Methods in Molecular Biology

Series Editor
John M. Walker
School of Life and Medical Sciences
University of Hertfordshire
Hatfield, Hertfordshire, AL10 9AB, UK

For further volumes:
http://www.springer.com/series/7651

Skeletal Muscle Regeneration in the Mouse

Methods and Protocols

Edited by

Michael Kyba

Lillehei Heart Institute, University of Minnesota, Minneapolis, MN, USA

Humana Press

Editor
Michael Kyba
Lillehei Heart Institute
University of Minnesota
Minneapolis, MN, USA

ISSN 1064-3745 ISSN 1940-6029 (electronic)
Methods in Molecular Biology
ISBN 978-1-4939-3808-7 ISBN 978-1-4939-3810-0 (eBook)
DOI 10.1007/978-1-4939-3810-0

Library of Congress Control Number: 2016948837

© Springer Science+Business Media New York 2016
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer Science+Business Media LLC New York

Preface

Although skeletal muscle is the most abundant tissue in the body, playing key roles in metabolism, heat generation, and macromolecule storage in addition to the obvious role in locomotion, our understanding of the mechanisms underlying the growth, damage, degeneration, and repair of this tissue is still very limited. The past decade has seen rapid advances in our understanding of the development and cell biology of skeletal muscle progenitor cells and a burgeoning of laboratory research on skeletal muscle regeneration. These advances rest in large part on novel technologies and methods that, combined with new genetic tools available in the mouse model, have reshaped the field. As the field has swelled with many new investigators focused on the mouse model, there seemed a need for a volume that collects these critical protocols, optimized for mouse but in most cases easily adaptable to rat or other mammalian models. I thank my many wonderful colleagues for their contributions to this collection. Methods have been grouped into three general areas: inducing damage, analysis of the progenitor cells of skeletal muscle, and measuring overall muscle function. It is our hope that this volume will serve as a comprehensive laboratory reference for research on skeletal muscle growth, damage, repair, degeneration, and regenerative therapy in the mouse model system.

Minneapolis, MN, USA *Michael Kyba*

Contents

Preface . . . . . *v*
Contributors . . . . . *ix*

PART I INJURY MODELS

1 Eccentric Contraction-Induced Muscle Injury: Reproducible, Quantitative, Physiological Models to Impair Skeletal Muscle's Capacity to Generate Force 3
Jarrod A. Call and Dawn A. Lowe

2 Volumetric Muscle Loss 19
Beth E. Pollot and Benjamin T. Corona

3 Freeze Injury of the Tibialis Anterior Muscle 33
Gengyun Le, Dawn A. Lowe, and Michael Kyba

4 Synergist Ablation as a Rodent Model to Study Satellite Cell Dynamics in Adult Skeletal Muscle 43
Tyler J. Kirby, John J. McCarthy, Charlotte A. Peterson, and Christopher S. Fry

5 Inducing and Evaluating Skeletal Muscle Injury by Notexin and Barium Chloride 53
Matthew T. Tierney and Alessandra Sacco

6 Cardiotoxin Induced Injury and Skeletal Muscle Regeneration 61
Glynnis A. Garry, Marie Lue Antony, and Daniel J. Garry

7 Fibrosis-Inducing Strategies in Regenerating Dystrophic and Normal Skeletal Muscle 73
Patrizia Pessina and Pura Muñoz-Cánoves

PART II EVALUATING PROGENITOR CELLS

8 Isolation, Cryosection and Immunostaining of Skeletal Muscle 85
Huascar P. Ortuste Quiroga, Katsumasa Goto, and Peter S. Zammit

9 Isolation of Mouse Periocular Tissue for Histological and Immunostaining Analyses of the Extraocular Muscles and Their Satellite Cells 101
Pascal Stuelsatz and Zipora Yablonka-Reuveni

10 Skeletal Muscle Tissue Clearing for LacZ and Fluorescent Reporters, and Immunofluorescence Staining 129
Mayank Verma, Bhavani SR Murkonda, Yoko Asakura, and Atsushi Asakura

11 Isolation, Culture, Functional Assays, and Immunofluorescence of Myofiber-Associated Satellite Cells 141
Thomas O. Vogler, Katherine E. Gadek, Adam B. Cadwallader, Tiffany L. Elston, and Bradley B. Olwin

12 Flow Cytometry and Transplantation-Based Quantitative Assays for Satellite Cell Self-Renewal and Differentiation 163
Robert W. Arpke and Michael Kyba

13 Noninvasive Tracking of Quiescent and Activated Muscle Stem Cell (MuSC) Engraftment Dynamics In Vivo 181
Andrew T. V. Ho and Helen M. Blau

14 Myogenic Progenitors from Mouse Pluripotent Stem Cells for Muscle Regeneration 191
Alessandro Magli, Tania Incitti, and Rita C. R. Perlingeiro

15 Assaying Human Myogenic Progenitor Cell Activity by Reconstitution of Muscle Fibers and Satellite Cells in Immunodeficient Mice 209
Maura H. Parker

16 Methods for Mitochondria and Mitophagy Flux Analyses in Stem Cells of Resting and Regenerating Skeletal Muscle 223
Laura García-Prat, Marta Martínez-Vicente, and Pura Muñoz-Cánoves

17 Identification, Isolation, and Characterization of Mesenchymal Progenitors in Mouse and Human Skeletal Muscle 241
Akiyoshi Uezumi, Takehiro Kasai, and Kunihiro Tsuchida

18 FACS Fractionation and Differentiation of Skeletal-Muscle Resident Multipotent Tie2+ Progenitors 255
Arpita A. Biswas and David J. Goldhamer

PART III MUSCLE FUNCTIONAL ASSAYS

19 In Vitro Assays to Determine Skeletal Muscle Physiologic Function 271
Justin E. Sperringer and Robert W. Grange

20 In Vivo Assessment of Muscle Contractility in Animal Studies 293
Shama R. Iyer, Ana P. Valencia, Erick O. Hernández-Ochoa, and Richard M. Lovering

21 Functional Measurement of Respiratory Muscle Motor Behaviors Using Transdiaphragmatic Pressure 309
Sarah M. Greising, Carlos B. Mantilla, and Gary C. Sieck

22 Assessment of the Contractile Properties of Permeabilized Skeletal Muscle Fibers 321
Dennis R. Claflin, Stuart M. Roche, Jonathan P. Gumucio, Christopher L. Mendias, and Susan V. Brooks

23 Analysis of Aerobic Respiration in Intact Skeletal Muscle Tissue by Microplate-Based Respirometry 337
Jonathan Shintaku and Denis C. Guttridge

Index *345*

Contributors

Marie Lue Antony • *Lillehei Heart Institute, University of Minnesota, Minneapolis, MN, USA*

Robert W. Arpke • *Department of Pediatrics, Lillehei Heart Institute and Department of Pediatrics, University of Minnesota, Minneapolis, MN, USA*

Atsushi Asakura • *Stem Cell Institute, University of Minnesota Medical School, Minneapolis, MN, USA; Paul & Sheila Wellstone Muscular Dystrophy Center, University of Minnesota Medical School, Minneapolis, MN, USA; Department of Neurology, University of Minnesota Medical School, Minneapolis, MN, USA*

Yoko Asakura • *Stem Cell Institute, University of Minnesota Medical School, Minneapolis, MN, USA; Paul & Sheila Wellstone Muscular Dystrophy Center, University of Minnesota Medical School, Minneapolis, MN, USA; Department of Neurology, University of Minnesota Medical School, Minneapolis, MN, USA*

Arpita A. Biswas • *Department of Molecular & Cell Biology, University of Connecticut Stem Cell Institute, University of Connecticut, Storrs, CT, USA*

Helen M. Blau • *Department of Microbiology & Immunology, Baxter Laboratory for Stem Cell Biology, Stanford University School of Medicine, Stanford, CA, USA*

Susan V. Brooks • *Department of Biomedical Engineering, University of Michigan Medical School, Ann Arbor, MI, USA; Department of Molecular & Integrative Physiology, University of Michigan Medical School, Ann Arbor, MI, USA*

Adam B. Cadwallader • *Department of Molecular, Cellular and Developmental Biology, University of Colorado at Boulder, Boulder, CO, USA*

Jarrod A. Call • *Department of Kinesiology, University of Georgia, Athens, GA, USA; Regenerative Bioscience Center, University of Georgia, Athens, GA, USA*

Dennis R. Claflin • *Department of Surgery, Section of Plastic Surgery, University of Michigan Medical School, Ann Arbor, MI, USA; Department of Biomedical Engineering, University of Michigan Medical School, Ann Arbor, MI, USA*

Benjamin T. Corona • *Extremity Trauma and Regenerative Medicine, United States Army Institute of Surgical Research, Fort Sam Houston, TX, USA*

Tiffany L. Elston • *Department of Molecular, Cellular and Developmental Biology, University of Colorado at Boulder, Boulder, CO, USA*

Christopher S. Fry • *Department of Nutrition and Metabolism, School of Health Professions, University of Texas Medical Branch, Galveston, TX, USA*

Katherine E. Gadek • *Department of Molecular, Cellular and Developmental Biology, University of Colorado at Boulder, Boulder, CO, USA*

Laura García-Prat • *Cell Biology Group, Department of Experimental and Health Sciences, Pompeu Fabra University (UPF), CIBER on Neurodegenerative Diseases (CIBERNED), Barcelona, Spain*

Daniel J. Garry • *Lillehei Heart Institute, University of Minnesota, Minneapolis, MN, USA*

Glynnis A. Garry • *UT Southwestern Medical Center, Dallas, TX, USA*

David J. Goldhamer • *Department of Molecular & Cell Biology, University of Connecticut Stem Cell Institute, University of Connecticut, Storrs, CT, USA*
Katsumasa Goto • *Department of Physiology, Graduate School of Health Sciences, Toyohashi SOZO University, Aichi, Japan*
Robert W. Grange • *Department of Human Nutrition, Foods and Exercise, Corporate Research Center, Virginia Tech University, Blacksburg, VA, USA*
Sarah M. Greising • *Department of Physiology and Biomedical Engineering, Mayo Clinic, Rochester, MN, USA*
Jonathan P. Gumucio • *Department of Orthopaedic Surgery, University of Michigan Medical School, Ann Arbor, MI, USA; Department of Molecular & Integrative Physiology, University of Michigan Medical School, Ann Arbor, MI, USA*
Denis C. Guttridge • *Department of Molecular Virology, Immunology, and Medical Genetics, The Ohio State University, Columbus, OH, USA; Center for Muscle Health and Neuromuscular Disorders, The Ohio State University, Columbus, OH, USA*
Erick O. Hernández-Ochoa • *Department of Biochemistry & Molecular Biology, University of Maryland School of Medicine, Baltimore, MD, USA*
Andrew T.V. Ho • *Department of Microbiology & Immunology, Baxter Laboratory for Stem Cell Biology, Stanford University School of Medicine, Stanford, CA, USA*
Tania Incitti • *Department of Medicine, Lillehei Heart Institute, University of Minnesota, Minneapolis, MN, USA*
Shama R. Iyer • *Department of Orthopaedics, University of Maryland School of Medicine, Baltimore, MD, USA*
Takehiro Kasai • *Department of Orthopedic Surgery, Nagoya University Graduate School of Medicine, Aichi, Japan*
Tyler J. Kirby • *Center for Muscle Biology, University of Kentucky, Lexington, KY, USA; Department of Physiology, College of Medicine, University of Kentucky, Lexington, KY, USA*
Michael Kyba • *Lillehei Heart Institute and Department of Pediatrics, University of Minnesota, Minneapolis, MN, USA*
Gengyun Le • *Department of Physical Medicine and Rehabilitation, University of Minnesota, Minneapolis, MN, USA*
Richard M. Lovering • *Department of Orthopaedics, University of Maryland School of Medicine, Baltimore, MD, USA*
Dawn A. Lowe • *Programs in Physical Therapy and Rehabilitation Science, Department of Physical Medicine and Rehabilitation Medical School, University of Minnesota, Minneapolis, MN, USA*
Alessandro Magli • *Department of Medicine, Lillehei Heart Institute, University of Minnesota, Minneapolis, MN, USA*
Carlos B. Mantilla • *Department of Physiology and Biomedical Engineering, Mayo Clinic, Rochester, MN, USA; Department of Anesthesiology, Mayo Clinic, Rochester, MN, USA*
Marta Martínez-Vicente • *Neurodegenerative Diseases Research Group, Vall d'Hebron Research Institute-CIBERNED, Barcelona, Spain*
John J. McCarthy • *Center for Muscle Biology, University of Kentucky, Lexington, KY, USA; Department of Physiology, College of Medicine, University of Kentucky, Lexington, KY, USA*

Christopher L. Mendias • *Department of Orthopaedic Surgery, University of Michigan Medical School, Ann Arbor, MI, USA; Department of Molecular & Integrative Physiology, University of Michigan Medical School, Ann Arbor, MI, USA*

Pura Muñoz-Cánoves • *Cell Biology Group, Department of Experimental and Health Sciences, Pompeu Fabra University (UPF), CIBER on Neurodegenerative Diseases (CIBERNED), Barcelona, Spain; Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, Spain*

Bradley B. Olwin • *Department of Molecular, Cellular and Developmental Biology, University of Colorado at Boulder, Boulder, CO, USA*

Huascar P. Ortuste Quiroga • *Randall Division of Cell and Molecular Biophysics, King's College London, London, UK*

Maura H. Parker • *Clinical Research Division, Fred Hutchinson Cancer Research Center, Seattle, WA, USA; Department of Medicine, University of Washington, Seattle, WA, USA*

Rita C.R. Perlingeiro • *Department of Medicine, Lillehei Heart Institute, University of Minnesota, Minneapolis, MN, USA*

Patrizia Pessina • *Cell Biology Group, Department of Experimental and Health Sciences, Pompeu Fabra University (UPF), CIBER on Neurodegenerative Diseases (CIBERNED), Barcelona, Spain*

Charlotte A. Peterson • *Center for Muscle Biology, University of Kentucky, Lexington, KY, USA; Department of Rehabilitation Sciences, College of Health Sciences, University of Kentucky, Lexington, KY, USA*

Beth E. Pollot • *Extremity Trauma and Regenerative Medicine, United States Army Institute of Surgical Research, Fort Sam Houston, TX, USA*

Stuart M. Roche • *Department of Orthopaedic Surgery, University of Michigan Medical School, Ann Arbor, MI, USA*

Bhavani SR Murkonda • *Stem Cell Institute, University of Minnesota Medical School, Minneapolis, MN, USA; Paul & Sheila Wellstone Muscular Dystrophy Center, University of Minnesota Medical School, Minneapolis, MN, USA; Department of Neurology, University of Minnesota Medical School, Minneapolis, MN, USA*

Alessandra Sacco • *Development, Aging and Regeneration Program, Sanford Children's Health Research Center, Sanford Burnham Prebys Medical Discovery Institute, La Jolla, CA, USA*

Jonathan Shintaku • *Department of Molecular Virology, Immunology, and Medical Genetics, The Ohio State University, Columbus, OH, USA; Center for Muscle Health and Neuromuscular Disorders, The Ohio State University, Columbus, OH, USA; Molecular, Cellular and Developmental Biology Graduate Program, The Ohio State University, Columbus, OH, USA*

Gary C. Sieck • *Department of Physiology and Biomedical Engineering, Mayo Clinic, Rochester, MN, USA; Department of Anesthesiology, Mayo Clinic, Rochester, MN, USA*

Justin E. Sperringer • *Department of Human Nutrition, Foods and Exercise, Corporate Research Center, Virginia Tech University, Blacksburg, VA, USA*

Pascal Stuelsatz • *Department of Biological Structure, School of Medicine, University of Washington, Seattle, WA, USA*

Matthew T. Tierney • *Graduate School of Biomedical Sciences, Sanford Burnham Prebys Medical Discovery Institute, La Jolla, CA, USA; Development, Aging and Regeneration Program, Sanford Children's Health Research Center, Sanford Burnham Prebys Medical Discovery Institute, La Jolla, CA, USA*

Kunihiro Tsuchida • *Division for Therapies Against Intractable Diseases, Institute for Comprehensive Medical Science, Fujita Health University, Aichi, Japan*
Akiyoshi Uezumi • *Division for Therapies Against Intractable Diseases, Institute for Comprehensive Medical Science, Fujita Health University, Aichi, Japan*
Ana P. Valencia • *Department of Orthopaedics, University of Maryland School of Medicine, Baltimore, MD, USA*
Mayank Verma • *Medical Scientist Training Program, University of Minnesota Medical School, Minneapolis, MN, USA; Stem Cell Institute, University of Minnesota Medical School, Minneapolis, MN, USA; Paul & Sheila Wellstone Muscular Dystrophy Center, University of Minnesota Medical School, Minneapolis, MN, USA; Department of Neurology, University of Minnesota Medical School, Minneapolis, MN, USA*
Thomas O. Vogler • *Department of Molecular, Cellular and Developmental Biology, University of Colorado at Boulder, Boulder, CO, USA*
Zipora Yablonka-Reuveni • *Department of Biological Structure, School of Medicine, University of Washington, Seattle, WA, USA*
Peter S. Zammit • *Randall Division of Cell and Molecular Biophysics, King's College London, London, UK*