Musculoskeletal Disorders

Musculoskeletal Disorders

The Fatigue Failure Mechanism

Sean Gallagher
Auburn University, Auburn, AL, USA

Mary F. Barbe
Temple University, Philadelphia, PA, USA

WILEY

This edition first published 2022

Registered Office
John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA

Editorial Office
John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

Wiley also publishes its books in a variety of electronic formats and by print-on-demand. Some content that appears in standard print versions of this book may not be available in other formats.

Library of Congress Cataloging-in-Publication Data applied for:

ISBN: 9781119640042

Cover image: © MDGRPHCS/Shutterstock
Cover design by Wiley

Set in 9.5/12.5pt STIXTwoText by Straive, Pondicherry, India

To Dad and Mom, who set a high bar; to Nancie for her constant love and support; and to Drew and Brendon for being wonderful and thoughtful sons.

Sean Gallagher

To my parents, who taught me how to dream; to Hugh, the love of my life, for his continued aid and support; and to Susan, my twin and other half of my soul, for always being my best friend, companion, and muse.

Mary F. Barbe

Contents

Preface

During the course of my [SG's] doctoral work with Dr. William S. Marras, I became familiar with the work of researchers such as Adams, Cyron, Hutton, and Brinckmann who had performed *ex vivo* studies examining the effects of repeated stress on fatigue failure of spinal motion segments (Adams & Hutton, 1985; Brinckmann, Biggemann, & Hilweg, 1988; Cyron & Hutton, 1978). When the time came to select a dissertation topic, the option of performing an *ex vivo* fatigue failure study on spines at different levels of forward flexion was offered and I accepted the opportunity. The results of our research showed once again that spines subjected to repeated stress exhibited a classic fatigue failure response, and that the relationship is also affected by the degree of flexion of the motion segments adopted (Gallagher et al., 2007).

This research added to the existing body of evidence that cadaveric spinal motion segments fail in accordance with the mechanism of fatigue failure. However, though *ex vivo* fatigue failure data (on various musculoskeletal tissues) had been accumulating for some time, the implications of this mechanism regarding tissue damage were generally neither reflected in the development of musculoskeletal risk assessment tools nor in epidemiological studies examining musculoskeletal disorder risk factors. It is not entirely clear why this is the case, but it is the author's belief that researchers were reluctant to assume that this process would work in a similar manner in the setting of a complex biological system. This is understandable as no real evidence existed at that time that such a process was actually taking place *in vivo*.

One day in 2011, I had just finished giving a fatigue-based presentation to some of my NIOSH colleagues in Pittsburgh and was walking out of the conference room door when I suddenly realized that the *S–N* curve (which governs the fatigue failure response of materials) would predict a specific pattern of interaction between the risk factors of force and repetition and that the interaction predicted would look exactly like the interaction observed in the classic studies by Silverstein et al. for carpal tunnel syndrome and by Armstrong et al. for hand-wrist tendinitis (Armstrong, Fine, Goldstein, Lifshitz, & Silverstein, 1987; Silverstein, Fine, & Armstrong, 1987).

This result strongly suggested that a fatigue failure process might indeed be occurring *in vivo*. This finding piqued my curiosity and I then performed (with my NIOSH collaborator John Heberger) a systematic review of epidemiology studies in the ergonomics literature that had tested for a force-repetition interaction. The goal was to examine whether studies that had tested the interaction found a pattern indicative of a fatigue failure process (like the aforementioned studies). Results of this review showed only twelve studies in the literature that reported results of a statistical test for the interaction of force and repetition (or which provided data by which such an interaction could be examined). Of these, ten provided data indicative of the predicted pattern, one that

tested for such an interaction consisted only high force tasks (where the test for interaction was meaningless), and in the other, the relationship was not present (Gallagher & Heberger, 2013). Overall, the results of this systematic review provided compelling evidence that many musculoskeletal disorder (MSD) outcomes exhibited a pattern of force and repetition that would suggest that a fatigue failure process might be an important etiological factor. This appeared to be the case across a wide range of disorders and joints.

Concurrent with the development of this paper, I met Mary Barbe, whose novel rat model provided additional support that fatigue failure of musculoskeletal tissues occurs *in vivo*. Her research demonstrated that damage to tendons, bone, and cartilage all followed the fatigue failure predicted force-repetition pattern (Barbe et al., 2013). The same was true for many cytokines, whose expression appears to be tied to the amount of damage occurring in musculoskeletal tissues (Barr, Barbe, & Clark, 2004). Since that time, we have continued to collaborate on numerous papers and projects.

In 2018, I asked Mary if she would be willing to collaborate on a book dealing with the fatigue failure model of MSD development. The idea was to provide evidence that fatigue failure was occurring in musculoskeletal tissues and to examine the diverse implications of fatigue failure occurring in a complex biological setting. As will be seen in this book, this process (a *modified* fatigue failure process) is likely influenced by numerous physiological and psychological factors, all of which would be expected to play important roles in maintaining musculoskeletal health.

This book is the result of our examination of the impact of the fatigue failure process and its interactions with biological and physiological mechanisms affecting musculoskeletal health. The book provides considerable information on the musculoskeletal and nervous systems; the epidemiology of MSDs; evidence that musculoskeletal tissues fail via a fatigue failure process; implications in terms of MSD etiology; remodeling and healing processes; use of fatigue failure methods in risk assessment; and numerous other topics. We hope that our readers will find this book helpful in understanding the etiology of MSDs and, conversely, the importance of the fatigue failure process in the maintenance of musculoskeletal health.

Bibliography

Adams, M., & Hutton, W. (1985). Gradual disc prolapse. *Spine*, *10*, 524–531.

Armstrong, T., Fine, L., Goldstein, S., Lifshitz, Y., & Silverstein, B. (1987). Ergonomics considerations in hand and wrist tendinitis. *The Journal of Hand Surgery*, *12A*, 830–837.

Barbe, M., Gallagher, S., Massicotte, V., Tytell, M., Popoff, S., & Barr-Gillespie, A. (2013). The interaction of force and repetition on musculoskeletal and neural tissue responses and sensorimotor behavior in a rat model of work-related musculoskeletal disorders. *BMC Musculoskskeletal Disorders*, *14*, 303.

Barr, A., Barbe, M., & Clark, B. (2004). Work-related musculoskeletal disorders of the hand and wrist: epidemiology, pathophysiology, and sensorimotor changes. *Journal of Orthopaedic & Sports Physical Therapy.*, *34*, 610–627.

Brinckmann, P., Biggemann, M., & Hilweg, D. (1988). Fatigue fracture of human lumbar vertebrae. *Clinical Biomechanics*, *3*(Suppl. 1), S1–S23.

Cyron, B., & Hutton, W. (1978). The fatigue strength of the lumbar neural arch in spondylolysis. *Journal of Bone and Joint Surgery*, *60B*, 234–238.

Gallagher, S., & Heberger, J. (2013). Examining the interaction of force and repetition on musculoskeletal disorder risk: A systematic literature review. *Human Factors*, *14*, 108–124.

Gallagher, S., Marras, W., Litsky, A., Burr, D., Landoll, J., & Matkovic, V. (2007). A comparison of fatigue failure responses of old versus middle-aged lumbar motion segments in simulated flexed lifting. *Spine*, *32*, 1832–1839.

Silverstein, B., Fine, L., & Armstrong, T. (1987). Occupational factors and carpal tunnel syndrome. *American Journal of Industrial Medicine*, *11*, 343–358.

Acknowledgments

The authors wish to acknowledge the following individuals who have aided in the process of writing this book:

First, we would like to acknowledge our spouses, Nancie and Hugh, respectively, for their support and tolerance during the development of this book. The demands of writing have unfortunately required them to put up with longish periods of our absence.

Acknowledgment is also due to the Center for Occupational Safety, Ergonomics, and Injury Prevention (COSEIP) team at Auburn University (both faculty and students), who have been integral in the development of the fatigue failure-based risk assessment tools presented in this book. We would like to thank faculty members Dr. Richard F. Sesek, Dr. Mark C. Schall, Jr., and Dr. Jerry Davis, along with former students (notably Dr. Rong Huangfu and Dr. Dania Bani Hani) for their critical contributions to risk assessment tool development. Other former and current students have contributed to this research including Dr. Tenchi Smith, Dr. Nick Smith, Ivan Nail, Nathan Pool, Bob Sesek, and Yuting Ma.

We would also like to acknowledge the National Institute for Occupational Safety and Health (NIOSH) for the long-standing funding provided in support of the Deep South Center for Occupational Health and Safety, along with other extramural funding. We also thank the National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS) and the National Center for Complementary and Integrative Health (NCCIH), which have helped advance our research in this area.

Great thanks is also due to our colleagues who have taken the time to review draft chapters of this book. In particular, we would like to thank Dr. Michael Zabala and Dr. Sa'd Hamasha (both of Auburn University) for their valuable time and assistance rendered in reviewing draft chapters in this book.

Finally, we would like to acknowledge the Wiley book team (especially Summers Scholl, Judy Howarth, Veerabaghu Nagarajan, Judit Anbu Hena Daniel, Rajalakshmi Venkatesaperumal, and Stefani Volk) for their support and patience during the development of this book. Their commitment is deeply appreciated as is their care and attention in the book's production.

Sean Gallagher
Mary F. Barbe

About the Authors

Sean Gallagher, PhD, CPE, FAIHA, is the Hal N. and Peggy S. Pennington Professor of Industrial and Systems Engineering at Auburn University. Dr. Gallagher has over 35 years of experience in the field of ergonomics, including having worked for the US Bureau of Mines, the National Institute for Occupational Safety and Health (NIOSH), and Auburn University. He is a Fellow of both the Human Factors and Ergonomics Society and the American Industrial Hygiene Association. Dr. Gallagher is a two-time recipient of the International Ergonomics Association/Liberty Mutual Medal in Occupational Safety and Ergonomics (2013 and 2018) and a recipient of the 2020 Paper of the Year Award by the journal *Ergonomics*. He has received various other team-based awards, including the 2009 Alice Hamilton Award for Excellence in Occupational Safety and Health (Educational Materials Category) and the 2011 HHS Innovates Award (Secretary's Pick).

Mary F. Barbe, PhD, FAAA, is currently a Full Professor at the Center for Translational Medicine at Lewis Katz School of Medicine of Temple University in Philadelphia. She has over 212 peer-reviewed publications to her credit. She has been involved in research investigating mechanisms and treatments for pain and work-related musculoskeletal disorders (repetitive strain injuries) in humans and using rat models. She is a Fellow of the American Association of Anatomists (FAAA) and of the American Society of Bone and Mineral Research. She is also the president of the Advances in Mineral Metabolism society for 2021–2023. She is the recipient of the Senior Faculty Research Excellence Award from the Lewis Katz School of Medicine in 2017, the Temple University Faculty Research Award from Temple University in 2019, the Educator Award from the Philadelphia Chapter of the Society for Neuroscience in 2008, the Christian R. and Mary F. Lindback Foundation Award from Temple University for Distinguished Teaching in 2008, and the Excellence in Teaching Award from College of Allied Health Professions in 1997 and 2007. Other awards that she has received include various team-based awards, including The ISSLS Prize for Lumbar Spine Research 2018 from the International Society for the Study of the Lumbar Spine.