
Contents

Series Preface.....	xi
Preface.....	xiii
About the Editor.....	xvii
List of Contributors.....	xix

Chapter 1 On Dental Cell Types and Cell Populations, Also in Light of Evolution..... 1

Jan Krivanek, Kaj Fried and Igor Adameyko

1.1	Introduction.....	1
1.1.1	Types of Teeth.....	3
1.1.2	Developmental Origin of Dental Cell Types.....	4
1.1.3	Cell Types and Continuously Growing Teeth.....	9
1.2	Current Perspective on Dental Cell Types.....	10
1.2.1	Epithelium-Derived Cell Types.....	10
1.2.2	Mesenchyme-Derived Cell Types.....	16
1.2.3	Blood Vessels.....	18
1.2.4	Dental Innervation and Associated Cell Types.....	19
1.2.5	Tissue-Residential Immune Cells of the Pulp.....	24
1.2.6	Cellular Composition of Structures Anchoring Teeth in Jaws.....	25
1.3	Evolution of Cell Types Building Odontodes.....	26
1.3.1	Evolution of Odontoblasts and Osteocytes.....	26
1.3.2	Evolution of Pulp Cells.....	31
1.3.3	Evolution of Cell Types Forming Tooth Attachment— Cementoblasts and Periodontal Ligamentum.....	32
1.3.4	Evolution of Ameloblasts.....	32
1.4	Perspectives of Single-Cell Omics Methods in the Evolution of Cell Types Building Odontodes.....	34
	References.....	38

Chapter 2 The Conquest of the Oropharynx by Odontogenic Epithelia..... 49

Ann Huysseune, Robert Cerny and P. Eckhard Witten

2.1	Introduction: What Are Teeth and Where Are They Formed?.....	49
2.2	The Odontogenic Epithelia: New Players.....	51
2.3	Odontogenesis Starts in Stratified Epithelia.....	56
2.4	Odontogenesis in the Oral Region Is Restricted to Odontogenic Bands or Dental Laminae.....	58
2.5	The Distribution of Pharyngeal Teeth: The Role of Retinoic Acid.....	59

2.6	Conclusions and Directions for Future Research.....	61
	Acknowledgments.....	61
	References.....	62
Chapter 3	The Neural Crest and the Development of Odontoskeletogenic Potential along the Body Axis.....	68
	<i>Jan Stundl and Marianne E. Bronner</i>	
3.1	Introduction.....	68
3.2	Distinct Neural Crest Subpopulations with Different Developmental Potential along the Anteroposterior Axis	73
3.3	Skeletal Biomineralization Is Tightly Associated with the Acquisition of Neural Crest	75
3.4	Schwann Cell Precursors, Cells with Neural Crest-like Developmental Potential	78
3.5	Neural Crest as a Generator of Odontoskeletogenic Potential along the Body Axis	81
3.6	Conclusion and Perspectives.....	86
	Acknowledgments.....	88
	References.....	88
Chapter 4	Evolutionary Genomics of Odontode Tissues.....	100
	<i>Tatjana Haitina and Mélanie Debais-Thibaud</i>	
4.1	Introduction.....	100
4.2	Tooth and Odontode Cells: Conserved Features in Extant Jawed Vertebrates.....	101
4.3	Tooth and Dermal Odontode Tissues: Variable Histological Features in Jawed Vertebrates.....	104
4.4	Tooth/Odontode Biomineralization, Shared Ancestral Processes?	106
4.5	General ECM Structural Components.....	107
4.5.1	Fibrillar and Minor Collagens	107
4.5.2	Proteoglycans.....	108
4.6	Matrix Mineralization Components	109
4.6.1	The Matrix- and Bone-Gla Proteins	109
4.6.2	The Specific Case of Type X Collagen	111
4.6.3	SPARC (Osteonectin) and SPARC-like Proteins	111
4.6.4	Extracellular Phosphatases	113
4.7	The Secretory Calcium-Binding Phosphoprotein Family	114
4.7.1	P/Q-Rich SCPPs.....	115
4.7.2	The SIBLING Family of Acidic SCPPs	118
4.8	Matrix Degradation Components	119
4.8.1	Matrixins: The Matrix Metalloproteinase Family.....	119
4.8.2	Adamalysins: The ADAM and ADAMTS Families.....	120
4.8.3	Astacins: The Bmp1/Tll and Meprins.....	121

4.8.4 Non-met zincin Proteases: Peptide Release and Ground Matrix Degradation 121

4.9 Concluding Remarks..... 122

References..... 124

Chapter 5 Odontoblast Repertoire Delivers Significantly Different Dental Tissues from Pluripotent Neural Crest-Derived Cells..... 141

Moya Meredith Smith, Aaron R.H. LeBlanc, Charlie Underwood and Zerina Johanson

5.1 Introduction..... 141

5.2 Model of Morphogenetic Units Formed from Cranial Neural Crest (CNC) 143

5.3 Development of Odontoblasts within a Tooth Module 144

5.3.1 Loss of Potential to Make Tooth Germs in Extant Holocephalans..... 144

5.3.2 Early Stages of Cell Differentiation in the Tooth Module..... 145

5.3.3 New Tooth Modules that Form Continuously in Adult Jaws 145

5.4 Evolution of Dentine Tissues and Odontoblast Plurality 147

5.5 Enameloid Production by Odontoblasts with Variation in Sharks and Rays (Elasmobranchii)..... 148

5.5.1 Shark Age Series in a Tooth Whorl 148

5.5.2 Enameloid as a Product of the Odontoblasts 150

5.5.3 Osteodentine as a Product of the Odontoblasts 150

5.5.4 Odontoblast Production in Dermal Saw Teeth 151

5.5.5 Rays Age Series in Tooth Whorls of *Rhinoptera* and *Rhinobatos* 154

5.6 Hypermineralised Dentine in Holocephalans without Teeth..... 158

5.6.1 Extinct Holocephalans with Teeth 158

5.6.2 Extant Forms without Teeth and New Hypermineralised Tissue Type 158

5.7 Odontoblasts in Bony Fishes (Actinopterygii), Fossil and Extant 162

5.7.1 Odontoblasts Manage the Coronal Enameloid in Crushing Teeth..... 162

5.7.2 Odontoblast Activity in the Dentine of In-Group Tetraodontiformes (Neopterygii; Eupercaria)..... 163

5.8 Odontoblasts Migrate to Repair Bone Damage in Heterostraci 166

5.8.1 Dentine Tubercles Renewed and Regenerated by Odontoblasts Making Orthodentine Infills..... 166

5.8.2 Response of Odontoblasts to Massive Damage from a Wound to the Armour 168

5.9 Discussion 170

5.9.1	Interpretations of the Odontoblast Repertoire	170
	Acknowledgments.....	174
	References.....	174
Chapter 6	Shifting Perspectives in the Study of Amniote Tooth Attachment and the Path Forward to Establishing Vertebrate Periodontal Tissue Homology	179
	<i>Aaron R.H. LeBlanc</i>	
6.1	Introduction.....	179
6.2	Describing Dentitions: Tooth Implantation and Attachment Are Different.....	181
6.3	What Do We Call the Attachment Tissues in Nonmammalian Amniotes?	182
6.4	Problematic Tissues and Structures.....	190
6.5	Ankylosis, Gomphosis, and the Variably Mineralized PDL: Lessons from Synapsids and Archosaurs.....	193
6.6	Heterochrony and Amniote Tooth Attachment Tissue Evolution.....	198
6.7	Development of the Periodontal Tissues and HERS, and Their Relationship with Tooth Implantation.....	200
6.8	Co-opting Cementum: More Shifts in Developmental Timing to Produce Complex and Continually Erupting Teeth	202
6.9	The Path Forward: What Do We Call the Attachment Tissues in Other Vertebrates?	205
	References.....	208
Chapter 7	Initiation and Periodic Patterning of Vertebrate Dentitions.....	215
	<i>Alexa Sadier and Vladimír Soukup</i>	
7.1	Introducing the Patterned Dentitions.....	215
7.2	Reaction–Diffusion Mechanisms and Periodic Patterning of Skin Derivatives.....	217
7.2.1	Basics of Reaction–Diffusion Mechanisms.....	217
7.2.2	Reaction–Diffusion Mechanisms in Patterning the Mammalian Hair Follicles.....	218
7.2.3	Patterning the Bird Plumage: Turing with and without a Wave.....	220
7.2.4	From Body Covers to Dentitions	221
7.3	Reaction–Diffusion Mechanisms and Periodic Patterning of Teeth.....	222
7.3.1	Specification of the Region Committed for Tooth Development	222
7.3.2	Specification of Tooth Competence in the Mouse	223

- 7.3.3 Specification of Tooth Competence in Ray-finned Fishes..... 224
- 7.3.4 How to Initiate Development of the Dentition: The Role of the Initiator Tooth 225
- 7.3.5 The Molecular Basis of Mammalian Dentition Patterning..... 228
- 7.3.6 Periodic Pattern Generators as Assemblers of Multirowed Dentitions 230
- 7.3.7 Dental Stem Cells as the Source of Patterned Replacing Dentitions..... 232
- 7.4 Prospects and Ideas for Periodic Tooth Patterning..... 234
 - 7.4.1 Mathematical Modeling for Periodic Tooth Patterning..... 234
 - 7.4.2 Identification of Molecular Players in the Reaction–Diffusion Mechanisms 238
 - 7.4.3 The Origin of Tooth Classes in Mammals 239
 - 7.4.4 Is the First Tooth Always Non-functional? 240
 - 7.4.5 Integrating Turing Patterns with Other Developmental Mechanisms 242
- 7.5 Conclusion..... 243
- Acknowledgments..... 243
- References..... 243

Chapter 8 The Selected Deviation: The Acquisition of In-situ Tooth Replacement by Creating a Gap to Fill 255

Donglei Chen

- 8.1 Introduction..... 255
 - 8.1.1 Did In-situ Tooth Replacement Evolve De Novo? 255
 - 8.1.2 Is Alternation a True Pattern of Dental Development?..... 255
- 8.2 Process Components of Odontode Ontogeny 260
 - 8.2.1 Identical Direction of Tooth Addition and Bone Growth 260
 - 8.2.2 Differential Timing between Tooth Addition and Bone Growth..... 262
 - 8.2.3 Gap-Filling Autonomy during the Initiation of Tooth Position 265
 - 8.2.4 Cyclic In-situ Tooth Replacement as a Modification of Columnar Succession 270
 - 8.2.5 The Deposition of Replacement Teeth Requires a Gap to Be Filled 274
- 8.3 Discussion 278
 - 8.3.1 Chemical Signals of Activation or Inhibition 278
 - 8.3.2 Dental Lamina and *Sox2*..... 279
 - 8.3.3 Odontogenic Gene Regulatory Network..... 280

8.3.4	Close Packing of Odontodes Coupled with Space Constraint of Skeleton.....	281
8.4	Conclusion.....	283
	References.....	284
Chapter 9	Complexity, Networking, and Many-Model Thinking Enhance Understanding of the Patterning, Variation, and Interactions of Human Teeth and Dental Arches	294
	<i>Alan Henry Brook and Matthew Brook O'Donnell</i>	
9.1	Introduction.....	294
9.2	Background.....	295
9.2.1	Investigating Variation Using Advances in Methodology and Concepts	295
9.3	The Developmental Basis for Variation.....	298
9.3.1	Process	298
9.3.2	Factors.....	302
9.3.3	Interactions.....	304
9.3.4	Patterning.....	304
9.4	Variation in Tooth Number, Size, and Shape.....	305
9.4.1	Prevalence	305
9.4.2	Factors.....	305
9.4.3	Interactions.....	309
9.5	Dental Arches	311
9.5.1	Development	311
9.5.2	Factors.....	312
9.6	Relationship and Coordination of Tooth and Dental Arch Development	315
9.6.1	Relationship	315
9.6.2	Coordination	316
9.7	Effect of Variations of Tooth Number, Size, and Shape on Dental Arches	317
9.8	Evolutionary Trends.....	319
9.9	Complexity, Networks, and Multiple Models Enhance Our Understanding of Development	320
9.9.1	Complexity and Networks	320
9.9.2	Multiple Models.....	321
	Acknowledgments.....	326
	References.....	326
Index.....		337