

Contents

	<i>Preface</i>	<i>page xi</i>
	<i>Notation</i>	<i>xiii</i>
1	Introduction	1
	1.1 The importance of lung mechanics	1
	1.2 Anatomy and physiology	2
	1.2.1 Gas exchange	2
	1.2.2 Control of breathing	4
	1.2.3 Lung mechanics	5
	1.3 Pathophysiology	6
	1.3.1 Obstructive lung disease	6
	1.3.2 Restrictive lung disease	7
	1.4 How do we assess lung mechanical function?	8
	1.4.1 Inverse modeling	9
	1.4.2 Forward modeling	11
	1.4.3 The modeling hierarchy	12
	Further reading	14
2	Collecting data	15
	2.1 Measurement theory	15
	2.1.1 Characteristics of transducers	15
	2.1.2 Digital data acquisition	18
	2.1.3 The sampling theorem and aliasing	20
	2.2 Measuring pressure, flow, and volume	22
	2.2.1 Pressure transducers	22
	2.2.2 Measuring lateral pressure	23
	2.2.3 Esophageal pressure	25
	2.2.4 Alveolar pressure	27
	2.2.5 Flow transducers	28
	2.2.6 Volume measurement	30
	2.2.7 Plethysmography	32
	2.3 Experimental scenarios	34
	Problems	35

3	The linear single-compartment model	37
3.1	Establishing the model	37
3.1.1	Model structure	37
3.1.2	The equation of motion	38
3.2	Fitting the model to data	44
3.2.1	Parameter estimation by least squares	44
3.2.2	Estimating confidence intervals	47
3.2.3	An example of model fitting	49
3.2.4	A historical note	52
3.3	Tracking model parameters that change with time	53
3.3.1	Recursive multiple linear regression	54
3.3.2	Dealing with systematic residuals	57
	Problems	61
4	Resistance and elastance	62
4.1	Physics of airway resistance	62
4.1.1	Viscosity	63
4.1.2	Laminar and turbulent flow	63
4.1.3	Poiseuille resistance	65
4.1.4	Resistance of the airway tree	68
4.2	Tissue resistance	71
4.3	Lung elastance	72
4.3.1	The effect of lung size	72
4.3.2	Surface tension	73
4.4	Resistance and elastance during bronchoconstriction	75
4.4.1	Dose-response relationship	76
4.4.2	Time-course of bronchoconstriction	78
4.4.3	Determinants of airways responsiveness	79
	Problems	81
5	Nonlinear single-compartment models	82
5.1	Flow-dependent resistance	82
5.2	Volume-dependent elastance	85
5.2.1	Nonlinear pressure-volume relationships	85
5.2.2	Mechanisms of elastic nonlinearity	87
5.3	Choosing between competing models	91
5.3.1	The F -ratio test	93
5.3.2	The Akaike criterion	95
	Problems	95
6	Flow limitation	97
6.1	FEV ₁ and FVC	97
6.2	Viscous mechanisms	98

6.3	Bernoulli effect	99
6.4	Wave speed	101
	Problems	106
7	Linear two-compartment models	108
7.1	Passive expiration	108
7.2	Two-compartment models of heterogeneous ventilation	109
7.2.1	The parallel model	111
7.2.2	The series model	114
7.2.3	Electrical analogs	116
7.3	A model of tissue viscoelasticity	117
7.4	Stress adaptation and frequency dependence	119
7.5	Resolving the model ambiguity problem	122
7.6	Fitting the two-compartment model to data	124
	Problems	126
8	The general linear model	127
8.1	Linear systems theory	127
8.1.1	Linear dynamic systems	128
8.1.2	Superposition	130
8.1.3	The impulse and step responses	130
8.1.4	Convolution	133
8.2	The Fourier transform	135
8.2.1	The discrete and fast Fourier transforms	135
8.2.2	The power spectrum	140
8.2.3	The convolution theorem for Fourier transforms	140
8.3	Impedance	142
8.3.1	The forced oscillation technique	143
8.3.2	A word about complex numbers	145
8.3.3	Signal processing	146
	Problems	148
9	Inverse models of lung impedance	150
9.1	Equations of motion in the frequency domain	150
9.2	Impedance of the single-compartment model	151
9.2.1	Resonant frequency and inertance	152
9.2.2	Regional lung impedance	156
9.3	Impedance of multi-compartment models	158
9.3.1	The viscoelastic model	158
9.3.2	Effects of ventilation heterogeneity	159
9.3.3	The six-element model	162
9.3.4	Transfer impedance	164
9.4	Acoustic impedance	166
	Problems	168

10	Constant phase model of impedance	169
10.1	Genesis of the constant phase model	169
10.1.1	Power-law stress relaxation	170
10.1.2	Fitting the constant phase model to lung impedance	172
10.1.3	Physiological interpretation	174
10.2	Heterogeneity and the constant phase model	175
10.2.1	Distributed constant phase models	176
10.2.2	Heterogeneity and hysteresivity	177
10.3	The fractional calculus	181
10.4	Applications of the constant phase model	183
	Problems	186
11	Nonlinear dynamic models	188
11.1	Theory of nonlinear systems	188
11.1.1	The Volterra series	188
11.1.2	Block-structured nonlinear models	189
11.2	Nonlinear system identification	190
11.2.1	Harmonic distortion	191
11.2.2	Identifying Wiener and Hammerstein models	193
11.3	Lung tissue rheology	193
11.3.1	Quasi-linear viscoelasticity	194
11.3.2	Power-law stress adaptation	195
	Problems	200
12	Epilogue	201
	<i>References</i>	207
	<i>Index</i>	218