

Outline of contents

- 1 Introduction..... 1**
- 2 Basics3**
Beat P. Kneubuehl
 - 2.1 The physics of wound ballistics3
 - 2.2 Ammunition and weapons33
 - 2.3 Ballistics65
- 3 General wound ballistics87**
Beat P. Kneubuehl
 - 3.1 Introduction87
 - 3.2 Processes in the wound channel; the temporary cavity95
 - 3.3 Simulants136
 - 3.4 Other approaches to simulation156
- 4 Wound ballistics of bullets and fragments..... 165**
Beat P. Kneubuehl
 - 4.1 The effectiveness of bullets165
 - 4.2 Wound ballistics of handgun bullets188
 - 4.3 Wound ballistics of rifle bullets219
 - 4.4 Wound ballistics of fragments.....242
 - 4.5 “Non-lethal” projectiles.....250
- 5 Wound ballistics and forensic medicine.....263**
 - 5.1 Conventional forensic medicine263
Markus A. Rothschild
 - 5.2 Modern graphical methods300
Michael J. Thali
 - 5.3 Experimental reconstruction.....306
Beat P. Kneubuehl, Michael J. Thali
- 6 Wound ballistics and surgery.....321**
Robin M. Coupland
 - 6.1 The historical connection between wound ballistics and surgery321
 - 6.2 Wound ballistics and ballistic trauma – what’s the difference?322
 - 6.3 Comparing simulated wounds and real wounds323
 - 6.4 Clinical features of real wounds328

6.5	The contribution of wound ballistics to the care of wounded people.....	329
6.6	Documenting ballistic trauma.....	333
7	Wound ballistics and international agreements.....	337
	<i>Beat P. Kneubuehl</i>	
7.1	Introduction	337
7.2	History of firearms and ammunition	337
7.3	International treaties	350

Appendices

A	Tables	359
A.1	List of tables in the main text	359
A.2	Characteristics of materials	361
A.3	Calibre designations (metric system)	362
A.4	Ballistic data for cartridges (metric system).....	364
A.5	Calibre designations (British/U.S. system).....	369
A.6	Ballistic data for cartridges (British/U.S. system).....	371
A.7	Bullet designations	376
A.8	Geometric data for selected bullets	377
A.9	Twist length, angle of twist and rotation	378
A.10	Ballistics tables (metric system)	380
A.11	Ballistics tables (British/U.S. system)	398
A.12	Shotguns and shot.....	416
B	Glossary.....	419
B.1	English ⇒ German ⇒ French	419
B.2	German ⇒ English ⇒ French	439
B.3	French ⇒ German ⇒ English	457
C	Bibliography	477
	Photo credits.....	503
	Index.....	505

Detailed table of contents

Table of symbols	XXI
Prefix symbols for decimal multiples and submultiples of SI units	XXV
Conversions.....	XXV
1 Introduction	1
2 Basics	3
2.1 The physics of wound ballistics	3
2.1.1 Preliminary remarks	3
2.1.2 Coordinates, systems of units and notation.....	3
2.1.3 Mechanics	4
2.1.3.1 Kinematics	4
2.1.3.2 Mass, momentum and force	7
2.1.3.3 Work and energy	8
2.1.3.4 Rotation.....	10
2.1.3.5 Laws of conservation of mass, energy and momentum ...	11
2.1.3.6 Equations of motion	12
2.1.4 Fluid dynamics	15
2.1.4.1 General.....	15
2.1.4.2 Basic concepts in thermodynamics.....	15
2.1.4.3 Material characteristics	18
2.1.4.4 Frictionless flow.....	21
2.1.4.5 Flow of a viscous fluid.....	23
2.1.5 Fluid jets.....	26
2.1.5.1 General.....	26
2.1.5.2 Exhaust flow from a muzzle	26
2.1.5.3 De Laval nozzles (converging-diverging nozzles).....	27
2.1.5.4 Jet velocity and energy.....	28
2.1.6 Measuring techniques for wound ballistics.....	29
2.1.6.1 General.....	29
2.1.6.2 Dynamic phenomena.....	30
2.1.6.3 Physical values.....	32
2.2 Ammunition and weapons.....	33
2.2.1 Introduction.....	33
2.2.2 Ammunition	34

2.2.2.1	The structure of a cartridge	34
2.2.2.2	Types of ammunition	41
2.2.2.3	Blank and irritant rounds	52
2.2.2.4	Fragmenting ammunition.....	53
2.2.3	Weapons	55
2.2.3.1	Firearm design and typology.....	55
2.2.3.2	Handguns	59
2.2.3.3	Long weapons	61
2.2.3.4	Alarm pistols and revolvers	65
2.3	Ballistics	65
2.3.1	Definitions.....	65
2.3.2	Interior ballistics.....	66
2.3.2.1	General	66
2.3.2.2	Powder combustion.....	66
2.3.2.3	The firing sequence	67
2.3.2.4	Interior ballistics calculations	68
2.3.2.5	Energy balance	69
2.3.3	Muzzle phenomena	69
2.3.3.1	Muzzle gas flow	69
2.3.3.2	Flash	70
2.3.4	Exterior ballistics	71
2.3.4.1	General; terms used.....	71
2.3.4.2	Exterior ballistics calculations	72
2.3.4.3	Ballistics tables	73
2.3.4.4	Proper motion of a bullet	73
2.3.4.5	Disturbances to the trajectory	74
2.3.5	Stability and tractability	75
2.3.5.1	Definition of stability	75
2.3.5.2	Spin-stabilized projectiles	76
2.3.5.3	Projectiles stabilized by air forces	78
2.3.5.4	Shoulder stabilization.....	78
2.3.5.5	Tractability	79
2.3.5.6	Stability and ricochets.....	80
2.3.6	Fragment ballistics	81
2.3.6.1	Acceleration of fragments	81
2.3.6.2	Exterior ballistics of fragments	82
2.3.7	Terminal ballistics models	83
2.3.7.1	General	83
2.3.7.2	The plugging model	83
2.3.7.3	The displacement model (ductile failure)	84
2.3.7.4	Bullet passing through a thin layer of material	84

3	General wound ballistics	87
3.1	Introduction	87
3.1.1	General	87
3.1.2	The history of wound ballistics	88
3.1.3	Basic relationships	93
3.2	Processes in the wound channel; the temporary cavity	95
3.2.1	Preliminary remarks	95
3.2.1.1	The concept of the “temporary cavity”	95
3.2.1.2	Different ways of looking at wounding	95
3.2.1.3	Modelling wound ballistics processes.....	96
3.2.2	Motion and behaviour of a bullet	97
3.2.2.1	Rifle bullets.....	97
3.2.2.2	Handgun bullets	103
3.2.2.3	Fragments and fragment-like projectiles.....	104
3.2.2.4	Possible types of wound channel	107
3.2.2.5	Physical models	107
3.2.3	The temporary cavity	110
3.2.3.1	Phenomenology of the temporary cavity	110
3.2.3.2	Quantitative description of the temporary cavity.....	117
3.2.3.3	Influence of impact conditions and bullet characteristics.....	118
3.2.3.4	The effect of the sectional density of a bullet on the shape of the temporary cavity	122
3.2.4	The effect of bullet design on behaviour.....	126
3.2.4.1	Categories of bullet	126
3.2.4.2	Deformation and fragmentation; general points	126
3.2.4.3	Experimental results.....	128
3.2.5	Patterns in bullet wounds to bones	131
3.2.6	Bullet temperature and sterility	133
3.2.6.1	Historical background	133
3.2.6.2	Bullet temperature.....	134
3.2.6.3	Bullets contaminated with bacteria	135
3.2.6.4	Burns due to bullets	136
3.3	Simulants	136
3.3.1	General	136
3.3.2	Gelatine	138
3.3.2.1	Characteristics and fabrication.....	138
3.3.2.2	Fabrication of gelatine blocks; preparation for experiments	138
3.3.2.3	Evaluating gelatine experiments	140
3.3.3	Glycerine soap (ballistic soap)	143
3.3.3.1	Characteristics and fabrication.....	143

3.3.3.2	Ageing.....	144
3.3.3.3	Evaluating soap experiments	145
3.3.3.4	Using soap to conduct measurements	146
3.3.4	Comparison between soap and gelatine	147
3.3.4.1	General.....	147
3.3.4.2	Availability, handling and measuring techniques	147
3.3.4.3	Reaction to bullets.....	148
3.3.4.4	Which simulant for which purpose?	150
3.3.4.5	Connection between the analysis methods	151
3.3.5	Bone	151
3.3.5.1	General.....	151
3.3.5.2	Hollow bones	152
3.3.5.3	Modelling the head.....	153
3.3.5.4	Literature regarding synthetic bones.....	153
3.3.6	Other simulants	155
3.4	Other approaches to simulation	156
3.4.1	Experiments on animals and cadavers	156
3.4.1.1	Animals	156
3.4.1.2	Cadavers.....	158
3.4.1.3	Cell cultures	159
3.4.2	Physical/mathematical models	159
3.4.2.1	General.....	159
3.4.2.2	SELLIER's velocity profiles	159
3.4.2.3	Computer Man	160
3.4.2.4	The "Verwundungsmodell Schütze" (VeMo-S)	162
4	Wound ballistics of bullets and fragments.....	165
4.1	The effectiveness of bullets	165
4.1.1	Effectiveness versus effect.....	165
4.1.1.1	Definitions.....	165
4.1.1.2	Factors that contribute to the effect of a bullet	165
4.1.2	Measures of effectiveness	167
4.1.2.1	Historical background.....	167
4.1.2.2	The "stopping power" fallacy	168
4.1.2.3	Traditional measures of effectiveness.....	169
4.1.2.4	Summary and conclusions	178
4.1.3	Determining the wounding potential of a bullet	180
4.1.3.1	Definition of the wounding potential.....	180
4.1.3.2	Measuring the wounding potential.....	181
4.1.4	Military effectiveness criteria	181
4.1.4.1	Definitions of effectiveness	181
4.1.4.2	Probability of incapacitation	183

4.2	Wound ballistics of handgun bullets	188
4.2.1	Penetration depth of handgun bullets and ability to pass through gelatine, soap, muscle and bone	188
4.2.1.1	General	188
4.2.1.2	Penetration depth in gelatine, soap and muscle	189
4.2.1.3	Penetration capacity in bone	197
4.2.1.4	Threshold velocities for eyes	202
4.2.2	Characteristics of handgun bullets	203
4.2.2.1	General	203
4.2.2.2	Bullets with good penetration properties	204
4.2.2.3	Bullets designed for maximum wounding potential	204
4.2.2.4	Police bullets	209
4.2.2.5	Unconventional bullet design	213
4.2.3	Gas and fluid jets as projectiles	215
4.2.3.1	General	215
4.2.3.2	Liquid jets	215
4.2.3.3	Gas jets	216
4.2.3.4	The effects of gas jets in the case of gas and alarm pistols	217
4.3	Wound ballistics of rifle bullets	219
4.3.1	Introduction	219
4.3.2	Remote effects	220
4.3.2.1	General	220
4.3.2.2	Shock waves	221
4.3.2.3	Biological/pathological consequences of shock waves	225
4.3.2.4	Pressure changes in blood vessels	230
4.3.2.5	The effects of pressure pulses on blood vessels	231
4.3.2.6	Bone fractures at locations remote from the wound channel	232
4.3.3	Non-expanding rifle bullets	233
4.3.3.1	Bullets designed for military use	233
4.3.3.2	The influence of the weapon	235
4.3.3.3	Shot and slugs	237
4.3.4	Expanding rifle bullets, hunting bullets	238
4.3.4.1	The wounding potential of hunting bullets	238
4.3.4.2	Lead-free hunting bullets	240
4.4	Wound ballistics of fragments	242
4.4.1	General	242
4.4.1.1	Frequency of fragment wounds	242
4.4.1.2	Wounds caused by fragments and similar projectiles	242
4.4.2	Equations of motion and energy for fragments	243
4.4.2.1	Hypotheses	243

4.4.2.2	The geometrical form of the wound channel	244
4.4.2.3	Equation of energy and motion	245
4.4.2.4	Entry wound diameter and penetration depth	245
4.4.3	Experimental verification of the models	246
4.4.3.1	Method	246
4.4.3.2	Entry wound diameter	246
4.4.3.3	Penetration depth	248
4.4.3.4	Comparison with other studies	249
4.4.3.5	Applications	249
4.5	“Non-lethal” projectiles	250
4.5.1	General	250
4.5.2	Projectile design	250
4.5.2.1	Projectiles with low sectional density	250
4.5.2.2	Expanding bullets	251
4.5.2.3	Rubber shot	254
4.5.2.4	Special projectiles for handguns	255
4.5.3	Wound ballistics of “non-lethal” projectiles	256
4.5.3.1	Penetrating projectiles	256
4.5.3.2	Non-penetrating projectiles	257
4.5.4	Dangerosity of projectiles	259
4.5.4.1	Criteria of dangerosity	259
4.5.4.2	Determining hazard areas	260
4.5.4.3	Danger area for persons wearing protective equipment	262
5	Wound ballistics and forensic medicine	263
5.1	Conventional forensic medicine	263
5.1.1	General	263
5.1.2	Crime-scene investigation	263
5.1.2.1	Bullet damage at the crime scene	263
5.1.2.2	Examination of the body at the scene	264
5.1.2.3	Bloodstain pattern analysis	265
5.1.3	Morphology of entry and exit wounds	267
5.1.3.1	Entry wounds	267
5.1.3.2	Exit wounds	271
5.1.3.3	Grazing shots	272
5.1.3.4	Indicators of muzzle-target distance	273
5.1.4	The wound channel	277
5.1.4.1	Wound morphology	277
5.1.4.2	The relationship between the wound channel and the direction of shot	278
5.1.5	Bullet wounds to the head	279
5.1.5.1	Brain injuries	279
5.1.5.2	Skull injuries	280

5.1.6	Bullet wounds to the trunk	283
5.1.6.1	The ribcage.....	283
5.1.6.2	Abdomen.....	284
5.1.7	Bullet wounds to bones	285
5.1.7.1	General.....	285
5.1.7.2	Flat bones.....	286
5.1.7.3	Long hollow bones.....	287
5.1.7.4	Vertebrae.....	288
5.1.8	Peculiarities of shotgun wounds.....	288
5.1.8.1	General.....	288
5.1.8.2	Morphology of entry wounds.....	289
5.1.8.3	Internal morphology of shotgun wounds	290
5.1.9	Causes of death and incapacitation	290
5.1.9.1	Causes of death	290
5.1.9.2	Incapacitation.....	292
5.1.10	Particular projectiles.....	294
5.1.10.1	Gas-powered weapons	294
5.1.10.2	Weapons firing blanks and irritants	295
5.1.10.3	Arrow wounds.....	297
5.1.10.4	Captive bolt pistols and bolt-firing tools	298
5.2	Modern graphical methods.....	300
5.2.1	Surface documentation.....	300
5.2.2	Radiological documentation.....	301
5.2.3	Combining surface and radiological documentation.....	303
5.2.4	Documenting crime scenes using modern imaging processes	305
5.2.5	3D visualization using VR headsets.....	305
5.3	Experimental reconstruction.....	306
5.3.1	Introduction	306
5.3.2	Reconstructing shooting incidents	307
5.3.2.1	Preliminary remarks.....	307
5.3.2.2	Points to bear in mind	307
5.3.2.3	Examples.....	308
5.3.3	Blunt force.....	312
5.3.3.1	Equipment used and experimental options	312
5.3.3.2	Examples.....	313
5.3.4	Using virtopsy in practice	315
5.3.4.1	Documentation and visualization.....	315
5.3.4.2	Example	318
6	Wound ballistics and surgery.....	321
6.1	The historical connection between wound ballistics and surgery	321
6.2	Wound ballistics and ballistic trauma – what’s the difference?	322
6.3	Comparing simulated wounds and real wounds.....	323

6.3.1	Preliminary remarks	323
6.3.2	Case studies	323
6.3.3	Conclusions	327
6.4	Clinical features of real wounds	328
6.5	The contribution of wound ballistics to the care of wounded people.....	329
6.5.1	The “wound profile”	329
6.5.2	What causes tissue damage?	329
6.5.3	Gas in tissues on a clinical x-ray	330
6.5.4	The “hot bullet” theory.....	330
6.5.5	Long bone fractures.....	331
6.5.6	Cranio-cerebral wounds	332
6.5.7	Unresolved issues.....	332
6.6	Documenting ballistic trauma.....	333
6.6.1	Overview	333
6.6.2	Scoring wounds in the field.....	333
6.6.3	The role of surgeons and the application of international humanitarian law	335
6.6.4	Documenting ballistic trauma – a wider responsibility for health professionals?	335
7	Wound ballistics and international agreements.....	337
7.1	Introduction	337
7.2	History of firearms and ammunition	337
7.2.1	General	337
7.2.2	The development of ammunition	338
7.2.2.1	The situation in 1800	338
7.2.2.2	The elongated bullet.....	338
7.2.2.3	The primer.....	339
7.2.2.4	The metal cartridge	339
7.2.2.5	Smokeless powder	340
7.2.2.6	Bullets	341
7.2.2.7	“Dum-dum” bullets.....	342
7.2.3	The development of firearms in the 19 th century	345
7.2.3.1	Muzzle loaders and their problems	345
7.2.3.2	Breech-loaders	345
7.2.3.3	Repeaters.....	346
7.2.3.4	Handguns	346
7.2.4	The 20 th century.....	347
7.2.4.1	Ammunition	347
7.2.4.2	Weapons.....	349
7.3	International treaties	350
7.3.1	Basic principles	350
7.3.2	The instruments	350

7.3.2.1	The original Geneva Convention (1864)	350
7.3.2.2	The St Petersburg Declaration (1868).....	351
7.3.2.3	The Brussels Conference (1874).....	351
7.3.2.4	The Hague Convention (1899).....	352
7.3.2.5	The Regulations concerning the Laws and Customs of War on Land (The Hague, 1907)	353
7.3.2.6	The Geneva Conventions of 1949.....	353
7.3.2.7	The 1977 protocols additional to the Geneva Conventions	354
7.3.2.8	The United Nations Conference (Geneva, 1980).....	355
7.3.2.9	The relevance of international instruments to wound ballistics	355
7.3.3	A basis for formulating future instruments of international humanitarian law	356
7.3.3.1	The disadvantages of the wording of existing conventions	356
7.3.3.2	Projectile-independent assessment processes	357
7.3.3.3	Formulation of standards	358

Appendices

A	Tables	359
A.1	List of tables in the main text	359
A.2	Characteristics of materials	361
A.2.1	Fluids and materials that behave like fluids.....	361
A.2.2	Solid materials	361
A.3	Calibre designations (metric system)	362
A.3.1	Handguns	362
A.3.2	Military rifles	363
A.3.3	Hunting and sporting rifles	363
A.4	Ballistic data for cartridges (metric system).....	364
A.4.1	Handgun cartridges	364
A.4.2	Military ammunition	365
A.4.3	Hunting and sporting ammunition	366
A.4.4	Pre-1900 weapons and ammunition.....	367
A.4.5	Ballistic performance of certain bows and crossbows.....	368
A.4.5.1	Technical data	368
A.4.5.2	Ballistic data	368
A.4.6	Ballistic data for various types of projectiles used in sport	368
A.5	Calibre designations (British/U.S. system).....	369
A.5.1	Handguns	369

A.5.2	Military rifles	370
A.5.3	Hunting and sporting rifles	370
A.6	Ballistic data for cartridges (British/U.S. system)	371
A.6.1	Handgun cartridges	371
A.6.2	Military ammunition	372
A.6.3	Hunting and sporting ammunition	373
A.6.4	Pre-1900 weapons and ammunition	374
A.6.5	Ballistic performance of certain bows and crossbows	375
A.4.6.1	Technical data	375
A.4.6.2	Ballistic data	375
A.6.6	Ballistic data for various types of projectiles used in sport	375
A.7	Bullet designations	376
A.7.1	Bullet form	376
A.7.2	Bullet material	376
A.7.3	Bullet structure	376
A.8	Geometric data for selected bullets	377
A.8.1	Military bullets	377
A.8.2	Other bullets	377
A.9	Twist length, angle of twist and rotation	378
A.9.1	Handguns	378
A.9.2	Rifles	378
A.9.2.1	Military rifles	378
A.9.2.2	Hunting and sporting rifles	379
A.10	Ballistics tables (metric system)	380
A.10.1	Notes	380
A.10.2	Handguns	380
A.10.3	Rifles	386
A.10.4	Old rifles	393
A.10.5	Various	395
A.11	Ballistics tables (British/U.S. system)	398
A.11.1	Notes	398
A.11.2	Handguns	398
A.11.3	Rifles	404
A.11.4	Old rifles	411
A.11.5	Various	413
A.12	Shotguns and shot	416
A.12.1	Calibres of shotgun barrels	416
A.12.2	Ballistic data for shot pellets	416
A.12.3	Designations for buckshot pellets	416
A.12.4	Designations for normal shotgun pellets: British/U.S. system ..	417
A.12.5	Designations for normal shotgun pellets: metric system	417

B Glossary.....	419
B.1 English $\Rightarrow$ German $\Rightarrow$ French	419
B.2 German $\Rightarrow$ English $\Rightarrow$ French	439
B.3 French $\Rightarrow$ German $\Rightarrow$ English	457
C Bibliography	477
General	477
Articles and papers.....	479
Photo credits.....	503
Index.....	505