

Contents

1	Introduction	1
1.1	Implants for Bone Tissue Engineering	1
1.2	Overview of Materials for Bone Tissue Engineering	5
1.2.1	Metals	5
1.2.2	Ceramics	9
1.2.3	Polymers	10
1.2.4	Composites	11
1.3	Closure	13
	References	14
2	Important Definitions and Concepts	17
2.1	Cell Biology Related Terms/Concepts	17
2.1.1	Cell	17
2.1.2	Protein	19
2.1.3	Extracellular Matrix (ECM)	21
2.1.4	Tissue	22
2.1.5	Stem Cell	23
2.1.6	Cell Adhesion and Cell-Cell Interaction	24
2.1.7	Cell Signalling	25
2.1.8	Growth Factors	26
2.1.9	Cell Differentiation	26
2.1.10	Cell Migration	27
2.1.11	Cell Division	28
2.1.12	Cell Apoptosis and Necrosis	30
2.1.13	Bacteria	31
2.2	Biomaterials Science Related Terms/Concepts	32
2.2.1	Biomaterial	32
2.2.2	Biocompatibility	33
2.2.3	Cytocompatibility	34
2.2.4	Cytotoxicity	34

2.2.5	Haemocompatibility	34
2.2.6	Host Response	35
2.3	Biocompatibility Assessment Related Terms	35
2.3.1	<i>in vitro</i>	35
2.3.2	<i>in vivo</i>	35
2.3.3	Assay	36
2.3.4	Bioassay	36
2.3.5	Histology	37
2.3.6	Staining	37
2.4	Bone Tissue Engineering Related Terms/Concepts	37
2.4.1	Scaffold	37
2.4.2	Implant	38
2.4.3	Tissue Engineering	38
2.4.4	Vascularization	39
2.4.5	Angiogenesis	39
2.4.6	Osteointegration/Osseointegration	39
2.4.7	Osteoinduction	40
2.4.8	Osteoconduction	40
2.5	Antimicrobial Property Related Terms/Concepts	40
2.5.1	Bacteriostatic	40
2.5.2	Bactericidal	40
2.5.3	Colony Forming Unit (CFU)	41
2.5.4	Biofilm	41
2.5.5	Biomaterial Associated Infection (BAI)	42
2.5.6	Antibiotic	42
	References	42
3	Natural Bone and Tooth: Structure and Properties	45
3.1	Overview	45
3.2	Structure and Properties of Bone Tissue-Specific Cells, Tissue and ECM	48
3.3	Anatomy of Natural Bone	50
3.4	Classification of Natural Bone	55
3.5	Structure of Natural Bone	55
3.5.1	Structure of Collagen	56
3.5.2	Structure of Hydroxyapatite	57
3.6	Mechanical Properties of Natural Bone	60
3.7	Functional Properties of Natural Bone	66
3.7.1	Dielectric Property	67
3.7.2	Piezoelectricity	68
3.7.3	Pyroelectricity	70
3.7.4	Ferroelectricity	71
3.8	Structure-Property Correlation of Natural Teeth	72
3.9	Summary	77
	References	78

4	Processing of Implant Biomaterials	87
4.1	How to Prepare Implantable Biomaterials?	87
4.2	Processing of Ceramics	90
4.3	Thermodynamic Aspect of Sintering	91
4.4	Mechanism and Kinetics of Sintering	95
4.5	Important Factors Influencing Sintering Process	98
4.6	Steps Involved in Producing Ceramic Compact	100
4.6.1	Ball Milling	101
4.6.2	Compaction	103
4.6.3	Pressureless Sintering	108
4.7	Microwave Sintering	109
4.8	Spark Plasma Sintering Based Consolidation of Ceramics	110
4.8.1	Effect of Various Parameters on Spark Plasma Sintering	112
4.8.2	Temperature Effect	112
4.9	Consolidation and Shaping of Polymers	115
4.9.1	Compression Molding	116
4.10	Injection Molding	120
4.10.1	Extrusion	122
4.11	Summary	124
	References	125
5	Fundamentals of Scaffolds Fabrication Using Low Temperature Additive Manufacturing	127
5.1	Introduction	127
5.2	Design and Structural Aspects	132
5.3	Low Temperature Additive Manufacturing Methods	133
5.3.1	Background	134
5.3.2	3D Powder Printing	135
5.3.3	3D Plotting	155
5.3.4	Post-Processing	160
5.4	Closure	164
	References	164
6	Mechanical Properties of Biomaterials	175
6.1	Overview	175
6.1.1	Mechanical Response of Materials	175
6.2	Why are Ceramics Brittle?	178
6.3	Cracking in Ceramics	179
6.4	Brittle Fracture of Ceramics	184
6.5	Concept of Fracture Toughness	189
6.6	Strength Variability of Ceramics	191
6.6.1	Weakest Link Fracture Statistics	192

6.7	Measurement of Basic Mechanical Properties	194
6.7.1	Vickers Bulk Indentation Measurements	194
6.7.2	Instrumented Microindentation Measurements	195
6.7.3	Compressive Strength	197
6.7.4	Flexural Strength	199
6.8	Diametral Compression Test	201
6.9	Dynamic Strength Evaluation	203
6.10	Elastic Modulus	205
6.11	Fracture Toughness	206
6.11.1	Long Crack Method	206
6.11.2	Indentation Microfracture (IM) Method	209
6.12	Toughening Mechanisms	210
6.13	Practical Guidelines for the Measurement of Mechanical Properties	213
6.14	Mechanical Properties of Polymeric Biomaterials	214
6.14.1	Viscoelastic Deformation Under Uniaxial Loading	214
6.14.2	Dynamic Mechanical Analysis (DMA)	217
6.15	Summary	218
	References	220
7	Friction and Wear Behavior	223
7.1	Introduction	223
7.2	Frictional Properties	224
7.3	Laws of Friction	225
7.4	Friction Mechanisms	226
7.5	Friction of Engineering Materials	227
7.6	Wear	230
7.7	Wear Mechanisms	232
7.7.1	Adhesive Wear	233
7.7.2	Abrasive Wear	234
7.7.3	Fatigue Wear	236
7.7.4	Fretting Wear	237
7.8	Experimental Assessment of Wear Properties	245
7.8.1	Guidelines for Conducting Friction and Wear Analysis	248
7.9	Closure	249
	References	250
8	Corrosion and Degradation of Implantable Biomaterials	253
8.1	Introduction	253
8.2	Physiological Environment in Relation to Corrosion	255
8.3	Clinical Significance	256

8.4	Corrosion Mechanisms	257
8.4.1	Galvanic Corrosion	257
8.4.2	Pitting and Crevice Corrosion	258
8.4.3	Stress Corrosion Cracking	259
8.4.4	Corrosion Fatigue	259
8.5	Thermodynamics of Electrochemical Corrosion	260
8.6	Theory of Aqueous Corrosion-Polarization	263
8.7	Kinetic Measurements of Corrosion	266
8.7.1	Linear Polarization	268
8.7.2	Tafel Extrapolation	270
8.7.3	Potentiodynamic Polarization	270
8.8	Illustrative Results of Electrochemical Corrosion of Metallic Implants in Simulated Physiological Environment	273
8.8.1	Corrosion Rates of Metallic Implants	276
8.8.2	Repassivation of Titanium Alloys	277
8.9	Degradation of Polymeric Biomaterials	278
8.9.1	Polymer Erosion and Degradation	280
8.9.2	Erosion Mechanism <i>in vitro</i>	281
8.9.3	Determination of Degradation Kinetics	282
8.10	Closure	285
	References	285
9	Probing Toxicity of Biomaterials and Biocompatibility	
	Assessment	291
9.1	Introduction	291
9.2	Relevance of Biocompatibility Assessment	293
9.3	Cell-Material Interaction	296
9.3.1	Substrate Stiffness	300
9.3.2	Substrate Topography	301
9.4	Evaluation of Toxicity	302
9.4.1	Cytotoxicity	302
9.4.2	Gene Expression and Cytokine Levels	308
9.4.3	Genotoxicity	308
9.5	Cyto/Genotoxicity of Bioceramics	313
9.6	Illustrative Examples of Cyto/Genotoxicity of Bioceramics and Its Eluates	315
9.6.1	Hydroxyapatite-Titanium Composites	316
9.6.2	HA-Zinc Oxide	319
9.6.3	HA-Ag and Ag-Doped HA	320
9.6.4	HA-Mullite	321
9.6.5	<i>in vivo</i> Toxicity of HA-BaTiO ₃ Eluates	322
9.6.6	β-Tri Calcium Phosphate Based Bioceramics	322
9.7	Haemocompatibility	323
9.7.1	Blood as a Tissue	323
9.7.2	Experimental Assessment of Hemocompatibility	325

9.8	Biocompatibility Assessment, <i>in vivo</i>	327
9.8.1	Ethical Committee Approval and Pre-Clinical Study Objectives	328
9.8.2	Rationale for Selection of Animal Strains and Defect Model	329
9.8.3	Assessment of Tissue Response.	332
9.8.4	Histological Analysis of Tissue Sections	333
9.8.5	Illustrative Examples of Histology and TEM Analysis of Tissue Compatibility.	335
9.9	Host Response Towards a Biomaterial	338
9.10	Relevance of Clinical Trials	341
9.11	Closure	343
	References.	344
10	Three Dimensional Porous Scaffolds: Mechanical and Biocompatibility Properties	353
10.1	Background	353
10.2	Materials Property Aspects in Scaffold Development	354
10.3	Importance of Porosity on Vascularization of 3D Scaffolds	355
10.4	3D-Plotted Scaffolds in Different Material Systems	359
10.5	Biofabrication with Cells	363
10.6	Biocompatibility Assessment of 3D Printed Scaffolds	365
10.6.1	<i>in vitro</i> Biocompatibility	366
10.6.2	<i>in vivo</i> Biocompatibility	368
10.7	Mechanical Properties of Porous 3D Scaffolds	371
10.8	Closure	374
	References.	376
11	Introduction to Biomechanics and Orthopedic Device Testing	385
11.1	Introduction	385
11.2	Biomechanics of Lower Extremity Joints	386
11.3	Human Gait	387
11.4	Kinetics of the Hip Joint.	389
11.5	Biomedical Device Testing	392
11.6	Joint Simulator Study	398
11.7	Hip Joint Simulator Testing	399
11.8	Knee Joint Simulator Testing	404
11.9	Closure	406
	References.	407
12	A Way Forward	409
12.1	Smart Design Concepts in Bone Tissue Engineering	409
12.2	Innovative Design of Biomaterials—Functionally Graded Implants	410
12.3	Biomaterial Concepts for Cartilage Tissue Engineering	411

12.4 Laser and Electric Field Induced Osteogenesis
for Bone Tissue Engineering 413

12.5 Scaffold Design Concepts for Skeletal Muscle Tissue
Engineering. 414

References. 416

Index 417

Biomaterials for Musculoskeletal Regeneration

Concepts

Basu, B.

2017, XXXIII, 420 p. 172 illus., 109 illus. in color.,

Hardcover

ISBN: 978-981-10-3058-1