

SEVENTH EDITION

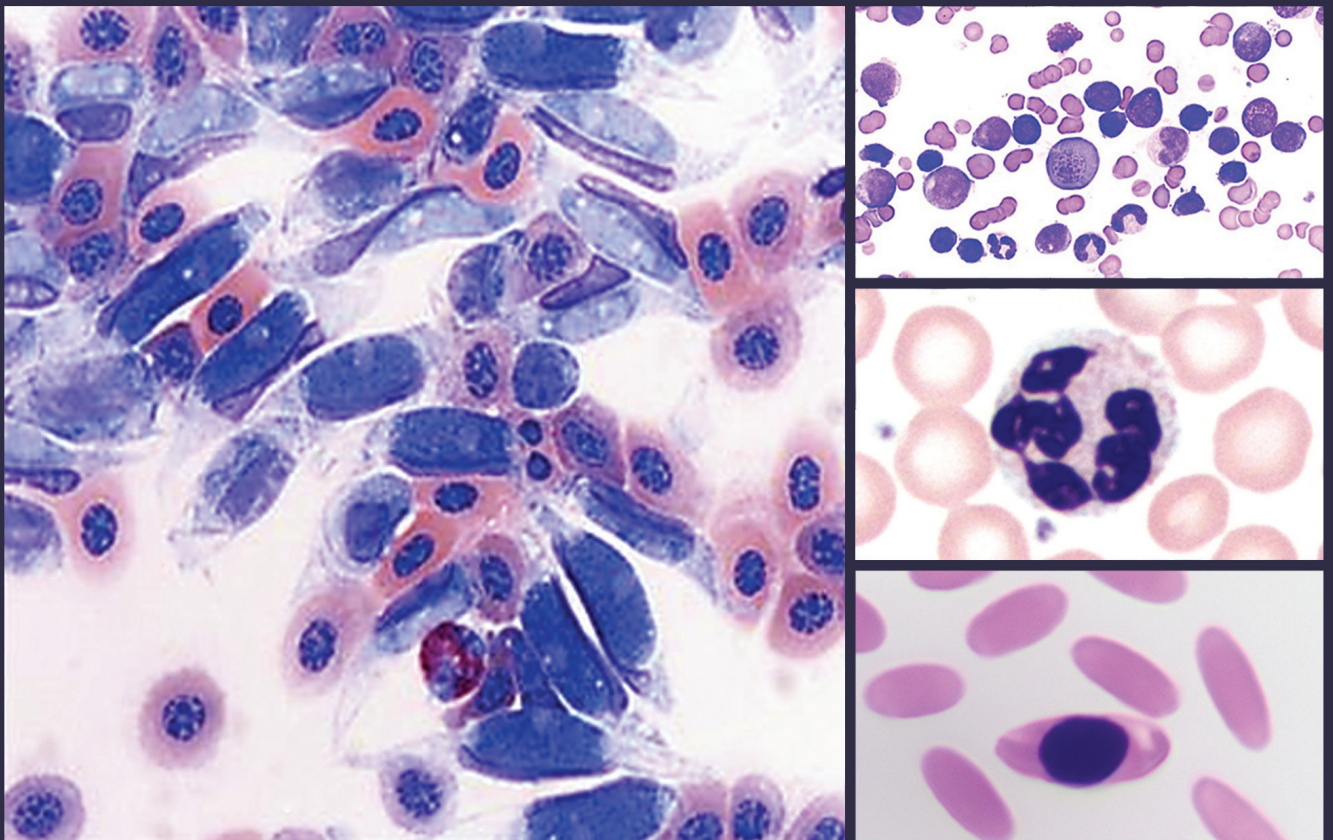
SCHALM'S

VETERINARY HEMATOLOGY

EDITED BY

MARJORY B. BROOKS | KENDAL E. HARR | DAVIS M. SEELIG

K. JANE WARDROP | DOUGLAS J. WEISS



WILEY Blackwell

SCHALM'S

VETERINARY
HEMATOLOGY

SCHALM'S

VETERINARY HEMATOLOGY

SEVENTH EDITION

EDITED BY

MARJORY B. BROOKS, DVM, DACVIM

Director, Comparative Coagulation Section,
Animal Health Diagnostic Center,
Cornell University,
Ithaca, New York, USA

KENDAL E. HARR, DVM, MS, DACVP

URIKA, LLC, Mukilteo, Washington, USA

DAVIS M. SEELIG, DVM, PhD, DACVP

Associate Professor, Clinical Pathology
Department of Veterinary Clinical Sciences
University of Minnesota, College of Veterinary Medicine
St. Paul, Minnesota, USA

K. JANE WARDROP, DVM, MS, DACVP

Professor and Director, Clinical Pathology Laboratory,
Department of Veterinary Clinical Sciences,
College of Veterinary Medicine,
Washington State University,
Pullman, Washington, USA

DOUGLAS J. WEISS, DVM, PhD, DACVP

Emeritus Professor,
College of Veterinary Medicine,
University of Minnesota,
St. Paul, Minnesota, USA

WILEY Blackwell

This edition first published 2022
© 2022 John Wiley & Sons, Inc

Edition History

Fifth Edition © 2000 Lippincott Williams & Wilkins; First printing Fifth edition © 2006 Blackwell Publishing, Second printing.
Sixth Edition first published 2010 © 2010 Blackwell Publishing Ltd.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, except as permitted by law. Advice on how to obtain permission to reuse material from this title is available at <http://www.wiley.com/go/permissions>.

The right of Marjory B. Brooks, Kendal E. Harr, Davis Seelig, K. Jane Wardrop, and Douglas J. Weiss to be identified as the authors of the editorial material in this work has been asserted in accordance with law.

Registered Office(s)

John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA
John Wiley & Sons Ltd., The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, UK

Editorial Office

111 River Street, Hoboken, NJ 07030, USA
101 Station Landing, Medford, MA 02155, 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.

Limit of Liability/Disclaimer of Warranty

The contents of this work are intended to further general scientific research, understanding, and discussion only and are not intended and should not be relied upon as recommending or promoting scientific method, diagnosis, or treatment by physicians for any particular patient. In view of ongoing research, equipment modifications, changes in governmental regulations, and the constant flow of information relating to the use of medicines, equipment, and devices, the reader is urged to review and evaluate the information provided in the package insert or instructions for each medicine, equipment, or device for, among other things, any changes in the instructions or indication of usage and for added warnings and precautions. While the publisher and authors have used their best efforts in preparing this work, they make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives, written sales materials, or promotional statements for this work. The fact that an organization, website, or product is referred to in this work as a citation and/or potential source of further information does not mean that the publisher and authors endorse the information or services the organization, website, or product may provide or recommendations it may make. This work is sold with the understanding that the publisher is not engaged in rendering professional services. The advice and strategies contained herein may not be suitable for your situation. You should consult with a specialist where appropriate. Further, readers should be aware that websites listed in this work may have changed or disappeared between when this work was written and when it is read. Neither the publisher nor authors shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

Library of Congress Cataloging-in-Publication Data Applied for

HB: 9781119500506

Cover Design: Wiley

Cover Image: Courtesy of Stacy Clothier, Kendal Harr, Sue Tornquist, and Doug Weiss

Set in 10/11pt PalatinoLTStd by Straive, Pondicherry, India

10 9 8 7 6 5 4 3 2 1



A Tribute to Oscar Schalm

Oscar W. Schalm was born in 1909 and reared in Sturgis, Michigan. Upon graduation from Michigan State University, he entered the College of Veterinary Medicine at the urging of fellow students. He married Dorothy Burns, also of Sturgis, in 1930 and after attaining his DVM degree in 1932, he joined the Department of Veterinary Science at Berkeley, California as a research associate. He remained on the Berkeley campus until 1948, earning an M.S. in 1933 and Ph.D. in 1935. In 1948, he relocated to Davis, California, as the Department of Veterinary Medicine became the new School of Veterinary Medicine at the Davis campus.

Early in his career, Oscar established himself as a leader in bovine mastitis research, a subject he continued at Davis. At the founding of the School of Veterinary Medicine, Oscar was assigned the responsibility for clinical pathology, a most fortuitous choice for the field and

generations of veterinary students. Oscar focused on the fledgling field of veterinary hematology. With his characteristic energy and productivity, within ten years he had written the first edition of the now classic *Veterinary Hematology*. The original and subsequent early editions represented compilations of materials that he had painstakingly collected and analyzed.

He became an authority in veterinary clinical hematology, and spread the gospel by a prodigious record of publications, national and international seminars, and through his classes at Davis to over 1500 veterinary students. He exemplified the teacher-researcher who can successfully share their expertise and motivate students. As evidence of his dedication to teaching and his students, he was selected three times to receive the School of Veterinary Medicine's Outstanding Teacher Award. He was listed in Educators of America in 1971 and 1973, and in 1973, he received the Davis Division of the Academic Senate's Outstanding Teaching Award.

Oscar's honors, awards, and prizes were many; some among them are the Borden Award in Veterinary Medicine (1964), the Gaines Award for Veterinarian of the Year (1965 and 1972), Alumni Award of Michigan State University (1969), and the Alumni Achievement Award of the School of Veterinary Medicine, University of California, Davis (1980). He was a Fulbright Scholar at the University of Munich in 1959, a visiting scholar and consultant to Israel in 1967, and was named Honorary Life Member of the Israeli Veterinary Medical Association in 1968.

Oscar Schalm retired in 1976, after 44 years of service to the university. He remained an active scholar, speaker, consultant, and contributor to prestigious journals throughout his retirement. At the time of his death, on September 15, 1982, a fourth edition of Schalm's *Veterinary Hematology* was in preparation. In recognition of Dr. Schalm's fundamental contributions to the field, all subsequent editions of this authoritative textbook have included his name in the title.

CONTENTS

Dedication	v
Contributors	xv
Preface	xxv
Acknowledgments	xxvii
SECTION I	
Hemolymphatic Tissue	1
CHAPTER 1	
Embryonic and Fetal Hematopoiesis 3	
KELLI L. BOYD and BRAD BOLON	
CHAPTER 2	
Stem Cell Biology 9	
DORI L. BORJESSON and JED A. OVERMANN	
CHAPTER 3	
Structure of the Bone Marrow 18	
NICOLE I. STACY and JOHN W. HARVEY	
CHAPTER 4	
The Hematopoietic System 27	
BRUCE D. CAR and DAVIS M. SEELIG	
CHAPTER 5	
Vasculogenesis and Endothelial Cell Production 37	
JONG HYUK KIM	
CHAPTER 6	
Cluster of Differentiation (CD) Antigens 41	
MELINDA J. WILKERSON and NORA L. SPRINGER	
CHAPTER 7	
Major Histocompatibility Complex Antigens 48	
PAUL R. HESS	
CHAPTER 8	
Lymphocyte Biology and Functions 63	
IAN TIZARD	
CHAPTER 9	
Structure and Function of Primary and Secondary Lymphoid Tissue 74	
CLEVERSON D. SOUZA, MEREDETH McENTIRE, V.E. TED VALLI, and ROBERT M. JACOBS	
SECTION II	
Hematotoxicity	85
CHAPTER 10	
Design and Methods of Nonclinical Hematotoxicity Studies 87	
WILLIAM J. REAGAN and ARMANDO R. IRIZARRY ROVIRA	
CHAPTER 11	
Interpretation of Hematologic Data in Nonclinical Studies 93	
JEFFREY McCARTNEY	
CHAPTER 12	
Nonclinical Evaluation of Compound-Related Cytopenias 100	
LAURIE G. O'ROURKE	
CHAPTER 13	
Nonclinical Evaluation of Compound-Related Alterations in Hemostasis 108	
F. POITOUT-BELISSENT	
CHAPTER 14	
Preclinical Evaluation of Immunotoxicity 116	
KRISTIN L. HENSON	
CHAPTER 15	
Blood and Bone Marrow Toxicity Induced by Drugs, Heavy Metals, Chemicals, and Toxic Plants 122	
DOUGLAS J. WEISS	

- CHAPTER 16**
Acute Myelotoxicity and Myelitis in Domestic and Laboratory Animals 133
ADAM D. AULBACH and DOUGLAS J. WEISS
- CHAPTER 17**
Chronic Inflammation and Secondary Myelofibrosis in Domestic and Laboratory Animals 138
ADAM D. AULBACH and DOUGLAS J. WEISS
- CHAPTER 18**
Infectious Injury to Bone Marrow 144
K. JANE WARDROP
- SECTION III**
Erythrocytes149
- CHAPTER 19**
Erythropoiesis 151
CHRISTINE SWARDSON OLVER
- CHAPTER 20**
Erythrocyte Structure and Function 158
CHRISTINE SWARDSON OLVER
- CHAPTER 21**
Erythrocyte Biochemistry 166
JOHN W. HARVEY
- CHAPTER 22**
Erythrokinetics and Erythrocyte Destruction 172
ANDREA PIRES DOS SANTOS, and JOHN A. CHRISTIAN
- CHAPTER 23**
Reticulocyte and Heinz Body Staining and Enumeration 181
HAROLD TVEDTEN and ANDREAS MORITZ
- CHAPTER 24**
Erythrocyte Morphology 188
ANNE M. BARGER
- CHAPTER 25**
Classification and Laboratory Evaluation of Anemia 198
HAROLD TVEDTEN
- CHAPTER 26**
Erythrocytosis 209
JOHN F. RANDOLPH, MARK E. PETERSON, and ERICA BEHLING-KELLY
- CHAPTER 27**
Iron and Copper Deficiencies, and Disorders of Iron Metabolism 215
LAUREN B. RADA KOVICH and CHRISTINE SWARDSON OLVER
- CHAPTER 28**
The Porphyrins—Disorders of Defective Heme Synthesis 221
ANDREA A. BOHN
- CHAPTER 29**
Hereditary Erythroenzymopathies 229
URS GIGER
- CHAPTER 30**
Erythrocyte Membrane Defects 238
MUTSUMI INABA and JOANNE B. MESSICK
- CHAPTER 31**
Congenital Dyserythropoiesis 248
DOUGLAS J. WEISS
- CHAPTER 32**
Anemia Associated with Oxidative Injury 252
ERICA BEHLING-KELLY and ASHLEIGH NEWMAN
- CHAPTER 33**
Anemia Caused by Rickettsia, Mycoplasma, and Protozoa 260
SUSAN FIELDER, ROBIN W. ALLISON, and JAMES H. MEINKOTH
- CHAPTER 34**
Anemia Associated with Bacterial and Viral Infections 273
GEORGE M. BARRINGTON and DEBRA C. SELLON
- CHAPTER 35**
Immune-Mediated Anemia in the Dog 278
JILLIAN M. HAINES, ANDREW MACKIN, and MICHAEL J. DAY
- CHAPTER 36**
Immune-Mediated Anemia in the Cat 292
ASHLEIGH NEWMAN and TRACY STOKOL
- CHAPTER 37**
Immune-Mediated Anemia in Ruminants and Horses 300
JENIFER R. GOLD
- CHAPTER 38**
Precursor-Targeted Immune-Mediated Anemia and Pure Red Cell Aplasia in Dogs and Cats 307
CYNTHIA A. LUCIDI
- CHAPTER 39**
Anemia of Inflammatory, Neoplastic, Renal, and Endocrine Diseases 313
AGATA K. GRZELAK and MICHAEL M. FRY
- CHAPTER 40**
Aplastic Anemia 318
JENNIFER L. BRAZZELL and DOUGLAS J. WEISS

SECTION IV**Leukocytes323****CHAPTER 41****Granulopoiesis 325**

M. JUDITH RADIN and MAXEY L. WELLMAN

CHAPTER 42**Neutrophil Structure and Biochemistry 333**

CLAIRE B. ANDREASEN

CHAPTER 43**Neutrophil Function and Response 339**

DANA N. LEVINE and CLAIRE B. ANDREASEN

CHAPTER 44**Neutrophil Function Disorders 347**

STEFANO COMAZZI, LUCA ARESU, and DOUGLAS J. WEISS

CHAPTER 45**Clinical Evaluation of Neutrophil Function 354**

STEFANO COMAZZI

CHAPTER 46**Eosinophils and Their Disorders 363**

KAREN M. YOUNG and ELIZABETH A. LAYNE

CHAPTER 47**Basophils, Mast Cells, and Their Disorders 373**

BRANDY C. KASTL and LISA M. POHLMAN

CHAPTER 48**Monocytes, Macrophages, and Dendritic Cell Production 381**

CLEVERSON D. SOUZA and DOUGLAS J. WEISS

CHAPTER 49**Monocytes and Macrophages and Their Disorders 386**

CLEVERSON D. SOUZA and MEAGHAN V. EREN

CHAPTER 50**Lymphocyte Ontogeny and Lymphopoiesis 395**

AMY L. WARREN and ROBIN M. YATES

CHAPTER 51**Structure, Function, and Disorders of Lymphoid Tissue 402**

AMY L. WARREN and ROBIN M. YATES

CHAPTER 52**Systemic Lupus Erythematosus 414**

LUC CHABANNE

CHAPTER 53**Feline Immunodeficiency Virus 424**

MARGARET J. HOSIE and HANS LUTZ

CHAPTER 54**T Cell, Immunoglobulin, and Complement Immunodeficiency Disorders 431**

PETER J. FELSBURG

CHAPTER 55**Severe Combined Immunodeficiencies 436**

STEVEN E. SUTER

CHAPTER 56**Lymphadenopathy Not Caused by Lymphoma 442**

HAROLD TVEDTEN

SECTION V**Hematologic Neoplasia449****CHAPTER 57****Cell-Cycle Control in Hematopoietic Cells 451**

JAIME F. MODIANO and CATHERINE A. ST. HILL

CHAPTER 58**Epidemiology of Hematopoietic Neoplasia 457**

MICHELLE G. RITT

CHAPTER 59**Genetics of Hematopoietic Neoplasia 463**

DIANA GIANNUZZI, JAIME F. MODIANO, and MATTHEW BREEN

CHAPTER 60**Transforming Retroviruses 471**

MARY JO BURKHARD

CHAPTER 61**Cytochemical Staining and Immunocytochemistry 478**

ROSE E. RASKIN, KELLY SANTANGELO, and KLAUDIA POLAK

CHAPTER 62**Determination of Clonality 500**

YUKO GOTO-KOSHINO and HAJIME TSUJIMOTO

CHAPTER 63**Immunophenotyping 508**

AUSTIN K. VIALL

CHAPTER 64**Flow Cytometry in Hematologic Neoplasia 515**

JAIME L. TARIGO, DAVIS M. SEELIG, and ANNE C. AVERY

CHAPTER 65**Classification and General Features of Lymphoma and Leukemia 528**

BARBARA C. RÜTGEN and JENNIFER BOUSCHOR

CHAPTER 66**Myeloproliferative Neoplasms 538**

ERIC J. FISH

CHAPTER 67
Myelodysplastic Syndromes 548
DOUGLAS J. WEISS and RANCE K. SELTON

CHAPTER 68
Acute Myeloid Leukemia 557
TRACY STOKOL

CHAPTER 69
B-Cell Tumors 570
LUCA ARESU, STEFANO COMAZZI, LAURA MARCONATO, and FRANCESCO BERTONI

CHAPTER 70
Plasma Cell Tumors 588
ANTONELLA BORGATTI

CHAPTER 71
Hodgkin and Hodgkin-Like Lymphoma 599
DANIEL A. HEINRICH and ERIN N. BURTON

CHAPTER 72
T-Cell Tumors 605
NARIMAN DERAVID, STEFAN KELLER, and DOROTHEE BIENZLE

CHAPTER 73
Mast Cell Neoplasia 626
MELINDA S. CAMUS

CHAPTER 74
Histiocytic Proliferative Diseases of Dogs and Cats 633
PETER F. MOORE

SECTION VI
Platelets.....649

CHAPTER 75
Thrombopoiesis 651
MARY K. BOUDREAU and PETE W. CHRISTOPHERSON

CHAPTER 76
Platelet Structure 658
MARY K. BOUDREAU and PETE W. CHRISTOPHERSON

CHAPTER 77
Platelet Signal Transduction and Activation Response 667
PETE W. CHRISTOPHERSON and MARY K. BOUDREAU

CHAPTER 78
Platelet Kinetics and Laboratory Evaluation of Thrombocytopenia 675
ADI WASSERKRUG-NAOR

CHAPTER 79
Evaluation of Platelet Function 686
PETE W. CHRISTOPHERSON and MARJORY B. BROOKS

CHAPTER 80
Immune Thrombocytopenia 696
DANA N. LeVINE and MARJORY B. BROOKS

CHAPTER 81
Nonimmune-Mediated Thrombocytopenia 709
JULIE ALLEN

CHAPTER 82
Thrombocytosis and Essential Thrombocythemia 721
JULIE ALLEN and TRACY STOKOL

CHAPTER 83
von Willebrand Disease 731
MARJORY B. BROOKS and JAMES L. CATALFAMO

CHAPTER 84
Inherited Platelet Disorders 739
MARY K. BOUDREAU and PETE W. CHRISTOPHERSON

CHAPTER 85
Acquired Platelet Dysfunction 747
BENJAMIN M. BRAINARD

CHAPTER 86
Treatment of Disorders of Platelet Number and Function 755
MARY BETH CALLAN

SECTION VII
Hemostasis763

CHAPTER 87
Overview of Hemostasis 765
MAUREEN A. McMICHAEL

CHAPTER 88
Laboratory Testing of Coagulation Disorders 787
MARJORY B. BROOKS

CHAPTER 89
Acquired Coagulopathies 804
MARJORY B. BROOKS and ARMELLE DE LAFORCADE

CHAPTER 90
Hereditary Coagulopathies 812
MARJORY B. BROOKS

- CHAPTER 91**
Thrombotic Disorders 821
ERICA BEHLING-KELLY and ROBERT GOGGS
- CHAPTER 92**
Disseminated Intravascular Coagulation 837
TRACY STOKOL
- CHAPTER 93**
Vascular Diseases 848
SEAN P. McDONOUGH
- CHAPTER 94**
Treatment of Hemostatic Defects 855
ROBERT GOGGS and ALEX M. LYNCH
- CHAPTER 95**
Avian Hemostasis 865
KAREN E. RUSSELL and J. JILL HEATLEY
- SECTION VIII**
Transfusion Medicine875
- CHAPTER 96**
Erythrocyte Antigens and Blood Groups 877
MARIE-CLAUDE BLAIS and MARIA CECILIA T. PENEDO
- CHAPTER 97**
Granulocyte and Platelet Antigens 891
JENNIFER S. THOMAS
- CHAPTER 98**
Principles of Canine and Feline Blood Collection,
Processing, and Storage 898
ANTHONY C. G. ABRAMS-OGG and SHAUNA L. BLOIS
- CHAPTER 99**
Red Blood Cell Transfusion in the Dog and Cat 908
MARY BETH CALLAN
- CHAPTER 100**
Transfusion of Plasma Products 914
MARJORY B. BROOKS
- CHAPTER 101**
Platelet and Granulocyte Transfusion 921
ANTHONY C. G. ABRAMS-OGG, and SHAUNA L. BLOIS
- CHAPTER 102**
Blood Transfusion in Large Animals 927
MARGARET C. MUDGE
- CHAPTER 103**
Blood Transfusion in Exotic Species 933
ANNELIESE STRUNK and ANKE C. STÖHR
- CHAPTER 104**
Transfusion Reactions 940
NICOLE M. WEINSTEIN
- CHAPTER 105**
Cellular Therapy 948
STEVEN E. SUTER and STEVEN DOW
- CHAPTER 106**
Clinical Use of Hematopoietic Growth
Factors 957
STEVEN E. SUTER
- CHAPTER 107**
Clinical Blood Typing and Crossmatching 964
K. JANE WARDROP
- SECTION IX**
Species-Specific Hematology969
- CHAPTER 108**
Hematology of Dogs 971
MAGGIE R. McCOURT and THERESA E. RIZZI
- CHAPTER 109**
Hematology of Cats 983
DEANNA M. W. SCHAEFER
- CHAPTER 110**
Hematology of Equids 993
KATHLEEN P. FREEMAN, ALISON J. FARR, and ANNALISA BARRELET
- CHAPTER 111**
Hematology of Bovids 1004
R. DARREN WOOD
- CHAPTER 112**
Hematology of Sheep and Goats 1012
JASON STAYT
- CHAPTER 113**
Hematology of Pigs 1019
CATHERINE E. THORN, ANDREW S. BOWMAN, and DAVID ECKERSALL
- CHAPTER 114**
Hematology of Rodentia 1026
AMY L. MacNEILL
- CHAPTER 115**
Hematology of Mustelids 1034
STACY CLOTHIER and CATHY JOHNSON-DELANEY
- CHAPTER 116**
Hematology of Cavies 1043
SAMANTHA J. M. EVANS and KURT L. ZIMMERMAN

CHAPTER 117
Hematology of Lagomorphs 1050
FRANCISCO O. CONRADO

CHAPTER 118
Hematology of Laboratory Animals 1058
KARYN E. ENOS and DAVID M. MOORE

CHAPTER 119
Hematology of Camelids 1073
SUSAN J. TORNUQUIST

CHAPTER 120
Hematology of Cervids 1079
BRIDGET C. GARNER

CHAPTER 121
Hematology of Paenungulata: Elephants, Sirenians,
and Hyraxes 1090
EMMA H. HOOIJBERG

CHAPTER 122
Hematology of Marine Mammals 1104
NICOLE I. STACY and HENDRIK H. NOLLENS

CHAPTER 123
Hematology of Galliformes 1114
JULIE PICCIONE and JESSICA HOKAMP

CHAPTER 124
Hematology of Psittacines 1127
DIANA SCHWARTZ and HUGUES BEAUFRÈRE

CHAPTER 125
Hematology of Anseriformes 1140
JESSICA HOKAMP and JULIE PICCIONE

CHAPTER 126
Hematology of Raptors 1148
JENNIFER JOHNS

CHAPTER 127
Hematology of Ratites 1159
PHILLIP CLARK

CHAPTER 128
Hematology of Elasmobranchs 1166
JILL E. ARNOLD and ALEXA DELAUNE

CHAPTER 129
Hematology of Salmonids 1176
JERE STERN

CHAPTER 130
Hematology of Ictaluridae 1182
PATRICIA GAUNT

CHAPTER 131
Hematology of Cyprinidae 1188
ILZE K. BERZINS and ALEXANDER E. PRIMUS

CHAPTER 132
Hematology of Lizards, Crocodylians,
and Tuatara 1197
CHARLOTTE HOLLINGER and JEAN A. PARÉ

CHAPTER 133
Hematology of Serpentes 1209
LAURA J. BLACK and MARJORIE BERCIER

CHAPTER 134
Hematology of Testudines 1219
JENNIFER D. STEINBERG and STEPHEN J. DIVERS

CHAPTER 135
Hematology of Amphibians 1228
PERRY BAIN and KENDAL E. HARR

CHAPTER 136
Hematology of Invertebrates 1233
JILL E. ARNOLD

SECTION X
**Quality Management and Laboratory
Techniques.....1241**

CHAPTER 137
Quality Management of Hematology
Techniques 1243
MARTINA STIRN and KATHLEEN P. FREEMAN

CHAPTER 138
Total Error and Proficiency Testing 1255
STEN WESTGARD and KATHLEEN P. FREEMAN

CHAPTER 139
Quantitative Diagnostic Test Validation 1263
BENTE FLATLAND

CHAPTER 140
Reference Intervals and Decision Limits 1273
KRISTEN R. FRIEDRICH, ASGER LUNDORFF JENSEN, and MADS
KJELGAARD-HANSEN

CHAPTER 141
Bone Marrow Evaluation 1285
NATALI B. BAUER and KENDAL E. HARR

CHAPTER 142
Flow Cytometry 1295
UNITY JEFFERY

CHAPTER 143**Testing for Immune-Mediated Hematologic Disease 1311**

K. JANE WARDROP, MELINDA J. WILKERSON, and CINZIA MASTRORILLI

CHAPTER 144**Electrophoresis and Acute-Phase Proteins 1320**

ALESSIA GIORDANO

CHAPTER 145**Molecular Diagnostic Techniques 1331**

ROBERT J. OSSIBOFF

CHAPTER 146**Genetic Evaluation of Inherited Hematologic Diseases 1337**

NOA SAFRA and DANIKA BANNASCH

SECTION 10 GLOSSARY 1351**Index.....1353**

Julie Allen, BVMS, MS, MRCVS, DACVIM (SAIM), DACVP

Veterinary Information Network
Davis, California, USA

Anthony C. G. Abrams-Ogg, DVM, DVSc, DACVIM

Department of Clinical Studies
Ontario Veterinary College
University of Guelph
Guelph, Ontario, Canada

Robin W. Allison, DVM, PhD

Department of Veterinary Pathobiology
College of Veterinary Medicine
Oklahoma State University
Stillwater, Oklahoma, USA

Claire B. Andreasen, DVM, PhD, DACVP

Department of Pathology
College of Veterinary Medicine
Iowa State University
Ames, Iowa, USA

Luca Aresu, DVM, PhD

Dipartimento di Scienze Veterinarie
Università degli Studi di Torino, Italy

Jill E. Arnold, MS, MLS (ASCP)^{CM}

ZooQuatic Laboratory, LLC
Baltimore, MD, USA

Adam D. Aulbach, DVM, DACVP

Charles River Laboratories
Mattawan, Michigan, USA

Anne C. Avery, VMD, PhD

Department of Microbiology, Immunology, and Pathology
Colorado State University
Fort Collins, Colorado, USA

Perry Bain, DVM, PhD, DACVP

Department of Biomedical Sciences
Cummings School of Veterinary Medicine at Tufts University
North Grafton, Massachusetts, USA

Danika Bannasch, DVM, PhD

Department of Population Health and Reproduction
School of Veterinary Medicine
University of California Davis
Davis, California, USA

Anne M. Barger, DVM, MS, DACVP

Department of Veterinary Clinical Medicine
College of Veterinary Medicine
University of Illinois
Urbana, Illinois, USA

Annalisa Barrelet, BVetMed, MS, CertESM, MRCVS

Rosssdales Laboratories
Newmarket, United Kingdom

George M. Barrington, DVM, PhD, DACVIM

Department of Veterinary Clinical Sciences
College of Veterinary Medicine
Washington State University
Pullman, Washington, USA

Natali B. Bauer, DVM, PhD

Justus-Liebig-Universität Gießen
Klinikum Veterinärmedizin
-klinische Laboratoriumsdiagnostik und klinische
Pathophysiologie-
Gießen, Germany

Hugues Beaufrère, DVM, PhD, DACZM, ABVP (Avian), ECZM (Avian)

Department of Clinical Studies
Ontario Veterinary College,
University of Guelph
Guelph, Ontario, Canada

Erica Behling-Kelly, DVM, PhD, DACVP

Department of Population Medicine and Diagnostic Sciences
College of Veterinary Medicine
Cornell University
Ithaca, New York, USA

Marjorie Bercier, DMV, DACZM

Department of Clinical Sciences
Cummings School of Veterinary Medicine at Tufts University
North Grafton, Massachusetts, USA

Francesco Bertoni

Institute of Oncology Research
Faculty of Biomedical Sciences
USI, Bellinzona, Switzerland
and
Oncology and Institute of Southern Switzerland
Bellinzona, Switzerland

Ilze K. Berzins, PhD, DVM, MPH

One Water, One Health, LLC
Golden Valley, Minnesota, USA

Dorothee Bienzle, DVM, MSc, PhD, DACVP

Department of Pathobiology
Ontario Veterinary College
University of Guelph
Guelph, Ontario, Canada

Laura J. Black, DVM, DACVP

Specialty VETPATH
Seattle, Washington, USA

Marie-Claude Blais, DMV, DACVIM

Department of Clinical Sciences
Faculté de médecine vétérinaire
Université de Montréal
Saint-Hyacinthe
Quebec, Ontario, Canada

Shauna L. Blois, DVM, DVSc, DACVIM

Department of Clinical Studies
Ontario Veterinary College
University of Guelph
Guelph, Ontario, Canada

Andrea A. Bohn, DVM, PhD, DACVP

Department of Microbiology, Immunology, and Pathology
Colorado State University
Fort Collins, Colorado, USA

Brad Bolon, DVM, PhD, DACVP, DABT

GEMpath Inc.
Cedar City, Utah, USA

**Antonella Borgatti, DVM, MS, DACVIM (Oncology)
DECVIM**

Department of Veterinary Clinical Sciences
College of Veterinary Medicine
University of Minnesota
St Paul, Minnesota, USA

Dori L. Borjesson

College of Veterinary Medicine
Washington State University
Pullman, Washington, USA

Mary K. Boudreaux, DVM, PhD

Department of Pathobiology
College of Veterinary Medicine
Auburn University
Auburn, Alabama, USA

Jennifer Bouschor, DVM

Department of Veterinary Clinical Sciences
College of Veterinary Medicine
University of Minnesota
St Paul, Minnesota, USA

Andrew S. Bowman, MS, DVM, PhD, DACVPM

College of Veterinary Medicine Department of Veterinary
Preventive Medicine
Columbus, Ohio, USA

Kelli L. Boyd DVM, PhD, DACVP

Department of Pathology, Microbiology, and Immunology
Vanderbilt University
Nashville, Tennessee, USA

Benjamin M. Brainard, VMD, DACVAA, DACVECC

Department of Small Animal Medicine and Surgery
College of Veterinary Medicine
University of Georgia
Athens, Georgia, USA

Jennifer L. Brazzell, DVM, MVetSc, MRCVS, DACVP

Veterinary Services
Marshfield Labs
Marshfield, Wisconsin, USA

Matthew Breen, PhD, CBIOL, FIBIOL

Department of Molecular Biomedical Sciences
College of Veterinary Medicine
North Carolina State University
Raleigh, North Carolina, USA

Marjory B. Brooks, DVM, DACVIM

Comparative Coagulation Section
Department of Population Medicine and Diagnostic Sciences
College of Veterinary Medicine
Cornell University
Ithaca, New York, USA

Mary Jo Burkhard, DVM, PhD, DACVP

Department of Veterinary Biosciences
College of Veterinary Medicine
The Ohio State University
Columbus, Ohio, USA

Erin N. Burton, MS, DVM, DACVP

Department of Veterinary and Biomedical Sciences
College of Veterinary Medicine
University of Minnesota
St. Paul, Minnesota, USA

Mary Beth Callan, VMD, DACVIM

Department of Clinical Sciences and Advanced Medicine
School of Veterinary Medicine
University of Pennsylvania
Philadelphia, Pennsylvania, USA

Melinda S. Camus

College of Veterinary Medicine
Auburn University
Auburn, Alabama, USA

Bruce D. Car, BVSc, MVS, PhD, DACVP, DABT
Bristol-Myers Squibb Company
Princeton, New Jersey, USA

James L. Catalfamo, MS, PhD
Department of Population Medicine & Diagnostic Sciences
College of Veterinary Medicine
Cornell University
Ithaca, New York, USA

Luc Chabanne, DVM, PhD
Laboratoire d'Hématologie, Clinique et Unité de
Médecine Interne
Département des Animaux de Compagnie
École Nationale Vétérinaire de Lyon
Lyon, France

John A. Christian, DVM, PhD
Department of Comparative Pathobiology
College of Veterinary Medicine
Purdue University
West Lafayette, Indiana, USA

Pete W. Christopherson, DVM, PhD, DACVP
Department of Pathobiology
Auburn University, College of Veterinary Medicine
Auburn, Alabama, USA

**Phillip Clark, BVSc, PhD, DVSc, MANZCVS,
DACVP, SFHEA, FFSc (RCPA)**
Curtin Medical School Faculty of Health Sciences
Curtin University
Perth, Western Australia, Australia

Stacy Clothier, DVM, MS, DACVP
Department of Biomedical Sciences and Pathobiology
Virginia-Maryland College of Veterinary Medicine
Blacksburg, Virginia, USA

Stefano Comazzi, DVM, PhD, DECVCP
Dipartimento di Medicina Veterinaria
Università degli Studi di Milano, Italy

Francisco O. Conrado, DVM, MSc, DACVP
Cummings School of Veterinary Medicine at Tufts University
North Grafton, Massachusetts, USA

**Michael J. Day, BSc, BVMS, PhD, DSc, Dr (hc),
DECVP, FASM, FRCPath, FRCVS***
Emeritus Professor
School of Veterinary and Life Sciences
Murdoch University
Western Australia, Australia
*deceased

Armelle de Laforcade, DVM, DACVP
Department of Clinical Sciences/Emergency/Critical Care
Cummings School of Veterinary Medicine at Tufts University
North Grafton, Massachusetts, USA

Alexa Delaune, DVM
Vice President of Veterinary Services
Mississippi Aquarium
Gulfport, Mississippi, USA

Nariman Deravi, DVM, DVSc, DACVP
IDEXX Laboratories
Toronto, Canada

**Stephen J. Divers, BVetMed, DZooMed,
DECZM(Herp), DECZM(ZHM), DACZM, FRCVS**
Department of Small Animal Medicine & Surgery
(Zoological Medicine)
College of Veterinary Medicine
University of Georgia
Athens, Georgia, USA

Andrea Pires dos Santos, DMV, MSc, PhD
College of Veterinary Medicine
Purdue University
West Lafayette, Indiana, USA

Steven Dow, DVM, PhD, DACVIM
Department of Clinical Sciences
Colorado State University
Fort Collins, Colorado, USA

David Eckersall, BSc, MBA, PhD, FRCPath, MAE
Institute of Biodiversity
Animal Health and Comparative Medicine
School of Veterinary Medicine
University of Glasgow
Glasgow, Scotland

Karyn E. Enos, DVM, MS, DACVP (Anatomic)
Concord Biomedical Sciences and Emerging Technologies
Lexington, Massachusetts, USA

Meaghan V. Eren, DVM, MS, DAVCP
Antech Diagnostics
Lake Success, New York, USA

Samantha J.M. Evans, DVM, PhD
Department of Veterinary Biosciences
College of Veterinary Medicine
The Ohio State University
Columbus, Ohio, USA

Alison J. Farr, BVetMed, FRCPath, MRCVS
IDEXX Laboratories, Ltd
Wetherby, West Yorkshire, United Kingdom

Peter J. Felsburg, VMD, PhD
School of Veterinary Medicine
University of Pennsylvania
Philadelphia, Pennsylvania, USA

Susan Fielder, DVM, MS, DACVP
Department of Pathobiology
Center for Veterinary Health Sciences
Oklahoma State University
Stillwater, Oklahoma, USA

Eric J. Fish, DVM, PhD, DACVP

IDEXX Laboratories
St. Petersburg, Florida, USA

Bente Flatland, DVM, MS, DACVP, DACVIM

Department of Biomedical and Diagnostic Sciences
College of Veterinary Medicine
University of Tennessee
Knoxville, Tennessee, USA

Kathleen P. Freeman, DVM, MS, PhD, DECVCP, FRCPath, MRCVS

SYNLAB-VPG/Exeter
Exeter, United Kingdom

Kristen R. Friedrichs, DVM, DACVP

Department of Pathobiological Sciences
School of Veterinary Medicine
University of Wisconsin
Madison, Wisconsin, USA

Michael M. Fry, DVM, MS, DACVP

Department of Biomedical and Diagnostic Sciences
College of Veterinary Medicine
University of Tennessee
Knoxville, Tennessee, USA

Bridget C. Garner, DVM, PhD, DACVP

Department of Pathology
University of Georgia College of Veterinary Medicine
Athens, Georgia, USA

Patricia Gaunt, DVM, PhD, DABVT

College of Veterinary Medicine
Mississippi State University
Stoneville, Mississippi, USA

Diana Giannuzzi, DVM, PhD

Department of Agronomy, Food, Natural Resources, Animals,
and Environment
University of Padua
Padua, Italy

Urs Giger, DMV, MS, FVH, DACVIM, DECVIM, DECVCP

School of Veterinary Medicine, School of Medicine
University of Pennsylvania
Philadelphia, Pennsylvania, USA

Alessia Giordano, DVM, PhD, DECVCP, EBVS (CP)

Department of Veterinary Medicine
Veterinary Teaching Hospital
University of Milan
Lodi, Italy

Robert Goggs, BVSc, PhD, DACVECC, DECVCP, MRCVS

Department of Clinical Sciences
College of Veterinary Medicine
Cornell University
Ithaca, New York USA

Jenifer R. Gold, DACVIM, DACVECC

Department of Veterinary Clinical Sciences
College of Veterinary Medicine
Washington State University
Pullman, Washington, USA

Yuko Goto-Koshino, PhD

Department of Veterinary Internal Medicine
Graduate School of Agricultural and Life Sciences
The University of Tokyo
Tokyo, Japan

Agata K. Grzelak, DVM

Department of Biomedical and Diagnostic Sciences
College of Veterinary Medicine
University of Tennessee
Knoxville, Tennessee, USA

Jillian M. Haines, DVM, MS, DACVIM

Department of Veterinary Clinical Sciences
College of Veterinary Medicine
Washington State University
Pullman, Washington, USA

Kendal E. Harr, DVM, MS, DACVP

URIKA, LLC
Mukilteo, Washington, USA

John W. Harvey, DVM, PhD, DACVP

Department of Physiological Sciences
College of Veterinary Medicine
University of Florida
Gainesville, Florida, USA

J. Jill Heatley, DVM, MS, DABVP, DACZM

Department of Small Animal Clinical Sciences
College of Veterinary Medicine & Biomedical Sciences
Texas A & M University
College Station, Texas, USA

Daniel A. Heinrich, DVM, DACVP

Department of Veterinary Clinical Sciences
College of Veterinary Medicine
University of Minnesota
St. Paul, Minnesota, USA

Kristin L. Henson, DVM, MS, DACVP

Novartis Institutes for Biomedical Research
Cambridge, Massachusetts, USA

Paul R. Hess, DVM, PhD, DACVIM

Department of Clinical Sciences
College of Veterinary Medicine
North Carolina State University
Raleigh, North Carolina, USA

Jessica Hokamp, DVM, PhD, DACVP

Department of Veterinary Biosciences
College of Veterinary Medicine
The Ohio State University
Columbus, Ohio, USA

Charlotte Hollinger, VMD, MS, DACVP

Wildlife Conservation Society
Bronx, New York, USA

Emma H. Hooijberg, BVSc, PhD, DECVCP

Department of Companion Animal Clinical Studies and
Veterinary Wildlife Centre
University of Pretoria
Pretoria, South Africa

Margaret J. Hosie, BVM&S, MRCVS, BSc, PhD

MRC-University of Glasgow Centre for Virus Research
Glasgow, United Kingdom

Mutsumi Inaba, DVM, PhD

Laboratory of Molecular Medicine
Graduate School of Veterinary Medicine
Hokkaido University
Sapporo, Japan

Armando R. Irizarry Rovira, DVM, PhD, DACVP

Director of Investigative Toxicology, Nonclinical Study
Management and Pathology
Lilly Research Laboratories—Toxicology, Drug Disposition,
and PKPD
Eli Lilly and Company
Indianapolis, Indiana, USA

Robert M. Jacobs, DVM, PhD, DACVP

Department of Pathobiology
Ontario Veterinary College
University of Guelph
Guelph, Ontario
Canada

Unity Jeffery, VetMB, PhD, DACVP

Department of Veterinary Pathobiology
College of Veterinary Medicine
Texas A&M University
College Station, Texas, USA

Asger Lundorff Jensen, DVM, PhD, MLP

Department of Veterinary Clinical Sciences
University of Copenhagen
Frederiksberg, Denmark

Jennifer Johns, DVM, PhD, DACVP

Department of Biomedical Sciences
Oregon State University Carlson College of Veterinary
Medicine
Corvallis, Oregon, USA

Cathy A. Johnson-Delaney, DVM, DABVP

NW Zoological Supply
Everett, Washington, USA

Brandy C. Kastl, DVM, DACV

Kansas State Veterinary Diagnostic Laboratory
Kansas State University
Manhattan, Kansas, USA

Stefan Keller, DVM, PhD, DECVCP

Department of Pathobiology
Ontario Veterinary College
University of Guelph
Guelph, Ontario, Canada

Jong Hyuk Kim, DVM, PhD

Department of Veterinary Clinical Sciences
College of Veterinary Medicine
University of Minnesota
St. Paul, Minnesota, USA

Mads Kjelgaard-Hansen, DVM, PhD

Department of Veterinary Clinical Sciences
University of Copenhagen
Frederiksberg, Denmark

Elizabeth A. Layne, DVM, DACVD

Department of Medical Sciences
School of Veterinary Medicine
University of Wisconsin–Madison
Madison, Wisconsin, USA

Dana N. LeVine, DVM, PhD, DACVIM (SAIM)

Department of Clinical Sciences
Auburn University College of Veterinary Medicine
Auburn, Alabama, United States

Cynthia A. Lucidi, DVM, PhD, DACVP

Veterinary Diagnostic Laboratory
College of Veterinary Medicine
Michigan State University
East Lansing, Michigan, USA

Hans Lutz, DMV, PhD, FVH, FAMH

Clinical Laboratory, Department of Clinical Diagnostic
Services
University of Zurich
Zurich, Switzerland

Alex M. Lynch, BVSc, DACVECC, MRCVS

Department of Clinical Sciences
College of Veterinary Medicine
North Carolina State University
Raleigh, North Carolina, USA

Andrew Mackin, BVMS, MVS, DVSc, FANZCVSc, DACVIM

Department of Clinical Sciences
College of Veterinary Medicine
Mississippi State University
Starkville, Mississippi, USA

Amy L. MacNeill, DVM, PhD, DACVP

Microbiology, Immunology, and Pathology
Department
College of Veterinary Medicine and Biomedical Sciences
Colorado State University
Fort Collins, Colorado, USA

Laura Marconato

Department of Veterinary Medical Sciences
University of Bologna
Bologna, Italy

Cinzia Mastrorilli, DVM, PhD, DACVP

Veterinary Clinical Pathologist
Ferrara, Italy

Jeffrey McCartney, DVM, MVSc, DACVP, DABT

Charles River Laboratories
Montreal, Quebec, Canada

Maggie R. McCourt, DVM, DACVP

Department of Veterinary Pathobiology
Center for Veterinary Health Sciences
Oklahoma State University
Stillwater, Oklahoma, USA

Sean P. McDonough, DVM, PhD, DACVP

Chief of Anatomic Pathology
Department of Biomedical Sciences
College of Veterinary Medicine
Cornell University
Ithaca, New York, USA

Meredeth McEntire, DVM, MS, DACVP

Department of Veterinary Clinical Sciences
College of Veterinary Medicine
Washington State University
Pullman, Washington, USA

Maureen A. McMichael, DVM, M.Ed., DACVECC

Department of Clinical Sciences
College of Veterinary Medicine
Auburn University
Auburn, Alabama, USA

James H. Meinkoth, DVM, MS, PhD, DACVP

Department of Veterinary Pathobiology
College of Veterinary Medicine
Oklahoma State University
Stillwater, Oklahoma, USA

Joanne B. Messick, VMD, PhD, DACVP

Department of Comparative Pathobiology
College of Veterinary Medicine
Purdue University
West Lafayette, Indiana, USA

Jaime F. Modiano, VMD, PhD

Department of Veterinary Clinical Sciences
College of Veterinary Medicine
Masonic Cancer Center
University of Minnesota
Minneapolis/St. Paul, Minnesota, USA

David M. Moore, MS, DVM, DACLAM

Department of Biomedical Sciences and Pathobiology
Virginia-Maryland College of Veterinary Medicine
Blacksburg, Virginia, USA

Peter F. Moore, BVSc, PhD, DACVP

Department Pathology Microbiology and Immunology
University of California-Davis
School of Veterinary Medicine
Davis, California, USA

Andreas Moritz, Dr. med. vet., Prof., DEVIM-CA, Assoc. Memb. ECVCP

Department of Veterinary Clinical Sciences
Justus-Liebig-University Giessen,
Giessen, Germany

Margaret C. Mudge, VMD, DACVS, DACVECC

Department of Veterinary Clinical Sciences
College of Veterinary Medicine
Ohio State University
Columbus, Ohio, USA

Ashleigh Newman, VMD, DACVP

Department of Population Medicine and Diagnostic
Sciences
College of Veterinary Medicine
Cornell University
Ithaca, New York, USA

Hendrik Nollens, DVM, MSc, PhD

Pacific Marine Mammal Center
Laguna Beach, California, USA

Christine Swardson Olver, DVM, PhD, DACVP

Department of Microbiology, Immunology, and Pathology
Colorado State University
Fort Collins, Colorado, USA

Laurie G. O'Rourke, DVM, PhD, DACVP, DECVCP

Friday Harbor, Washington, USA

Robert J. Ossiboff, DVM, PhD, DACVP

Department of Comparative, Diagnostic, and Population
Medicine
College of Veterinary Medicine
University of Florida
Gainesville, Florida, USA

Jed A. Overmann, DVM, DACVP

Abbott Laboratories
St. Paul, Minnesota, USA

Jean A. Paré, DMV, DVSc, DACZM, DECZM (ZHM)

Wildlife Conservation Society
Bronx, New York, USA

Maria Cecilia T. Penedo, PhD

Veterinary Genetics Laboratory
School of Veterinary Medicine
University of California
Davis, California, USA

Mark E. Peterson, DVM, DACVIM

Animal Endocrine Clinic
New York, USA
and
Department of Clinical Sciences
College of Veterinary Medicine Cornell University
Ithaca, New York, USA

Julie Piccione, DVM, MS, DACVP

Texas A&M Veterinary Medical Diagnostic Laboratory
College Station, Texas, USA

Lisa M. Pohlman, BS, DVM, MS, DACVP

Veterinary Diagnostic Laboratory
Department of Diagnostic Medicine/Pathobiology
College of Veterinary Medicine
Kansas State University
Manhattan, Kansas, USA

F. Poitout-Belissent, DVM, DACVP, DECVCP

Charles River Laboratories
Montréal, Québec, Canada

Kludia Polak, DVM

Department of Microbiology, Immunology, and Pathology
College of Veterinary Medicine and Biomedical Sciences
Colorado State University
Fort Collins, Colorado, USA

Alexander E. Primus, DVM, PhD

Department of Veterinary Population Medicine
College of Veterinary Medicine
University of Minnesota
Saint Paul, Minnesota, USA

Lauren B. Radakovich, DVM, PhD, DACVP

Department of Microbiology, Immunology, and Pathology
College of Veterinary Medicine and Biomedical Sciences
Colorado State University
Fort Collins, Colorado, USA

M. Judith Radin, DVM, PhD, DACVP

Department of Veterinary Biosciences
College of Veterinary Medicine
Columbus, Ohio, USA

John F. Randolph, DVM, DACVIM

Department of Clinical Sciences
College of Veterinary Medicine

Cornell University
Ithaca, New York, USA

Rose E. Raskin, DVM, PhD, DACVP

Department of Comparative Pathobiology
School of Veterinary Medicine
Purdue University
West Lafayette, Indiana, USA

William J. Reagan, DVM, PhD, DACVP, Research Fellow

Pfizer Drug Safety Research and Development
Eastern Point Rd 8274/1203
Groton, Connecticut, USA

Michelle G. Ritt DVM, DACVIM (Small Animal)

Department of Veterinary Clinical Sciences
College of Veterinary Medicine
St. Paul, Minnesota, USA

Theresa E. Rizzi, DVM, DACVP

Department of Veterinary Pathobiology
Center for Veterinary Health Sciences
Oklahoma State University
Stillwater, Oklahoma, USA

Karen E. Russell, DVM, PhD, DACVP

Department of Veterinary Pathobiology
College of Veterinary Medicine & Biomedical Sciences
Texas A & M University
College Station, Texas, USA

Barbara C. Rütgen, DVM

Institute of Immunology
Department of Pathobiology
University of Veterinary Medicine Vienna
Vienna, Austria

Noa Safra DVM PhD DACVP (clinical pathology)

Zoetis, Inc.
Parsippany, NJ, USA

Kelly Santangelo, DVM, PhD, DACVP

Department of Microbiology, Immunology, and Pathology
College of Veterinary Medicine and Biomedical Sciences
Colorado State University
Fort Collins, Colorado, USA

Deanna M. W. Schaefer, DVM, MS, MT(ASCP), DACVP

Department of Biomedical and Diagnostic Sciences
The University of Tennessee, College of Veterinary Medicine
Knoxville, Tennessee, USA

Diana Schwartz, DVM, DACVP

VDx Veterinary Diagnostics
Davis, California, USA

Davis M. Seelig, DVM, PhD, DACVP
Department of Veterinary Clinical Sciences
University of Minnesota, College of Veterinary Medicine
St. Paul, Minnesota, USA

Debra C. Sellon, DVM, PhD, DACVIM
Department of Veterinary Clinical Sciences
College of Veterinary Medicine
Washington State University
Pullman, Washington, USA

Rance K. Sellon
Department of Veterinary Clinical Sciences
College of Veterinary Medicine
Washington State University
Pullman, Washington, USA

Cleverson D. Souza, DVM, PhD, DACVP
Department of Veterinary Clinical Sciences
College of Veterinary Medicine
Washington State University
Pullman, Washington, USA

Nora L. Springer
Department of Diagnostic Medicine and Pathobiology
College of Veterinary Medicine
Kansas State University
Manhattan, Kansas, USA

Catherine A. St. Hill, DVM, PhD
Allina Health
Minneapolis, Minnesota, USA

Nicole I. Stacy, DVM, DMV, DACVP
Department of Comparative, Diagnostic, and Population
Medicine
College of Veterinary Medicine
University of Florida
Gainesville, Florida, USA

Jason Stayt, BVSc, DACVP
Vetpath Laboratory Services
Ascot, Western Australia, Australia

Jennifer D. Steinberg, DVM, DACVP
Lacuna Diagnostics, Inc.
Baltimore, Maryland, USA

Jere Stern, DVM
Department of Pathobiology
Auburn University
College of Veterinary Medicine
Auburn, Alabama, USA

Martina Stirn, DMV, DECVCP
Clinical Laboratory
Vetsuisse Faculty
University of Zurich
Zurich, Switzerland

**Anke C. Stöhr, med vet, MS, DECZM (Herpetology),
ZB Reptilien**
Department of Veterinary Clinical Sciences
School of Veterinary Medicine
Louisiana State University
Baton Rouge, Louisiana, USA

Tracy Stokol, BVSc, PhD, DACVP
Department of Population Medicine and Diagnostic
Sciences
College of Veterinary Medicine
Cornell University
Ithaca, New York, USA

Anneliese Strunk, DVM, DABVP (Avian)
Center for Bird and Exotic Animal Medicine
Bothell, Washington, USA

Steven E. Suter, VMD, PhD, DACVIM
Department of Clinical Sciences
North Carolina State University,
Raleigh, North Carolina, USA

Jaime L. Tarigo, DVM, PhD, DACVP
Department of Pathology
College of Veterinary Medicine
University of Georgia
Athens, Georgia, USA

Jennifer S. Thomas, DVM, PhD, DACVP
Department of Pathobiology and Diagnostic
Investigation
College of Veterinary Medicine
Michigan State University
East Lansing, Michigan, USA

Catherine E. Thorn, DVM, DVSc, MSc, DACVP
Antech Diagnostics
Atlanta, Georgia, USA

Ian Tizard, DVM, PhD, ACVM
Department of Veterinary Pathobiology
College of Veterinary Medicine and Biomedical Sciences
Texas A&M University
College Station, Texas, USA

Susan J. Tornquist, DVM, MS, PhD, DACVP
Carlson College of Veterinary Medicine
Oregon State University
Corvallis, Oregon, USA

Hajime Tsujimoto, PhD
Department of Veterinary Internal Medicine
Graduate School of Agriculture and Life Sciences
The University of Tokyo
Tokyo, Japan

Harold Tvedten, DVM, PhD, DACVP, DECVCP
 Clinical Chemistry Laboratory
 University Animal Hospital
 Swedish University of Agricultural Sciences
 Uppsala, Sweden

V.E. Ted Valli, DVM, MSc, PhD, DACVP
 VDX Pathology
 Davis, California, USA

Austin K. Viall, DVM, MS, DACVP
 Department of Veterinary Pathology
 College of Veterinary Medicine
 Iowa State University
 Ames, Iowa, USA

K. Jane Wardrop, DVM, MS, DACVP
 Department of Veterinary Clinical Sciences
 College of Veterinary Medicine
 Washington State University
 Pullman, Washington, USA

Amy L. Warren, BSc, BVSc (Hons.), PhD, DACVP
 Department of Veterinary Clinical and Diagnostic Sciences
 Faculty of Veterinary Medicine
 University of Calgary
 Calgary, Alberta, Canada

Adi Wasserkrug-Naor, DVM, DACVP
 Novartis
 East Hanover, New Jersey, USA

Nicole M. Weinstein, DVM, DACVP
 Department of Veterinary Pathobiology
 School of Veterinary Medicine
 University of Pennsylvania
 Philadelphia, Pennsylvania, USA

Douglas J. Weiss, DVM, PhD, DACVP, Emeritus Professor
 College of Veterinary Medicine
 University of Minnesota
 Saint Paul, Minnesota, USA

Maxey L. Wellman, DVM, PhD, DACVP
 Department of Veterinary Biosciences,
 The Ohio State University
 Columbus, Ohio, USA

Sten Westgard, MS
 Westgard QC, Inc.
 Madison, Wisconsin, USA

Melinda J. Wilkerson, DVM, PhD, DACVP
 Department of Pathobiology
 School of Veterinary Medicine
 St. George's University
 Grenada, West Indies

R. Darren Wood, DVM, DVSc, DACVP
 Department of Pathobiology
 Ontario Veterinary College
 University of Guelph
 Guelph, Ontario, Canada

Robin M. Yates, BSc., BVSc (Hons.), PhD, MTEM
 Department of Comparative Biology and Experimental
 Medicine
 Department of Biochemistry and Molecular Biology
 Faculty of Veterinary Medicine, and Faculty of Medicine
 University of Calgary
 Calgary, Alberta, Canada

Karen M. Young, VMD, PhD
 Professor of Clinical Pathology
 Department of Pathobiological Sciences
 School of Veterinary Medicine
 University of Wisconsin–Madison, Wisconsin, USA

Kurt L. Zimmerman, DVM, PhD, DACVP
 Department of Biomedical Sciences & Pathobiology
 Virginia-Maryland College of Veterinary Medicine
 Blacksburg, Virginia, USA

PREFACE

Veterinary clinical pathology has changed considerably since publication of the 6th edition of *Schalm's Veterinary Hematology*. No longer the practitioners of a discipline that deals primarily with the clinical evaluation of dog and cat samples, clinical pathologists are now called on to use their diagnostic skills for a broad variety of animal species. Current specialty areas encompass diverse fields such as pharmaceutical compound and device development and the management of zoo and free-range wildlife. Beyond nontraditional species, clinical pathologists have broadened the scope of their diagnostic expertise to incorporate genomics, proteomics, and metabolomics, and use novel assay platforms such as expression arrays, microfluidic devices, and multiplex immunoassays. Significant advances have also been made in more traditional techniques including flow cytometry, blood typing serology, and platelet function testing.

We have assembled a team of editors capable of covering this exceptional diversity in species and subject areas that now comprise the field of clinical pathology. Dr. Marjory Brooks' career has focused on comparative hemostasis and the development of translational

biomarkers for preclinical and diagnostic applications. Dr. Kendal Harr provides expertise in nondomestic species and has devoted the past 15 years to making ASVCP's quality assurance guidelines more robust. Dr. Davis Seelig provides expertise in basic molecular biology, research techniques, and in hematopoietic neoplasia. Dr. Jane Wardrop has expertise in hematological disorders and transfusion medicine. Dr. Douglas Weiss has expertise in bone marrow disorders, infectious disease, and molecular biology.

Specific changes in this edition include a new section titled "Hemolymphatic Tissue" for detailed coverage of basic pathophysiology and disease mechanisms, expanded "Species-Specific Hematology" and "Hematotoxicity" sections, and more in-depth molecular and genetics content. Additionally, we have extensively revised and rearranged chapters to address emerging topics and to provide a more logical sequence for the material. With recognition of the hard work of our contributing authors, we are proud to provide the reader with a comprehensive, coherent, and state of the art presentation of topics in clinical pathology.

ACKNOWLEDGMENTS

To the teachers and mentors, who set me on the path of discovery, and to the students, clinicians, and colleagues, who continually bring new insights and challenges to the journey.

Marjory Brooks



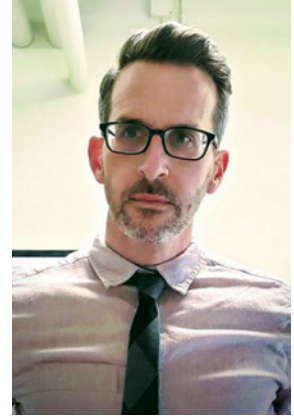
I would like to express my gratitude to my whole family for their support and patience during the time it has taken to construct this tome. Especially my husband, Bob, who thankfully has fabulous cooking skills (among others) and my daughters, Lily and Maeve, who have, since the start of this work, matured to wonderful, fascinating adults. And, of course, my mom whose voice I still hear and provides guidance to this day. I also appreciate my co-editors, who have helped me become a better editor, reviewer, and author, especially Dr. K. Jane Wardrop.

Kendal E. Harr



To Catherine and Angela, who (in their own unique ways) provided much needed emotional support and relief. To my coworkers and resident trainees, who tolerated the many mornings and afternoons in which I was squirreled away in my office.

Davis Seelig



To my family for their continued support, and to my colleagues around the world, who contributed to the making of this edition. Your work inspires me to be a better author, researcher, teacher, and person.

K. Jane Wardrop



To my parents (Bud and Dorothy) for their strength, moral guidance, and work ethic, my family (Jane, Matthew, Kal) for their love and support, which was essential to my career as well as my well-being, and to Barb for partnering with me in undertaking a whole new vision of how to live in harmony with the earth and all living things.

Douglas J. Weiss (FF)

