## **Second Edition**

## Statistical Thinking for Non-Statisticians in Drug Regulation

Statistical Thinking for Non-Statisticians in Drug Regulation, Second Edition, is a need-to-know guide to understanding statistical methodology, statistical data and results within drug development and clinical trials.

It provides non-statisticians working in the pharmaceutical and medical device industries with an accessible introduction to the knowledge they need when working with statistical information and communicating with statisticians. It covers the statistical aspects of design, conduct, analysis and presentation of data from clinical trials in drug regulation and improves the ability to read, understand and critically appraise statistical methodology in papers and reports. As such, it is directly concerned with the day-to-day practice and the regulatory requirements of drug development and clinical trials.



Fully conversant with current regulatory requirements, this second edition includes five new chapters covering Bayesian statistics, adaptive designs, observational studies, methods for safety analysis and monitoring and statistics for diagnosis.

Authored by a respected lecturer and consultant to the pharmaceutical industry, *Statistical Thinking for Non-Statisticians in Drug Regulation* is an ideal guide for physicians, clinical research scientists, managers and associates, data managers, medical writers, regulatory personnel and for all non-statisticians working and learning within the pharmaceutical industry.

www.wiley.com/wiley-blackwell

WILEY Blackwell





		to the second cutton, Av
	Prefa	ace to the first edition, xvii
	Abb	reviations, xxi
1	Basic	c ideas in clinical trial design 1
	1.1	Historical perspective 1
	1.2	Control groups 2
	1.3	Placebos and blinding, 3
	1.4	Randomisation, 3
		1.4.1 Unrestricted randomisation, 4
		1.4.2 Block randomisation, 4
		1.4.3 Unequal randomisation, 5
		1.4.4 Stratified randomisation, 6
		1.4.5 Central randomisation, 7
		1.4.6 Dynamic allocation and minimisation, 8
		1.4.7 Cluster randomisation, 9
	1.5	Bias and precision, 9
	1.6	Between- and within-patient designs, 11
	1.7	Crossover trials, 12
	1.8	Signal, noise and evidence, 13
		1.8.1 Signal, 13.
		1.8.2 Noise, 13
		1.8.3 Signal-to-noise ratio, 14
	1.9	Confirmatory and exploratory trials, 15
	1.10	Superiority, equivalence and non-inferiority trials, 16
	1.11	Data and endpoint types, 17
	1.12	Choice of endpoint, 18
		1.12.1 Primary variables, 18
		1.12.2 Secondary variables, 19
		1.12.3 Surrogate variables, 20
		1.12.4 Global assessment variables, 21
		1.12.5 Composite variables, 21
		1.12.6 Categorisation, 21
2	Samp	oling and inferential statistics, 23

2.1

2.2

Sample and population, 23

Sample statistics and population parameters, 24

	2.2.1 Sample and population distribution, 24
	2.2.2 Median and mean, 25
	2.2.3 Standard deviation, 25
	2.2.4 Notation, 26
	2.2.5 Box plots, 27
2.3	The normal distribution, 28
2.4	Sampling and the standard error of the mean, 31
2.5	Standard errors more generally, 34
	2.5.1 The standard error for the difference between two means, 34
	2.5.2 Standard errors for proportions, 37
	2.5.3 The general setting, 37
Con	afidence intervals and $p$ -values, 38
3.1	Confidence intervals for a single mean, 38
	3.1.1 The 95 per cent Confidence interval, 38
	3.1.2 Changing the confidence coefficient, 40
	3.1.3 Changing the multiplying constant, 40
	3.1.4 The role of the standard error, 41
3.2	Confidence interval for other parameters, 42
	3.2.1 Difference between two means, 42
	3.2.2 Confidence interval for proportions, 43
	3.2.3 General case, 44
	3.2.4 Bootstrap Confidence interval, 45
3.3	Hypothesis testing, 45
	3.3.1 Interpreting the <i>p</i> -value, 46
	3.3.2 Calculating the <i>p</i> -value, 47
	3.3.3 A common process, 50
	3.3.4 The language of statistical significance, 53
	3.3.5 One-sided and two-sided tests, 54
Test	ts for simple treatment comparisons, 56
	The unneited t test 56
	The private test 57
	Interpreting the t-tests 60
	The shi severe test for him any data (1
	4.4.1 Pearson chi-square, 61
	4.4.2 The link to a ratio of the signal to the standard error, 64
4.5	Measures of treatment hanefit 64
	4.5.1. Odds ratio 65
	4.5.2 Palative rick 65
	4.5.3 Palative risk reduction 66
	4.5.4 Number needed to treat, 66
	4.5.5 Confidence intervals, 67
	4.5.6 Interpretation, 68
	2. Sainple statistics and/topulsation parameters, put the exercises

4.6	Fisher's exact test, 69
	Tests for categorical and ordinal data, 71
	4.7.1 Categorical data, 71
	4.7.2 Ordered categorical (ordinal) data, 73
	4.7.3 Measures of treatment benefit, 74
4.8	Extensions for multiple treatment groups, 75
	4.8.1 Between-patient designs and continuous data, 75
	4.8.2 Within-patient designs and continuous data, 76
	4.8.3 Binary, categorical and ordinal data, 76
	4.8.4 Dose-ranging studies, 77
	4.8.5 Further discussion, 77
Adi	usting the analysis, 78
5.1	Objectives for adjusted analysis, 78
5.2	Comparing treatments for continuous data, 78
	Least squares means, 82
	Evaluating the homogeneity of the treatment effect, 83
	5.4.1 Treatment-by-factor interactions, 83
	5.4.2 Quantitative and qualitative interactions, 85
5.5	Methods for binary, categorical and ordinal data, 86
	Multi-centre trials, 87
	5.6.1 Adjusting for centre, 87
	5.6.2 Significant treatment-by-centre interactions, 87
	5.6.3 Combining centres, 88
Reg	ression and analysis of covariance, 89
61	Adjusting for baseline factors 89
6.2	Simple linear regression, 89
6.3	Multiple regression, 91
6.4	Logistic regression, 94
6.5	Analysis of covariance for continuous data, 94
	6.5.1 Main effect of treatment, 94
	6.5.2 Treatment-by-covariate interactions, 96
	6.5.3 A single model, 98 ON 20.0 drive meldong and
	6.5.4 Connection with adjusted analyses, 98
	6.5.5 Advantages of ANCOVA, 99
	6.5.6 Least squares means, 100
	Binary, categorical and ordinal data, 101
6.7	Regulatory aspects of the use of covariates, 103
6.8	Baseline testing, 105

7 Intention-to-treat and analysis sets, 107

7.1 The principle of intention-to-treat, 107

7.2 The practice of intention-to-treat, 110
7.2.1 Full analysis set, 110

	7.3	Missing data, 113	
		7.3.1 Introduction, 113 de danibuo la brogona benebro Sa	
		7.3.2 Complete cases analysis, 114	
		7.3.3 Last observation carried forward, 114	
		7.3.4 Success/failure classification, 114	
		7.3.5 Worst-case/best-case classification, 115	
		7.3.6 Sensitivity, 115	
		7.3.7 Avoidance of missing data, 116	
		7.3.8 Multiple imputation, 117	
	7.4	Intention-to-treat and time-to-event data, 118	
	7.5	General questions and considerations, 120	
8	8 Power and sample size, 123		
	8.1	Type I and type II errors, 123	
	8.2	Power, 124 palls an antisate salidas attemparated and autisate	
	8.3	Calculating sample size, 127	
	8.4	Impact of changing the parameters, 130	
		8.4.1 Standard deviation, 130	
		8.4.2 Event rate in the control group, 130	
		8.4.3 Clinically relevant difference, 131	
	8.5	Regulatory aspects, 132	
		8.5.1 Power >80 per cent, 132	
		8.5.2 Powering on the per-protocol set, 132	
		8.5.3 Sample size adjustment, 133	
	8.6	Reporting the sample size calculation, 134	
9 Statistical significance and clinical importance, 136			
	9.1	Link between <i>p</i> -values and Confidence intervals, 136	
	9.2	Confidence intervals for clinical importance, 137	
	9.3	Misinterpretation of the <i>p</i> -value, 139	
		9.3.1 Conclusions of similarity, 139	
		9.3.2 The problem with 0.05, 140	
	9.4	Single pivotal trial and 0.05, 140	
10	Mult	tiple testing, 142	
	10.1	Inflation of the type I error, 142	
		10 1 1 False positives 142	
		10.1.2 A simulated trial, 142	
	10.2	How does multiplicity arise?, 143	
	10.3	Regulatory view, 144	
	10.4	Multiple primary endpoints, 145	
		10.4.1 Avoiding adjustment, 145	
		10.4.2 Significance needed on all endpoints, 145	

7.2.2 Per-protocol set, 112

7.2.3 Sensitivity, 112

	10.4.4 Variables ranked according to clinical importance:	
	Hierarchical testing, 146	
10.5	Methods for adjustment, 149	
	10.5.1 Bonferroni correction, 149	
	10.5.2 Hochberg correction, 150	
	10.5.3 Interim analyses, 151	
10.6	Multiple comparisons, 152	
10.7	Repeated evaluation over time, 153	
10.8	Subgroup testing, 154	
10.9	Other areas for multiplicity, 156	
	10.9.1 Using different statistical tests, 156	
	10.9.2 Different analysis sets, 156	
	10.9.3 Pre-planning, 157	
Non	a-parametric and related methods, 158	
	Assumptions underlying the t-tests and their	
	extensions, 158	
11.2	2 Homogeneity of variance, 158	
	The assumption of normality, 159	
	Non-normality and transformations, 161	
11.5	Non-parametric tests, 164	
	11.5.1 The Mann–Whitney U-test, 164	
	11.5.2 The Wilcoxon signed rank test, 166	
	11.5.3 General comments, 167	
11.6	Advantages and disadvantages of non-parametric methods, 168	3
	Outliers, 169 Commission of the angle of the content of the conten	
Equ	ivalence and non-inferiority, 170	
12.1	Demonstrating similarity, 170	
12.2	2 Confidence intervals for equivalence, 172	
12 3	3. Confidence intervals for non-inferiority, 173	
12.4	A p-value approach, 174	
12.5	5 Assay sensitivity, 176	
	6 Analysis sets, 178	
	7 The choice of $\Delta$ , 179	
	12.7.1 Bioequivalence, 179	
	12.7.2 Therapeutic equivalence, 180	
	12.7.3 Non-inferiority, 180	
	12.7.4 The 10 per cent rule for cure rates, 182	
12.8		
12.9	Sample size calculations, 184	
12.	10 Switching between non-inferiority and superiority, 186	

10.4.3 Composite endpoints, 146

3	The analysis of survival data, 189					
	13.1	Time-to-event data and censoring, 189				
	13.2	Kaplan-Meier curves, 190				
		13.2.1 Plotting Kaplan-Meier curves, 190				
		13.2.2 Event rates and relative risk, 192				
		13.2.3 Median event times, 192				
	13.3	Treatment comparisons, 193				
	13.4	The hazard ratio, 196				
		13.4.1 The hazard rate, 196				
		13.4.2 Constant hazard ratio, 197				
		13.4.3 Non-constant hazard ratio, 197				
		13.4.4 Link to survival curves, 198				
		13.4.5 Calculating Kaplan-Meier curves, 199				
	13.5	Adjusted analyses, 199				
		13.5.1 Stratified methods, 200				
		13.5.2 Proportional hazards regression, 200				
		13.5.3 Accelerated failure time model, 201				
	13.6	Independent censoring, 202				
	13.7	Sample size calculations, 203				
4	Interim analysis and data monitoring committees, 205					
		Stopping rules for interim analysis, 205				
		Stopping for efficacy and futility, 206				
		14.2.1 Efficacy, 206				
		14.2.2 Futility and conditional power, 207				
		14.2.3 Some practical issues, 208				
		14.2.4 Analyses following completion of recruitment, 209				
	14.3	Monitoring safety, 210				
	14.4	Data monitoring committees, 211				
		14.4.1 Introduction and responsibilities, 211				
		14.4.2 Structure and process, 212				
		14.4.3 Meetings and recommendations, 214				
5	Baves	ian statistics, 215				
		Introduction, 215				
		Prior and posterior distributions, 215				
		15.2.1 Prior beliefs, 215				
		15.2.2 Prior to posterior, 217				
		15.2.3 Bayes theorem, 217				
	15.3	Bayesian inference, 219				
		15.3.1 Frequentist methods, 219				
		15.3.2 Posterior probabilities 219				

15.3.3 Credible intervals, 220 Management and a second sec

15.4 Case study, 221

			and regulatory acceptance, 222
	15.6	Discuss	sion, 224 Manual PAS considerate LEVI
16	7.00		signs, 225
	16.1	What a	are adaptive designs?, 225
		16.1.1	Advantages and drawbacks, 225
		16.1.2	Restricted adaptations, 226
		16.1.3	Flexible adaptations, 227
	16.2	Minim	ising bias, 228
		16.2.1	Control of type I error, 228
		16.2.2	Estimation, 229
		16.2.3	Behavioural issues, 230
		16.2.4	Exploratory trials, 232
	16.3		ded sample size re-estimation, 232
			Product of <i>p</i> -values, 232
			Weighting the two parts of the trial, 233
			Rationale, 234
	16.4		ess phase II/III studies, 234
			Standard framework, 234
		16.4.2	Aspects of the <i>p</i> -value calculation, 235
			Logistical challenges, 236
	16.5		types of adaptation, 236
			Changing the primary endpoint, 236
			Focusing on a sub-population, 237
			Dropping the placebo arm in a non-inferiority trial, 237
	16.6		r regulatory considerations, 238
			Impact on power, 238
			Non-standard experimental settings, 239
47	Obco	rustion	al studies, 241
17			
	17.1	17.1.1	Non-randomised comparisons, 241
		17.1.1	Study types, 241
			Sources of bias, 243
			An empirical investigation, 244
			Selection bias in concurrently controlled studies:
			An empirical evaluation, 245
		17.1.0	Selection bias in historically controlled studies:
		1717	An empirical evaluation, 246
	17.0		Some conclusions, 246
	17.2		nce on design, conduct and analysis, 247
			Regulatory guidance, 247
		17.2.2	Strengthening the Reporting of Observational Studies in
			Epidemiology, 248

	17.3	Evaluating and adjusting for selection bias, 249
		17.3.1 Baseline balance, 249
		17.3.2 Adjusting for imbalances using stratification and
		analysis of covariance, 250
		17.3.3 Propensity scores, 250
		17.3.4 Different methods for adjustment:
		An empirical evaluation, 253
		17.3.5 Some conclusions, 256
	17.4	Case-control studies, 257
		17.4.1 Background, 257
		17.4.2 Odds ratio and Relative risk, 259
18	Meta	-analysis, 261
		Definition, 261 CERTAIN MARKET STATE OF THE CONTROL
		Objectives, 263 SEC Popular of the Control of the C
		Statistical methodology, 264
		18.3.1 Methods for combination, 264
		18.3.2 Confidence intervals, 265
		18.3.3 Fixed and random effects, 265
		18.3.4 Graphical methods, 266
		18.3.5 Detecting heterogeneity, 266
		18.3.6 Robustness, 269
		18.3.7 Rare events, 269
		18.3.8 Individual patient data, 269
	18.4	Case study, 270
		Ensuring scientific validity, 271
		18.5.1 Planning, 271
		18.5.2 Assessing the risk of bias, 273
		18.5.3 Publication bias and funnel plots, 273
		18.5.4 Preferred Reporting Items for Systematic
		Reviews and Meta-Analyses, 275
	18.6	Further regulatory aspects, 275
10		nods for the safety analysis and safety monitoring, 277
13		Introduction, 277
	17.1	19.1.1 Methods for safety data, 277
		19.1.2 The rule of three, 278
	10 2	Routine evaluation in clinical studies, 279
	17.4	
		19.2.1 Types of data, 280 19.2.2 Adverse events, 281
		19.2.3 Laboratory data, 284
		19.2.4 ECG data, 287
		19.2.5 Vital signs, 288

		19.2.6 Safety summary across trials, 288
		19.2.7 Specific safety studies, 289
	19.3	Data monitoring committees, 289
	19.4	Assessing benefit–risk, 290
		19.4.1 Current approaches, 290
		19.4.2 Multi-criteria decision analysis, 291
		19.4.3 Quality-Adjusted Time without Symptoms
		or Toxicity, 297
	19.5	Pharmacovigilance, 299
		19.5.1 Post-approval safety monitoring, 299
		19.5.2 Proportional reporting ratios, 300
		19.5.3 Bayesian shrinkage, 302
20	Diag	mosis, 304
	20.1	Introduction, 304
	20.2	Measures of diagnostic performance, 304
		20.2.1 Sensitivity and specificity, 304
		20.2.2 Positive and negative predictive value, 305
		20.2.3 False positive and false negative rates, 306
		20.2.4 Prevalence, 306
		20.2.5 Likelihood ratio, 307
		20.2.6 Predictive accuracy, 307
	75.4	20.2.7 Choosing the correct cut-point, 307
	20.3	Receiver operating characteristic curves, 308
		20.3.1 Receiver operating characteristic, 308
	20.4	20.3.2 Comparing ROC curves, 309
	20.4	Diagnostic performance using regression models, 310
		Aspects of trial design for diagnostic agents, 312
	20.0	Assessing agreement, 313
		20.6.1 The kappa statistic, 313
	ndard	20.6.2 Other applications for kappa, 314
1		role of statistics and statisticians, 316
	21.1	The importance of statistical thinking at
	21.2	the design stage, 316
		Regulatory guidelines, 317
	21.5	The statistics process, 321
		21.3.1 The statistical methods section of the
		protocol, 321 21.3.2 The statistical analysis plan, 322
		21.3.2 The statistical allalysis plan, 322 21.3.3 The data validation plan, 322
		21.3.4 The blind review, 322
		21.3.5 Statistical analysis, 323
		- The state of the

- 21.3.6 Reporting the analysis, 323
- 21.3.7 Pre-planning, 324
- 21.3.8 Sensitivity and robustness, 326

e Some conclusions, 256 - 1799, while

- 21.4 The regulatory submission, 327
- 21.5 Publications and presentations, 328

References, 331

Index, 339