase anaplastic lymphoma kinase (ALK-negative) in the fibrous capsule of silicone breast prostheses, placed for cosmetic reasons. Similar cases have been reported in the literature. Although an increased risk of ALCL in patients with breast prostheses has been speculated, no studies have been conducted so far.

Objective To determine whether ALCL risk is associated with breast prostheses.

Design A search for all patients with lymphoma in the breast diagnosed in the Netherlands between 1990 and 2006 was performed through the population-based nationwide pathology database. Subsequently, we performed an individually matched

- De Jong et al., *JAMA* 2008
- Observation of 2 pts with ALCL in fibrous capsule of saline-filled silicone breast implant, some similar cases described in literature
- Question: Do breast implants cause ALCL?
- What type of study would you do to investigate this?

Answer: case-control study

- Identified all 429 pts with biopsy-proven primary NHL of the breast in 1990–2006 in NL from PALGA
- 11/389 female pts had ALCL
- 11 subjects with other lymphomas in the breast as controls
- Medical records obtained for all cases & controls
- Presence of breast implant asked by letter to treating physician

Observed contingency table

Breast implant	Cases	Controls	
Yes	5	1	6
No	6	10	16
	11	11	22

What is the hypothesis (and alternative) of interest here?

Observed contingency table

Breast implant	Cases	Controls	
Yes	5	1	6
No	6	10	16
	11	11	22

H_0 : % pts w/ breast implants equal among cases & controls

H_1 : proportions not equal

equivalently:

H_0 : no association between breast implants & case status

H_1 : association

Proportion of implants under the null?

Breast implant	Cases	Controls	
Yes	5	1	6
No	6	10	16
	11	11	22

$$6/22 = .27 \text{ (27\%)}$$

Confidence interval around a single proportion

$$\left[p - z_{\alpha/2} \sqrt{p(1-p)/n}, \quad p + z_{\alpha/2} \sqrt{p(1-p)/n} \right]$$

$$\Rightarrow \left[.27 - 1.96 \sqrt{.27(1-.27)/22}, \quad .27 + 1.96 \sqrt{.27(1-.27)/22} \right]$$

$$\Rightarrow [.08, .46]$$

(for large n, and p not near zero or unity)

CI around single proportion in SPSS¹

Dataset alcl_small_casecontrol.sav

implant				
	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	16	72.7	72.7
	1.00	6	27.3	100.0
Total		22	100.0	

Ratio Statistics for implant / one

Mean		.273
95% Confidence Interval for Mean	Lower Bound	.071
	Upper Bound	.475

The confidence intervals are constructed by assuming a Normal distribution for the ratios.

Pearson chi-square test

Compare observed table w/ expected table under the null

Breast implant	Observed		Expected		
	Cases	Controls	Cases	Controls	
Yes	5	1	$11*6/22=3$	$11*6/22=3$	6
No	6	10	$11*16/22=8$	$11*16/22=8$	16
	11	11	11	11	22

$$\sum_{\text{cells}} \frac{(|O - E| - 1/2)^2}{E} > \chi^2_{(\#rows-1)*(\#columns-1), .95}$$

where O & E are observed & expected frequencies, respectively, for each cell in 2×2 contingency table; $1/2$ is continuity or Yates' correction (little difference unless $n < 40$ or E s very small)

Here:

$$(|5 - 3| - .5)^2/3 + (|1 - 3| - .5)^2/3 + (|6 - 8| - .5)^2/8 + (|10 - 8| - .5)^2/8 = 2.06$$

at $(2-1)*(2-1)=1$ degrees of freedom

Pearson chi-square in SPSS²

case * implant Crosstabulation

Count		implant		Total
		.00	1.00	
case	.00	10	1	11
	1.00	6	5	11
Total		16	6	22

Risk Estimate

	Value	95% Confidence Interval	
		Lower	Upper
Odds Ratio for case (.00 / 1.00)	8.333	.776	89.470
For cohort implant = .00	1.667	.942	2.950
For cohort implant = 1.00	.200	.028	1.445
N of Valid Cases	22		

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	3.667 ^a	1	.056		
Continuity Correction ^b	2.063	1	.151		
Likelihood Ratio	3.922	1	.048		
Fisher's Exact Test				.149	.074
Linear-by-Linear Association	3.500	1	.061		
N of Valid Cases	22				

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 3.00.

b. Computed only for a 2x2 table

Chi-square tests

- Pearson: based on O-E under independence
- Goodness of fit: same as Pearson, but can be used with E based on specific distribution other than independence
- Can all be extended to r-by-c tables w/ $DF=(r-1)*(c-1)$
- Chi-square tests are asymptotic tests (for large N)
for small N: Fisher's exact test

An example of Fisher's exact test

Observed table	Next stronger	Strongest table
7 2 9	8 1 9	9 0 9
5 6 11	4 7 11	3 8 11
12 8 20	12 8 20	12 8 20

- Obtain tables stronger than the observed table by reducing the cell with the lowest count by 1 in steps
- Compute the probability for each table $P = \frac{(a+b)!(c+d)!(a+c)!(b+d)!}{N!a!b!c!d!}$

$$\left. \begin{aligned}
 P_{\text{observed}} &= \frac{9!11!12!8!}{20!7!2!5!6!} = .132 \\
 P_{\text{stronger}} &= \frac{9!11!12!8!}{20!8!1!4!7!} = .024 \\
 P_{\text{strongest}} &= \frac{9!11!12!8!}{20!9!0!3!8!} = .001
 \end{aligned} \right\} P_{\text{total (one-tailed)}} = .157$$

Interpretation of Fisher's exact test

- $p = .157$, i.e., there is a 15.7% chance under the null that, given the sample size, we would get a table as strong or stronger as the observed table by chance alone
- At $\alpha = .05$, distribution in observed table is not significantly different from chance
- Possible for r-by-c tables
- 2-tailed p is sum of probabilities of all tables with p equal or less than the observed p

Is a 2-by-2 analysis sufficient? Confounding?

- A variable correlated with the variable of interest (e.g., exposure or treatment) and with the outcome is a potential confounder
- E.g., age and calendar year of diagnosis are potential confounders of the association between breast implants & ALCL
 1. Prevalence of breast implants is increasing with calendar year
 2. ALCL is more common at older age
 3. ALCL cases have fewer breast implants than random sample of non-ALCL cases: apparent protective effect, but due to confounding bias

ALCL study: matching to control confounding

- 11 controls matched to cases by age at DX (within 5 yrs) & yr of DX (within 2 yrs)
- More specifically: for each case, one woman is randomly chosen from all women with an age at DX within 5 yrs of that of the case & diagnosed within 2 yrs of the case

McNemar test for dependent samples

- 2 dependent samples
 - Before-after or other repeated measure of same units
 - Matched-pairs studies with similar units measured at different times
- Depends only on number of discordant pairs (diagonal)

Before	After		Case	Control	
	Exposed	Nonexposed		Exp.	Nonexp.
Exposed	a	b	Exp.	a	b
Nonexposed	c	d	Nonexp.	c	d

- $\chi^2 = (|b-c|-1)^2 / (b+c)$ at 1 DF (continuity-corrected)

- Other example: pair of raters both evaluate same set of objects & provide binary (yes/no) rating
- Test focuses on discordant pairs – pairs where the raters disagree
- Discordant pairs skewed in one direction (e.g., more yes/no than no/yes) → evidence that overall proportion of yeses higher for one rater than the other
- Discordant pairs split evenly → evidence that overall proportion about the same for both raters
- Multivariate analogon to McNemar is conditional logistic regression

ALCL study: McNemar test for 1:1 matched design³

Data set alcl_one_to_one_matched.sav

	implant_cases	implant_controls
1	1	0
2	1	0
3	1	0
4	1	0
5	1	0
6	0	1
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0

implant_controls & implant_cases

	implant_cases	
implant_controls	0	1
0	5	5
1	1	0

Test Statistics^b

	implant_controls & implant_cases
N	11
Exact Sig. (2-tailed)	.219 ^a
Exact Sig. (1-tailed)	.109
Point Probability	.094

a. Binomial distribution used.

b. McNemar Test

6 discordant pairs, under H_0 : 3 in each direction, observed: 5 vs. 1

Binomial point probability: $P(X=5)=.094$

Two-sided $p=2* [.094+P(X=6)]=.219 \Rightarrow P(X=6)=.0155$

Alternatively: $(|5 - 1| - 1)^2 / (5 + 1) = 9/6 = 1.5$ at χ_1^2

$\Rightarrow p=.22067$

Exact vs. asymptotic procedures

- Most standard statistical tests assume that the test statistic is asymptotically normally distributed
- This may not be the case for small studies
- Exact tests are based on permutation or Monte Carlo simulation (re-sampling)
- In small studies, p-values of an exact test can be smaller or larger than those of the corresponding asymptotic test
- More and more statistical packages include exact methods, but often computationally intensive

What they really did: individually matched case-control study

- 35 controls from 389 pts with other lymphomas in the breast
- Matched by age at DX (within 5 yrs) and yr of DX (within 2 yrs)

Breast implant	Cases	Controls	
Yes	5	1	6
No	6	34	40
	11	35	46

- McNemar only for matched pairs (1:1)
- Standard 2-by-2 analysis⁴
Crude OR=28.3, asymptotic 95% CI 2.8–287.1, p=.002
- Conditional logistic regression (asymptotic) for >1 controls per case
via Cox regression⁵
OR=18.2, 95% CI 2.1–156.8, p=.008 (reported)
- Matching is controlling for confounding at the design stage
- Confounding can also be controlled, however less efficiently, at the analysis stage: Cochran-Mantel-Haenszel test or adjustment in regression models

Tumor volume study

ORIGINAL ARTICLE

TUMOR VOLUME AS PROGNOSTIC FACTOR IN CHEMORADIATION FOR ADVANCED HEAD AND NECK CANCER

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- 360 pts w/ advanced head & neck squamous cell carcinoma (oral cavity, oropharynx, hypopharynx)
- Diagnosed 1997–2006 in 6 hospitals
- Chemoradiation for functionally/anatomically unresectable disease
- Primary tumor volume measured by pretreatment MRI or CT
- 72% male, mean age 56 yrs (range, 25–85)
- Followed for local recurrence (median, 20 months)

Data set tumorvolume.sav

- Includes several transformations of original variables based on code in `transformations_syntax.txt`
- Codebook `labels.doc` describes variable labels
- Categorizing continuous volume
 $\text{volumeg4} = 1 + (\text{Tumor_volume} > 20) + (\text{Tumor_volume} > 40) + (\text{Tumor_volume} > 60)$
SPSS: Click Transform – Compute Variable

<code>volumeg4</code>	<code>Tumor_volume</code>
1	≤ 20
2	$> 20 - \leq 40$
3	$> 40 - \leq 60$
4	> 60

Cochran-Mantel-Haenszel test

- Test association in stratified 2-by-2 tables, e.g., whether there is an association between volume & gender stratified by tumor site

- $$\frac{\sum_i a_i * d_i / N_i}{\sum_i b_i * c_i / N_i} = \sum \frac{b_i * c_i / N_i}{\sum b_i * c_i / N_i} \times \frac{a_i * d_i}{b_i * c_i}$$

- Stratified OR is weighted mean with weights approximating the inverse variance of individual ORs if near 1 (stratified Pearson)
- Usually comes with Breslow-Day test of homogeneity of ORs across strata (but limited power unless sample size in all strata is large & heterogeneity is substantial)

Association between volume & gender stratified by tumor site

- Overall odds ratio⁶

volumeg2 * Gender Crosstabulation

Count		Gender		Total
		0	1	
volumeg2	1.00	195	84	279
	2.00	67	17	84
Total		262	101	363

- Pearson χ^2 $p=.077$, OR=.589

- Test of homogeneity, common OR & CMH test⁷

volumeg2 * Gender * Tumor_site Crosstabulation

Tumor_site		Gender		Total
		0	1	
1	volumeg2 1.00	42	19	61
	2.00	14	6	20
	Total	56	25	81
2	volumeg2 1.00	124	51	175
	2.00	40	11	51
	Total	164	62	226
3	volumeg2 1.00	29	14	43
	2.00	13	0	13
	Total	42	14	56

Risk Estimate

Tumor_site	Value	95% Confidence Interval	
		Lower	Upper
1	Odds Ratio for volumeg2 (1.00 / 2.00)	.947	2.844
	For cohort Gender = 0	.984	1.372
	For cohort Gender = 1	1.038	2.234
	N of Valid Cases	81	
2	Odds Ratio for volumeg2 (1.00 / 2.00)	.669	1.405
	For cohort Gender = 0	.903	1.073
	For cohort Gender = 1	1.351	2.394
	N of Valid Cases	226	
3	For cohort Gender = 0	.674	.830
	N of Valid Cases	56	

Tests of Homogeneity of the Odds Ratio

	Chi-Squared	df	Asymp. Sig. (2-sided)
Breslow-Day	4.334	2	.115
Tarone's	4.334	2	.115

Tests of Conditional Independence

	Chi-Squared	df	Asymp. Sig. (2-sided)
Cochran's	3.177	1	.075
Mantel-Haenszel	2.679	1	.102

Under the conditional independence assumption, Cochran's statistic is asymptotically distributed as a 1 df chi-squared distribution, only if the number of strata is fixed, while the Mantel-Haenszel statistic is always asymptotically distributed as a 1 df chi-squared distribution. Note that the continuity correction is removed from the Mantel-Haenszel statistic when the sum of the differences between the observed and the expected is 0.

- Common OR=.588 ⇒ no confounding by tumor site

Chi-square goodness of fit test with specified distribution

- Question: Is infusion side (single- vs. double-sided) distributed 50-50?
- Provide SPSS with expected proportions: 50-50⁸

	Observed N	Expected N	Residual
1	170	180.0	-10.0
2	190	180.0	10.0
Total	360		

	Infusion_side
Chi-Square	1.111 ^a
df	1
Asymp. Sig.	.292

a. 0 cells (.0%) have expected frequencies less than 5. The minimum expected cell frequency is 180.0.

- $p = .292$: data are consistent with 50-50 split

New question: is pre-treatment health status of NKI pts better vs. pts treated elsewhere?

- Variable `who` represents general health status of pts in 3 ordered categories (0, 1, 2)
- `nki=1` for NKI pts, 0 otherwise
- Question rephrased: Does prevalence of NKI-pts change (increase/decrease) with WHO status?
- Is Pearson's χ^2 test appropriate?

Linear-by-linear association test (also called Cochran-Armitage or Mantel-Haenszel)

- Tests for trend in binomial proportions across levels of a single factor
- Appropriate for a 2-way table where one variable has 2 levels & the other variable is at least ordinal
- 2-level variable represents response, other variable represents an explanatory variable with ordered levels

Age group	Age	Score	Gender	
			Male	Female
1	≤ 20	18	15	13
2	$>20-\leq 60$	48	24	12
3	>60	71	35	9

Linear-by-linear association test

- Choice of scores: for numeric variables, group mean or median can be used, for ordinal variables, meaningful scores should be chosen
- Null hypothesis: no trend, i.e., binomial proportion the same for all levels of the explanatory variable
- Positive (negative) standardized test statistic indicates increasing (decreasing) trend

Linear-by-linear association test⁹

WHO * nki Crosstabulation

			nki		Total
			.00	1.00	
WHO 0	Count	65	61	126	
	% within WHO	51.6%	48.4%	100.0%	
1	Count	41	61	102	
	% within WHO	40.2%	59.8%	100.0%	
2	Count	3	7	10	
	% within WHO	30.0%	70.0%	100.0%	
Total	Count	109	129	238	
	% within WHO	45.8%	54.2%	100.0%	

Chi-Square Tests

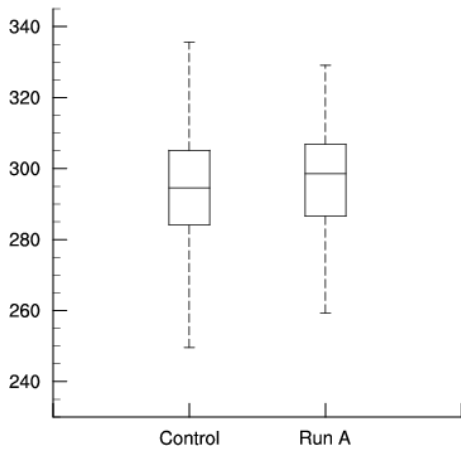
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	3.996 ^a	2	.136	.141		
Likelihood Ratio	4.037	2	.133	.145		
Fisher's Exact Test	3.913			.137		
Linear-by-Linear Association	3.975 ^b	1	.046	.056	.029	.012
N of Valid Cases	238					

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 4.58.

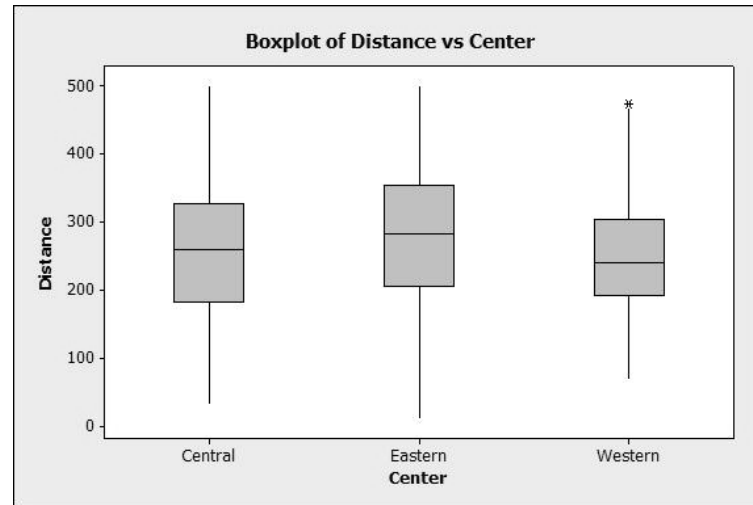
b. The standardized statistic is 1.994.

χ^2 test of trend (linear-by-linear) using scores 0, 1, 2 more powerful to detect ordered alternatives compared with Pearson χ^2

More than 2 categories: Linear-by-linear

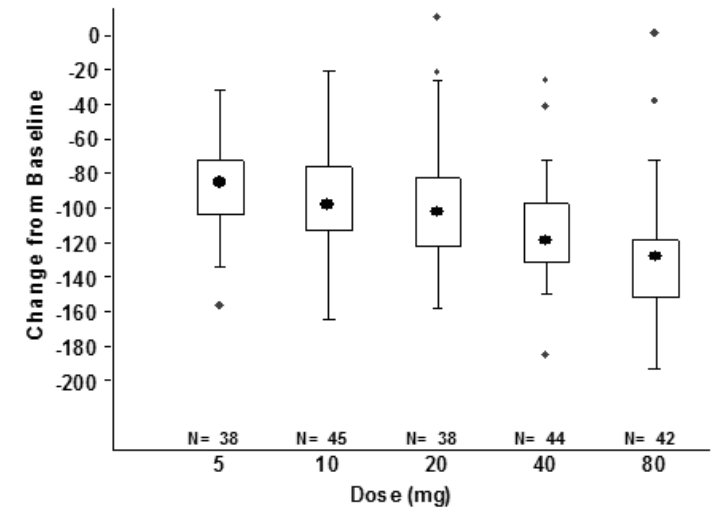


Wilcoxon
(Mann Whitney U)



Kruskal-Wallis*

Boxplots of Response at Endpoint by Dose for Study 1



Linear-by-linear

* non-parametric t-test for > 2 groups

Linear-by-linear association test

- Requires that independent samples (row score) be ordinally arranged as well as that test variable (column score) be binary or ordinal
- Null hypothesis: test variable does not differ between groups
- Tests significance of linear relationship between 2 ordinal variables
- Scores can be specified

Association between tumor-volume & N-stage?

- K-W tests for general homogeneity (ignores order in N-stage)
- L-by-L tests against trend alternatives – more powerful than K-W (p=.008 vs. .067)
N-stage as row scores & tumor volume categories as column scores¹⁰

volume4 * N_stage Crosstabulation

Count		N_stage				Total
		0	1	2	3	
volume4	1.00	28	18	60	11	117
	2.00	31	15	71	9	126
	3.00	7	12	36	3	58
	4.00	7	4	42	8	61
Total		73	49	209	31	362

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	16.181 ^a	9	.063
Likelihood Ratio	16.897	9	.050
Linear-by-Linear Association	7.002	1	.008
N of Valid Cases	362		

a. 1 cells (6.3%) have expected count less than 5. The minimum expected count is 4.97.

- Trend test more powerful than Pearson χ^2 : p=.008 vs. .063

- N-stage categories: degree of spread to regional lymph nodes
 N0: tumor cells absent from regional nodes
 N1: regional lymph node metastasis present
 N2: tumor spread to an extent between N1 & N3
 N3: tumor spread to more distant or numerous regional nodes
- consider N3 much worse than N2 and use score of 10 instead of 3¹¹

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	16.181 ^a	9	.063
Likelihood Ratio	16.897	9	.050
Linear-by-Linear Association	1.702	1	.192
N of Valid Cases	362		

a. 1 cells (6.3%) have expected count less than 5. The minimum expected count is 4.97.

- P=.192: tendency for more higher volume tumors with increasing N stage is not continuing for N3 as it did for N0-N2

Which test to use when?

Groups	Outcome data scale		
	Binomial	Nominal	Ordinal (Continuous)
Single sample	Binomial	χ^2 goodness of fit	
Paired samples	McNemar Sign		Wilcoxon Signed Rank One-sample T
2 independent samples	Fisher's Exact Pearson's χ^2 Cochran-Mantel-Haenszel (stratified)	Fisher's Exact Pearson's χ^2	Wilcoxon Mann Whitney Two-sample T
K independent unordered samples	Fisher's Exact Pearson's χ^2	Fisher's Exact Pearson's χ^2	ANOVA Kruskal-Wallis
K independent ordered samples	Linear-by-linear		Linear-by-linear

SPSS code (syntax and clicking)

1. CI around single proportion

Click Analyze – Descriptive Statistics – Frequencies and select variable `implant`. Click Transform – Compute Variable and fill in an arbitrary new variable name with value 1. Click Analyze – Descriptive Statistics – Ratio and select variable `implant` and the new variable. Click Statistics and request confidence intervals.

```
FREQUENCIES VARIABLES=implant
  /ORDER=ANALYSIS.
COMPUTE one=1.
EXECUTE.
RATIO STATISTICS implant WITH one
  /MISSING=EXCLUDE
  /PRINT=CIN(95) MEAN.
```

2. Pearson chi-square

Click Analyze – Descriptive Statistics – Crosstabs and select variables case and implant.

```
CROSSTABS
```

```
/TABLES=case BY implant  
/FORMAT=AVALUE TABLES  
/STATISTICS=CHISQ RISK  
/CELLS=COUNT  
/COUNT ROUND CELL.
```

3. McNemar test for 1:1 matched design

Click Analyze – Nonparametric Tests – (Legacy Dialogs) – 2 Related Samples and select variables implant_controls and implant_cases and request McNemar's test. Click Exact and request calculation of an exact p-value.

```
NPAR TESTS
```

```
/MCNEMAR=implant_controls WITH implant_cases (PAIRED)  
/MISSING ANALYSIS  
/METHOD=EXACT TIMER(5).
```

4. Standard 2-by-2 analysis

Click Analyze – Descriptive Statistics – Crosstabs and select the variables. Click Statistics and request Chi-square and Risk. Click Exact and request exact p-values.

```
CROSSTABS
```

```
  /TABLES=implant BY case  
  /FORMAT=AVALUE TABLES  
  /STATISTICS=CHISQ RISK  
  /CELLS=COUNT  
  /COUNT ROUND CELL  
  /METHOD=MC CIN(99) SAMPLES(10000).
```


5. Conditional logistic regression (asymptotic) for >1 controls per case via Cox regression

Click Transform – Compute Variable and calculate a new variable `dv` with value “2-case”. Click Analyze – Survival – Cox Regression and select variable `dv` as Time and `case` as Status. Define a value of 1 as an event. Select variable `implant` as a covariate and `setno` as a stratum.

```
COMPUTE dv=2-case.  
EXECUTE.  
COXREG dv  
  /STATUS=case(1)  
  /STRATA=setno  
  /METHOD=ENTER implant  
  /PRINT=CI(95)  
  /CRITERIA=PIN(.05) POUT(.10) ITERATE(20).
```

6. Overall odds ratio

Click Analyze – Descriptive Statistics – Crosstabs and select the variables. Click Statistics and request Chi-square and Risk. Click Exact and request exact p-values.

```
CROSSTABS
```

```
  /TABLES=volume2 BY Gender
```

```
  /FORMAT=AVALUE TABLES
```

```
  /STATISTICS=CHISQ RISK
```

```
  /CELLS=COUNT
```

```
  /COUNT ROUND CELL
```

```
  /METHOD=EXACT TIMER(5).
```

7. Test of homogeneity, common OR & CMH test
As above. Select variable Tumor_site as a Layer. Click Statistics and request the Cochran-Mantel-Haenszel test.

```
CROSSTABS
  /TABLES=volume2 BY Gender BY Tumor_site
  /FORMAT=AVALUE TABLES
  /STATISTICS=RISK CMH(1)
  /CELLS=COUNT
  /COUNT ROUND CELL
  /METHOD=EXACT TIMER(5).
```

8. Provide SPSS with expected proportions: 50-50
Click Analyze – Nonparametric Tests – Legacy Dialogs – Chi-square, select variable Infusion_side and add Expected Values.

```
NPAR TESTS
  /CHISQUARE=Infusion_side
  /EXPECTED=50 50
  /MISSING ANALYSIS.
```

9. Linear-by-linear association test

Click Analyze – Descriptive Statistics – Crosstabs, select variables and request Chi-square under Statistics.

```
CROSSTABS
```

```
/TABLES=WHO BY nki  
/FORMAT=AVALUE TABLES  
/STATISTICS=CHISQ  
/CELLS=COUNT ROW  
/COUNT ROUND CELL  
/METHOD=EXACT TIMER(5).
```

10. Linear-by-linear test with N-stage as row scores & tumor volume categories as column scores

Click Analyze – Descriptive Statistics – Crosstabs, select variables and request Chi-square under Statistics.

```
CROSSTABS
```

```
/TABLES=volumeg4 BY N_stage  
/FORMAT=AVALUE TABLES  
/STATISTICS=CHISQ  
/CELLS=COUNT  
/COUNT ROUND CELL.
```

11. Linear-by-linear test with score of 10 instead of 3 for N3

Click Transform – Compute Variable and create variable `n_stage_new` as `n_stage*(n_stage<3)+10*(n_stage=3)`. Click Analyze – Descriptive Statistics – Crosstabs, select variables `volumeg4` and `n_stage_new` and request Chi-square under Statistics.

```
COMPUTE n_stage_new=n_stage*(n_stage<3)+10*(n_stage=3).  
EXECUTE.  
CROSSTABS  
  /TABLES=volumeg4 BY n_stage_new  
  /FORMAT=AVALUE TABLES  
  /STATISTICS=CHISQ  
  /CELLS=COUNT  
  /COUNT ROUND CELL.
```