CONNECTIVE TISSUE MATRIX

Part 2

TOPICS IN MOLECULAR AND STRUCTURAL BIOLOGY

Series Editors

Stephen Neidle
*Institute of Cancer Research
Sutton, Surrey, UK*

Watson Fuller
*Department of Physics
University of Keele, UK*

Protein–Nucleic Acid Interaction
Edited by Wolfram Saenger and Udo Heinemann

Calcified Tissue
Edited by David Hukins

Oligodeoxynucleotides
Edited by Jack S. Cohen

Molecular Mechanisms in Muscular Contraction
Edited by John M. Squire

Connective Tissue Matrix, Part 2
Edited by David Hukins

New Techniques of Optical Microscopy and Microspectroscopy
Edited by Richard Cherry

Molecular Dynamics
Edited by Julia Goodfellow

CONNECTIVE TISSUE MATRIX

Part 2

Edited by

DAVID W. L. HUKINS

*Department of Medical Biophysics
University of Manchester, UK*

M

MACMILLAN
PRESS

Scientific & Medical

© The Macmillan Press Ltd 1990

Softcover reprint of the hardcover 1st edition 1990 978-0-333-45319-3

All rights reserved. No reproduction, copy or transmission of this publication may be made without written permission.

No paragraph of this publication may be reproduced, copied or transmitted save with written permission or in accordance with the provisions of the Copyright, Designs and Patents Act 1988, or under the terms of any licence permitting limited copying issued by the Copyright Licensing Agency, 33-4 Alfred Place, London WC1E 7DP.

Any person who does any unauthorised act in relation to this publication may be liable to criminal prosecution and civil claims for damages.

First published 1990

Published by
THE MACMILLAN PRESS LTD
Houndmills, Basingstoke, Hampshire RG21 2XS
and London
Companies and representatives
throughout the world

Filmset by Wearside Tradespools,
Fulwell, Sunderland
Printed in Great Britain by WBC Print

British Library Cataloguing in Publication Data
Connective tissue matrix.
Pt. 2

1. Connective tissues
I. Hukins, David W. L. II. Series
612.75

ISSN 0265-4377

ISBN 978-1-349-09867-5

ISBN 978-1-349-09865-1 (eBook)

DOI 10.1007/978-1-349-09865-1

Contents

<i>Preface</i>	ix
<i>The contributors</i>	xi
1 Dynamic aspects of connective tissue structure and function <i>D. W. L. Hukins</i>	1
Introduction	1
Composition	2
Development	3
Ageing, degeneration and pathology	4
Turnover, remodelling and repair	5
Mechanical properties	7
2 The role of extracellular matrix in development <i>J. B. L. Bard</i>	11
Introduction	11
The extracellular matrix	12
The constituents of the ECM	14
Developmental functions of ECM	22
Ducted gland morphogenesis	29
Morphogenesis of the corneal stroma	34
The future	39
3 Solute transport in articular cartilage and the intervertebral disc <i>J. P. G. Urban</i>	44
Introduction	44
Structure of the matrix	46
Partition coefficients	50
Transport through the matrix	52
Physiological aspects of solute transport	56
4 Poroelastic finite element models for soft tissue structures <i>B. R. Simon</i>	66
Introduction	66

Background	67
Theory	68
Material properties	73
Finite element formulations	77
Representative FEM results	84
Conclusions	88
5 Electromechanical and physicochemical regulation of cartilage strength and metabolism <i>A. J. Grodzinsky and E. H. Frank</i>	91
Introduction	91
Swelling stress and electromechanical forces	92
Electrokinetic transduction	97
Fields, forces and flows: regulation of cartilage metabolism	114
6 Structure and function of intramuscular connective tissue <i>P. P. Purslow and V. C. Duan</i>	127
Introduction	127
The general structure of muscle	128
The structure of intramuscular connective tissues	130
Composition of muscle connective tissue	135
The myotendinous junction	142
Functions of the extracellular matrix of skeletal muscle	146
Mechanical functions of intramuscular connective tissue	149
Changes in intramuscular connective tissue due to exercise, injury and disease	158
Conclusion	160
7 Physicochemical properties of vascular elastin <i>C. P. Winlove and K. H. Parker</i>	167
Introduction	167
Histology and biochemistry	168
Physical studies on the conformation and structure of elastin	175
The contribution of elastin to the mechanical properties of blood vessels	180
The permeability properties of elastin membranes	184
Conclusions	192
8 Structural basis of dilatation of the cervix <i>R. M. Aspden</i>	199
Introduction	199
Composition and structure	200
Mechanical properties	206
Fibre reinforcing and changes in composition	216
Post-partum restoration	224

Conclusions	225
9 MR imaging of connective tissue degeneration <i>D. S. Hickey, R. M. Aspden, G. J. Sivewright and D. J. Prendergast</i>	229
Introduction	229
Magnetic resonance images	231
Representation of image structure	238
Interpretation in terms of tissue biochemistry	246
Connective tissue imaging	248
Discussion	256
10 Tissue repair with the aid of carbon fibre <i>R. J. Minns</i>	261
Introduction	261
Repair of osteochondral defects	261
Clinical experience of carbon fibre arthroplasty in the knee	275
Repair of hernia	279
Carbon fibre as a pressure-sore prosthesis	287
<i>Index</i>	297

Preface

The structures of connective tissue matrices are responsible for many of the remarkable mechanical properties of the body. In the musculo-skeletal system, the contractile properties of muscle are often emphasized, while such tissues as bone, tendon, ligament and cartilage are sometimes considered to be static, inert and relatively unimportant. However, the rigidity of bone is essential for locomotion, it is constantly being remodelled and it acts as a reservoir of calcium in the body. Tendons, ligaments and cartilages have a similar macromolecular composition but do not contain mineral, so that they lack the rigidity of bone. Their internal structures enable them to withstand the high forces to which they are subjected and, at least in the case of tendons and ligaments, these structures are dynamic so that the response of the tissues adapts to the magnitude of the applied force. Indeed, connective tissues are even implicated in the properties of muscles themselves, as described in Chapter 6. Many other biological systems rely on connective tissues for their mechanical properties—blood vessels (Chapter 7) and uterine cervix (Chapter 8) provide examples.

Matrix components also effect the development of tissues and influence the transport of nutrients to, and waste products from, cells. These aspects of connective tissue matrix are developed further in Chapters 2 and 3. Changes also occur during ageing, degeneration and disease. To some extent the tissues are capable of repair. However, as the population ages, and subjects itself to increasingly sophisticated forms of trauma, these natural repair mechanisms may have to be assisted by medical treatment. Chapter 10 provides an example of the use of a synthetic material (carbon fibre) to aid tissue repair.

The emphasis in this volume is on how connective tissue matrix changes its properties and influences biological processes. Chapter 1 provides a general overview of the subject and subsequent chapters provide specific examples. These chapters cover selected topics of current research and are not intended to provide a comprehensive review. Some, e.g. Chapter 4, emphasize technique, while others, e.g. Chapter 2, concentrate on biol-

ogical properties. Furthermore, the chapters illustrate the influence of a wide range of disciplines, although this volume tends to concentrate on the more physical and physico-chemical aspects of the subject—reflecting my own interests and the scope of this series. This volume is intended as a sequel to *Connective Tissue Matrix* (published in this series in 1984). *Calcified Tissue* (published in this series in 1989) deals with related tissues whose composition and properties are modified by calcification.

Manchester, 1990

D. W. L. H.

The Contributors

R. M. Aspden

Dept of Biochemistry and Molecular Biology
University of Manchester
Stopford Building
Manchester M13 9PT, UK

J. B. L. Bard

MRC Human Genetics Unit
Western General Hospital
Edinburgh EH4 2XU, UK

V. C. Duance

AFRC Institute of Food Research
Bristol Laboratory
Langford
Bristol BS18 7DY, UK

E. H. Frank

Dept of Electrical Engineering and Computer Science
Massachusetts Institute of Technology
Cambridge
MA 02139, USA

A. J. Grodzinsky

Dept of Electrical Engineering and Computer Science
Massachusetts Institute of Technology
Cambridge
MA 02139, USA

D. S. Hickey

BTG
Enterprise House
Manchester Science Park
Manchester M15 4EN, UK

D. W. L. Hukins

Dept of Medical Biophysics
University of Manchester
Stopford Building
Manchester M13 9PT, UK

R. J. Minns

Regional Medical Physics Dept
Durham Unit
Dryburn Hospital
Durham DH1 5TW, UK

K. H. Parker

Physiological Flow Studies Unit
Imperial College of Science, Technology and Medicine
London SW7 2AZ, UK

D. J. Prendergast

IBM
Athelstan House
St Clement St
Winchester
Hampshire SO23 9DR, UK

P. P. Purslow

AFRC Institute of Food Research
Bristol Laboratory
Langford
Bristol BS18 7DY, UK

G. J. Sivewright

Dept of Medical Biophysics
University of Manchester
Stopford Building
Manchester M13 9PT, UK

B. R. Simon

Dept of Aerospace and Mechanical
Engineering
College of Engineering and Mines

University of Arizona
Tucson
AZ 85721, USA

J. P. G. Urban

Laboratory of Physiology
University of Oxford
Parks Road
Oxford OX1 3PT, UK

C. P. Winlove

Physiological Flow Studies Unit
Imperial College of Science, Tech-
nology and Medicine
London SW7 2AZ, UK