HANDBOOK OF EXPERIMENTAL IMMUNOLOGY
IN FOUR VOLUMES

Volume 2: Cellular Immunology

EDITED BY

D. M. WEIR MD, FRCP

L. A. Herzenberg PhD Caroline Blackwell PhD

Leonore A. Herzenberg DSc

FOURTH EDITION

Blackwell Scientific Publications
Editorial offices:
Osney Mead, Oxford, OX2 0EL
8 John Street, London, WC1N 2ES
23 Ainslie Place, Edinburgh, EH3 6AJ
52 Beacon Street, Boston
Massachusetts 02108, USA
667 Lytton Avenue, Palo Alto
California 94301, USA
107 Barry Street, Carlton
Victoria 3053, Australia

First published 1967
Second edition 1973
Third edition 1978
Reprinted 1979
Fourth Edition 1986

Printed in Great Britain
at the Alden Press, Oxford

DISTRIBUTORS
USA
Blackwell Scientific Publications Inc
PO Box 50009, Palo Alto
California 94303

Blackwell Mosby Book Distributors
11830 Westline Industrial Drive
St Louis, Missouri 63141

Canada
The C. V. Mosby Company
5240 Finch Avenue East
Scarborough, Ontario

Australia
Blackwell Scientific Publications
(Australia) Pty Ltd
107 Barry Street
Carlton, Victoria 3053

British Library
Cataloguing in Publication Data

Handbook of experimental immunology.—4th ed. 1. Immunology—Laboratory manuals I. Weir, D.M. II. Herzenberg, L.A. III. Blackwell, C. IV. Herzenberg, Leonore A. 599.02'9'028 QR183

ISBN 0-632-01499-7
ISBN 0-632-00975-6 v. 1
ISBN 0-632-01378-8 v. 2
ISBN 0-632-01379-6 v. 3
ISBN 0-632-01381-8 v. 4

Contributors

C. A. Allen, *Imperial Cancer Research Fund, London, UK*

G. A. Andres, *Department of Pathology, State University of New York at Buffalo, NY, USA*

J. D. Ansell, *Department of Zoology, University of Edinburgh, Edinburgh, UK*

P. K. C. Austwick, *Department of Allergy and Clinical Immunology, Cardiothoracic Institute, London, UK*

J. Austyn, *Sir William Dunn School of Pathology, University of Oxford, Oxford, UK*

T. Bachi, *Institute for Immunology and Virology, University of Zurich, Zurich, Switzerland*

J. A. Badwey, *Department of Biological Chemistry, Harvard Medical School. Boston, Mass, USA*

D. Baltimore, *Whitehead Institute for Biomedical Research, Cambridge, Mass, USA*

M. J. Banda, *Laboratory of Radiobiology and Environmental Health, University of California, San Francisco, Ca, USA*

A. N. Barclay, *MRC Cellular Immunology Unit, Sir William Dunn School of Pathology, University of Oxford, Oxford, UK*

G. R. Barclay, *Blood Transfusion Centre, Royal Infirmary, Edinburgh, UK*

B. Benacerraf, *Department of Pathology, Harvard Medical School, Boston, Mass, USA*

P. Beverley, *ICRF Human Tumour Immunology Group, School of Medicine, University College London, London, UK*

D. E. Bidwell, *Nuffield Laboratories of Comparative Medicine, Zoological Society of London, London, UK*

C. Caroline Blackwell, *Department of Bacteriology, University of Edinburgh, Edinburgh, UK*

A. E. Bolton, *Department of Biological Science. Sheffield City Polytechnic, Sheffield, UK*

J. Braun, *Department of Pathology, University of California, Los Angeles, Ca, USA*

P. H. Brodeur, *Department of Pathology, Tufts University, Boston, Mass, USA*

C. J. Burrell, *Division of Virology, Institute of Medical and Veterinary Science, Adelaide, Australia*

E. C. Butcher, *Department of Pathology, Stanford University Medical School, Stanford, Ca, USA*

G. C. Butcher, *Institute of Animal Physiology, Agricultural Research Council, Babraham, Cambridge, UK*

H. Cantor, *Department of Pathology, Harvard Medical School, Boston, Mass, USA*

P. Chandler, *Transplantation Biology Section, Clinical Research Centre, Harrow, UK*

M. W. Clark, *Department of Biochemistry and Microbiology, University of Victoria, BC, Canada*

J. E. Coligan, *National Institute of Allergy and Infectious Diseases, Bethesda, Md, USA*

Suzanne Cory, *The Walter and Eliza Hall Institute of Medical Research, Royal Melbourne Hospital, Victoria, Australia*

O. Cromwell, *Department of Allergy and Clinical Immunology, Cardiothoracic Institute, London, UK*

M. R. Daha, *Department of Nephrology, University Hospital, Leiden, The Netherlands*

M. M. Davis, *Department of Medical Microbiology, Stanford University Medical School, Stanford, Ca, USA*

R. Dildrop, *Institute of Genetics, University of Cologne, Cologne, Federal Republic of Germany*

G. J. Dougherty, *Imperial Cancer Research Fund, London, UK*

S. Dreborg, *Allergy and Diagnostics Division, Pharmacia AB, Uppsala, Sweden*

D. W. Dresser, *Division of Immunology, National Institute for Medical Research, Mill Hill, London, UK*

S. R. Durham, *Department of Allergy and Clinical Immunology, Cardiothoracic Institute, London, UK*

P. J. Edelson, *Department of Pediatrics, New York Hospital, Cornell Medical Centre, New York, NY, USA*

A. B. Edmundson, *Department of Biology, University of Utah, Salt Lake City, Utah, USA*

R. Einarsson, *Biochemistry Division, Pharmacia AB, University of Uppsala, Uppsala, Sweden*

E. L. Elson, *Department of Biological Chemistry, Washington University Medical Centre, St. Louis, Mo, USA*

R. A. Elton, *Medical Computing and Statistics Group, University of Edinburgh, Edinburgh, UK*

Katherine R. Ely, *Department of Biology, University of Utah, Salt Lake City, Utah, USA*

E. G. Engleman, *Department of Medicine, Stanford University, School of Medicine, Stanford, Ca, USA*

R. A. B. Ezekowitz, *Sir William Dunn School of Pathology, University of Oxford, Oxford, UK*

C. G. Fathman, *Department of Medicine, Stanford University School of Medicine, Stanford, Ca, USA*

A. S. Fauci, *Laboratory of Immunoregulation, National Institute of Health, Bethesda, Md, USA*

S. Felder, *Department of Biological Chemistry, Washington University School of Medicine, St. Louis, Mo, USA*

Lorraine Flaherty, *Centre for Laboratories and Research, New York State Department of Health, Albany, NY, USA*

The late W. L. Ford, *Department of Immunology, University of Manchester, Manchester, UK*

J. Forman, *Department of Microbiology, University of Texas Southwestern Medical School, Dallas, Texas, USA*

Sara Fuchs, *Department of Clinical Immunology, The Weizmann Institute of Science, Rehovot, Israel*

H. H. Fudenberg, *Department of Basic and Clinical Immunology and Microbiology, Medical University of South Carolina, Charleston, SC, USA*

W. Gerhard, *Wistar Institute of Anatomy and Biology, Philadelphia, Pa, USA*

Elizabeth J. Glass, *Animal Breeding Research Organisation, Edinburgh, UK*

W. Godfrey, *Department of Microbiology, University of California, San Francisco, Ca, USA*

J. W. Goding, *Department of Pathology and Immunology, Monash Medical School, Victoria, Australia*

S. Gordon, *Sir William Dunn School of Pathology, University of Oxford, Oxford, UK*

D. R. Green, *Department of Immunology, University of Alberta, Edmonton, Canada*

Margaret C. Green, *The Jackson Laboratory, Bar Harbor, Maine, USA*

N. M. Gough, *Ludwig Institute for Cancer Reseach, Royal Melbourne Hospital, Victoria, Australia*

G. A. Gutman, *Department of Microbiology and Molecular Genetics, University of California, Irvine, Ca, USA*

J. Guyden, *Department of Microbiology and Immunology, University of California, San Francisco, Ca, USA*

S. Habu, *Department of Cell Biology, Tokai University, Japan*

S. Hakomori, *Division of Biochemical Oncology, Fred Hutchinson Cancer Research Center, Seattle, Wash, USA*

E. Handman, *Laboratory of Immunoparasitology, The Walter and Eliza Hall Institute of Medical Research, Royal Melbourne Hospital, Victoria, Australia*

R. R. Hardy, *Institute for Molecular and Cellular Biology, Osaka University, Osaka, Japan*

R. A. Harrison, *Mechanisms in Tumour Immunity Unit, MRC Centre, Cambridge, UK*

K. Hayakawa, *Department of Genetics, Stanford University School of Medicine, Stanford, Ca, USA*

W. J. Herbert, *Animal Services Unit, University of Dundee, Dundee, UK*

L. A. Herzenberg, *Department of Genetics, Stanford University School of Medicine, Stanford, Ca, USA*

Leonore A. Herzenberg, *Department of Genetics, Stanford University School of Medicine, Stanford, Ca, USA*

Eadie Heyderman, *Department of Histopathology, St. Thomas's Hospital Medical School, London, UK*

S. Hirsch, *Sir William Dunn School of Pathology, University of Oxford, Oxford, UK*

Nancy M. Hogg, *Imperial Cancer Research Fund, London, UK*

E. J. Holborow, *Bone and Joint Research Unit, London Hospital Medical College, London, UK*

L. Hood, *Division of Biology, California Institute of Technology, Pasadena, Ca, USA*

J. C. Howard, *Institute of Animal Physiology, Agricultural Research Council, Babraham, Cambridge, UK*

Maureen Howard, *National Institute of Allergy and Infectious Diseases, Bethesda, Md, USA*

K. C. Hsu, *Department of Microbiology, College of Physicians and Surgeons of New York, NY, USA*

D. A. Hume, *Sir William Dunn School of Pathology, University of Oxford, Oxford, UK*

S. V. Hunt, *MRC Cellular Immunology Unit, Sir William Dunn School of Pathology, University of Oxford, Oxford, UK*

W. M. Hunter, *Celltec Ltd, Slough, Berkshire, UK*

G. M. Iverson, *Dept of Pathology, Howard Hughes Medical Institute, Yale University, New Haven, Conn, USA*

M. K. Jenkins, *Department of Microbiology-Immunology, Northwestern University, Chicago, Ill, USA*

G. D. Johnson, *Department of Immunology, University of Birmingham, Birmingham, UK*

M. J. Johnston, *Department of Genetics, Stanford University Medical School, Stanford, Ca, USA*

E. A. Kabat, *Department of Microbiology, College of Physicians and Surgeons of Columbia University, New York, NY, USA*

M. E. Kamarck, *Department of Biology, Yale University, New Haven, Conn, USA*

R. Kannagi, *Division of Biochemical Oncology, Fred Hutchinson Cancer, Seattle, Wash, USA*

J. Kappler, *Department of Medicine, National Jewish Hospital and Research Center, Denver, Co, USA*

M. J. Karnovsky, *Department of Biological Chemistry, Harvard Medical School, Boston, Mass, USA*

M. L. Karnovsky, *Department of Pathology, Harvard Medical School, Boston, Mass, USA*

R. A. Kautz, *Department of Genetics, Stanford University School of Medicine, Stanford, Ca, USA*

Paula Kavathas, *Department of Genetics, Stanford University School of Medicine, Stanford, Ca, USA*

A. B. Kay, *Department of Allergy and Clinical Immunology, Cardiothoracic Institute, London, UK*

B. S. Kim, *Department of Microbiology-Immunology, Northwestern University, Chicago, Ill, USA*

T. J. Kindt, *National Institute of Allergy and Infectious Disease, Bethesda, Md, USA*

T. J. Kipps, *Scripps Clinic and Research Foundation, La Jolla, Ca, USA*

M. Klein, *Department of Immunology, Toronto Western Hospital, Ontario, Canada*

R. D. Kornberg, *Department of Cell Biology, Stanford University Medical School, Stanford, Ca, USA*

P. J. Lachmann, *Mechanisms in Tumour Immunity Unit, MRC Centre, Cambridge, UK*

H. C. Lane, *Laboratory of Immunoregulation, National Institute of Health, Bethesda, Maryland, USA*

L. L. Lanier, *Becton Dickinson Monoclonal Center Inc, Mountain View, Ca, USA*

P. C. J. Leijh, *Department of Infectious Diseases, University Hospital, Leiden, The Netherlands*

Sheelagh Lloyd, *Department of Clinical Veterinary Medicine, University of Cambridge, Cambridge, UK*

Joan L. Longbottom, *Department of Clinical Immunology, Cardiothoracic Institute, London, UK*

Eva Lotta Larsen, *Department of Immunobiology, Karolinska Institute, Stockholm, Sweden*

W. H. R. Lumsden, *19a Merchiston Crescent, Edinburgh, UK*

W. Lutz, *Medical Computing and Statistics Group, University of Edinburgh, Edinburgh, UK*

W. H. McBride, *Department of Radiation Oncology, University of California, Los Angeles, USA*

M. C. McCann, *Blood Transfusion Centre, Royal Infirmary, Edinburgh, UK*

J. A. McIntyre, *Department of Obstetrics and Gynaecology, Southern Illinois School of Medicine, Springfield, Ill, USA*

Judith A. MacKay, *Department of Allergy and Clinical Immunology, Cardiothoracic Institute, London, UK*

Rose A. Mage, *Laboratory of Immunology, National Institute of Allergy and Infectious Diseases, Bethesda, Md, USA*

O. Mäkelä, *Department of Bacteriology and Immunology, University of Helsinki, Helsinki, Finland*

Phillipa Marrack, *Department of Medicine, National Jewish Hospital and Research Center, Denver, Co. USA*

Olivia Martinez, *Department of Microbiology and Immunology, University of California, Berkeley, Ca, USA*

D. W. Mason, *MRC Cellular Immunology Unit, Sir William Dunn School of Pathology, University of Oxford, Oxford, UK*

R. Melvold, *Dept of Microbiology and Immunology, Northwestern University Medical School, Chicago, Ill, USA*

T. G. Merrett, *RAST Allergy Unit, Benenden Chest Hospital, Cranbrook, Kent, UK*

H. S. Micklem, *Department of Zoology, University of Edinburgh, Edinburgh, UK*

R. G. Miller, *Ontario Cancer Institute, University of Toronto, Toronto, Ontario, Canada*

S. D. Miller, *Department of Microbiology Immunology, The Medical and Dental Schools, Ill, Northwestern University, Chicago, USA*

C. Milstein, *Laboratory of Molecular Biology, Medical Research Council The Medical School, Cambridge, UK*

G. F. Mitchell, *Laboratory of Immunoparasitology, The Walter and Eliza Hall Institute of Medical Research, Royal Melbourne Hospital, Victoria, Australia*

W. A. Moore, *Department of Genetics, Stanford University School of Medicine, Stanford, Ca, USA*

Sherie L. Morrison, *Department of Microbiology Columbia University College of Physicians and Surgeons, New York, NY, USA*

D. B. Murphy, *Department of Pathology, Yale University, New Haven, Conn, USA*

R. M. Nakamura, *Department of Pathology, Scripps Clinic and Research Foundation, La Jolla, Ca, USA*

Y. Nakao, *Department of Medicine, University of Kobe, Japan*

C. J. Newby, *Department of Genetics, Stanford University Medical School, Stanford, Ca, USA*

L. A. Nilsson, *Department of Medical Microbiology, University of Gothenburg, Gothenburg, Sweden*

G. J. V. Nossal, *Walter and Eliza Hall Institute of Medical Research, Royal Melbourne Hospital, Victoria, Australia*

V. Oi, *Becton Dickinson Monoclonal Center, Mountain View, Ca, USA*

K. Okumura, *Department of Immunology, Juntendo University, Tokyo, Japan*

Ö. Ouchterlony, *Department of Medical Microbiology, University of Gothenborg, Gothenburg, Sweden*

Z. Ovary, *Department of Pathology, New York University Medical Center, New York, NY, USA*

W. Page Faulk, *Medi-Search AG, Meiringen, Switzerland*

P. Parham, *Department of Cell Biology, Stanford University School of Medicine, Stanford, Ca, USA*

D. R. Parks, *Department of Genetics, Stanford University School of Medicine, Stanford, Ca, USA*

M. Parson, *Department of Genetics, Stanford University School of Medicine, Stanford, Ca, USA*

T. W. Pearson, *Department of Biochemistry and Microbiology, University of Victoria, BC, Canada*

N. O. Petersen, *Department of Chemistry, University of Western Ontario, London, Ontario, Canada*

M. Potter, *Laboratory of Genetics, National Cancer Institute, Bethesda, Md, USA*

I. R. Poxton, *Department of Bacteriology, University Medical School, Edinburgh, UK*

A. Radbruch, *Institute of Genetics, University of Cologne, Cologne, Federal Republic of Germany*

P. Ralph, *Department of Cell Biology, Cetus Corporation, Emeryville, Ca, USA*

K. Rajewsky, *Institute of Genetics, University of Cologne, Cologne, Federal Republic of Germany*

U. Ramstedt, *Department of Immunology, Karolinska Institute, Stockholm, Sweden*

Elizabeth Raveche, *National Institute of Health, Bethesda, Md, USA*

L. F. Reichardt, *Department of Neurology, University of California, San Francisco, Ca, USA*

J. Reidler, *Department of Cell Biology, Stanford University School of Medicine, Stanford, Ca, USA*

R. Riblet, *Department of Immunology, Medical Biology Institute, La Jolla, Ca, USA*

J. M. Robinson, *Department of Pathology, Harvard Medicol School, Poston, Mass., USA*

F. S. Rosen, *Division of Immunology, Children's Hospital Medical Center, Boston, Mass, USA*

R. V. Rouse, *Department of Pathology, Stanford University School of Medicine, Stanford, Ca, USA*

F. A. Ruddle, *Department of Biology, Yale University, New Haven, Conn, USA*

T. Sasazuki, *Department of Genetics, Medical Institute of Bioregulation, Kyushu University, Fukuoka, Japan*

M. S. Schanfield, *Genetic Testing Institute, Atlanta, Georgia, USA*

Beatrice C. Seegal, *Department of Microbiology, College of Physicians and Surgeons of Columbia University, New York, NY, USA*

M. Sela, *Department of Chemical Immunology, The Weizmann Institute of Science, Rehovot, Israel*

I. J. T. Seppälä, *Department of Bacteriology and Immunology, University of Helsinki, Helsinki, Finland*

E. E. Sercarz, *Department of Microbiology, University of California, Los Angeles, Ca, USA*

Eva Severinson, *Department of Immunobiology, Karolinska Institute, Stockholm, Sweden*

N. Shastri, *Department of Microbiology, University of California, Los Angeles, Ca, USA*

J. F. L. Shaw, *Department of Surgery, University of Cambridge, Cambridge, UK*

S. C. Silverstein, *Laboratory of Cellular Physiology and Immunology, The Rockefeller University, New York, NY, USA*

R. J. Shaw, *Department of Allergy and Clinical Immunology, Cardiothoracic Institute, London, UK*

K. Simonovitch, *Department of Immunology, Toronto Western Hospital, Ontario, Canada*

Elizabeth Simpson, *Transplantation Biology Section, Clinical Research Centre, Harrow, UK*

L. Smith, *Division of Biology, California Institute of Technology, Pasadena, Ca, USA*

E. J. L. Soulsby, *Department of Clinical Veterinary Medicine, University of Cambridge, UK*

D. M. Spalding, *Division of Clinical Immunology and Rheumatology, University of Alabama in Birmingham, Birmingham, Alabama, USA*

T. A. Springer, *Dana Farber Cancer Institute, Harvard Medical School, Boston, Mass, USA*

D. R. Stanworth, *Department of Immunology, University of Birmingham, Birmingham, UK*

Phyllis M. Starkey, *Sir William Dunn School of Pathology, University of Oxford, Oxford, UK*

A. D. Steinberg, *National Institute of Health, Bethesda, Md, USA*

R. M. Steinman, *Laboratory of Cellular Physiology, and Immunology, The Rockefeller University, New York, NY, USA*

M. Steinmetz, *Basel Institute for Immunology, Basel, Switzerland*

M. W. Steward, *Department of Medical Microbiology, London School of Hygiene and Tropical Medicine, London, UK*

C. C. Stewart, *Experimental Pathology Group, Los*

Alamos National Laboratory, Los Alamos, New Mexico, USA

J. Stewart, *Department of Bacteriology, University of Edinburgh, Edinburgh, UK*

E. J. Stott, *Institute for Research on Animal Diseases, Newbury, Berkshire, UK*

T. Tada, *Department of Immunology, University of Tokyo, Tokyo, Japan*

N. Takemura, *Medical Research Institute, Tokyo Medical and Dental University, Tokyo, Japan*

R. Takemura, *Laboratory of Radiobiology and Environmental Health, University of California, San Francisco, Ca, USA*

M. Taniguchi, *Department of Immunology, Chiba University, Chiba, Japan*

Glenys Thomson, *Department of Genetics, University of California, Berkeley, Ca, USA*

P. W. Tucker, *Department of Microbiology, University of Texas, Southwestern Medical School, Dallas, Texas, USA*

T. Tokuhisa, *Department of Immunology, Chiba University, Chiba, Japan*

M. W. Turner, *Department of Immunology, Institute of Child Health, London, UK*

D. A. J. Tyrrell, *MRC Common Cold Unit, Harvard Hospital, Salisbury, Wiltshire, UK*

E. R. Unanue, *Department of Pathology, Harvard Medical School, Boston, Mass, USA*

J. Unkeless, *The Rockefeller University, New York, NY, USA*

R. J. Urbaniak, *Aberdeen and North East of Scotland Blood Transfusion Service, Aberdeen, UK*

E. E. Uzgiris, *Department of Cell Biology, Stanford University School of Medicine, Stanford, Ca, USA*

Karen L. Valentino, *Department of Physiology, University of California School of Medicine, San Francisco, Ca, USA*

R. van Furth, *Department of Infectious Diseases, University Hospital, Leiden, The Netherlands*

E. van Loghem, *The Netherlands Red Cross Blood Transfusion Service, Amsterdam, The Netherlands*

W. C. van Voorhis, *Laboratory of Cellular Physiology, The Rockefeller University, New York, NY, USA*

Theda L. van Zwet, *Department of Infectious Diseases, University Hospital, Leiden, The Netherlands*

A. Voller, *Nuffield Laboratories of Comparative Medicine, Zoological Society of London, London, UK*

C. Waltenbaugh, *Department of Microbiology-Immunology, Northwestern University, Chicago, Il, USA*

R. A. Warnke, *Department of Pathology, Stanford University Medical School, Stanford, Ca, USA*

D. M. Weir, *Department of Bacteriology, University of Edinburgh, Edinburgh, UK*

Zena Werb, *Laboratory of Radiobiology and Environmental Health, University of California, San Francisco, Ca, USA*

G. Whalen, *Laboratory of Immunoregulation, National Institute of Health, Md, USA*

A. G. White, *Department of Surgery, Faculty of Medicine, Kuwait University, Kuwait*

D. J. G. White, *Department of Surgery, University of Cambridge, Cambridge, UK*

H. Wigzell, *Department of Immunology, Karolinska Institute, Stockholm, Sweden*

P. C. Wilkinson, *Department of Bacteriology and Immunology, University of Glasgow, Glasgow, UK*

A. F. Williams, *MRC Cellular Immunology Unit, Sir William Dunn School of Pathology, University of Oxford, Oxford, UK*

F. P. Winstanley, *Armed Services University, Washington, DC, USA*

Janet Winter, *Department of Physiology, University of California, San Francisco, Ca, USA*

L. Wofsy, *Department of Microbiology and Immunology, University of California, Berkeley, Ca, USA*

S. D. Wright, *Laboratory of Cellular Physiology and Immunology, The Rockefeller University, New York, NY, USA*

M. Zauderer, *Department of Microbiology and Oncology, University of Rochester, Rochester, NY, USA.*

D. Zelaschi, *Department of Genetics, Stanford University School of Medicine, Stanford, Ca, USA*

Preface

The pace of progress in immunology has not slackened since the last edition of this handbook. The subject now draws heavily on molecular biology and genetics and this has necessitated the inclusion of an additional volume on **Genetics and Molecular Immunology**. The explosion in the development of hybridoma technology and cell culture, since the last edition, can be seen from the many chapters in each volume that employ monoclonal reagents and cell lines. Some idea of the expansion of the field can be gained from the **Cellular Immunology** volume where contributions on phagocytes and lymphocytes now occupy 30 chapters compared to 12 in the previous edition. A new section on immunoregulation contains 14 chapters and there are now 6 chapters devoted to mammalian cell membrane antigens in the **Immunochemistry** volume.

It is now no longer possible for one editor to keep in touch with the enormous expansion in this field, and I am much indebted to my co-editors Len and Leonore Herzenberg who have joined me in the task of co-opting research workers in the wide range of disciplines now contributing to the field of immunology. I am particularly grateful to my wife Dr Caroline Blackwell for her help with the massive editing task.

Amongst the many new features of this edition is the provision of overviews for many of the sections. I am most grateful to our contributors in the methodology sections for their efforts to achieve a consistent style of presentation of the procedures, and I hope that this will help in the accessibility of the descriptive material. A work of this size inevitably takes a number of years to put together but considerable effort has gone into introducing up to date material into the chapters. This has been achieved by enabling and encouraging contributors to introduce new material and references during the proof stages of their chapters.

I wish to thank Hilary Flenley for her careful and thorough index, and Nigel Palmer and his staff at Blackwell Scientific Publications Edinburgh office without whom production of the new edition would have been impossible. Per Saugman has as always, maintained a benevolent paternal interest in the project.

D.M.W.

Contents

List of contributors xi
Preface xvii

VOLUME 2
CELLULAR IMMUNOLOGY

Phagocytes

41 Overview: The function of receptors in phagocytosis
S. D. WRIGHT AND S. C. SILVERSTEIN

42 Overview: The mononuclear phagocyte system
R. VAN FURTH

43 Plasma membrane markers to study differentiation, activation and localization of murine macrophages. Ag F4/80 and the mannosyl, fucosyl receptor
S. GORDON, PHYLLIS M. STARKEY, D. HUME, R. A. B. EZEKOWITZ, S. HIRSCH AND J. AUSTYN

44 Methods for studying the ontogeny of mononuclear phagocytes
C. C. STEWART

45 Macrophage cell lines
P. RALPH

46 *In vitro* determination of phagocytosis and intracellular killing by polymorphonuclear and mononuclear phagocytes
P. C. J. LEIJH, R. VAN FURTH AND THEDA L. VAN ZWET

47 Secreted proteins of resting and activated macrophages
ZENA WERB, M. J. BANDA, R. TAKEMURA AND S. GORDON

48 Macrophage membrane receptors
J. STEWART, ELIZABETH J. GLASS, D. M. WEIR AND M. R. DAHA

49 Dendritic cells
R. M. STEINMAN, W. C. VAN VOORHIS AND D. M. SPALDING

50 Reduction and excitation of oxygen by phagocytic leukocytes: biochemical and cytochemical techniques
J. A. BADWEY, J. M. ROBINSON, M. J. KARNOVSKY AND M. L. KARNOVSKY

51 Locomotion and chemotaxis of leukocytes
P. C. WILKINSON

52 Assays for phagocyte ecto-enzymes
P. J. EDELSON

The lymphoid system

53 Overview: Lymphocytes and their relations
H. S. MICKLEM

54 Physical methods for separation of lymphocyte subpopulations
R. G. MILLER

55 Preparative immunoselection of lymphocyte populations
S. V. HUNT

56 Genetic markers for following cell populations
J. D. ANSELL AND H. S. MICKLEM

57 Following cellular traffic: methods of labelling lymphocytes and other cells to trace their migration *in vivo*
E. C. BUTCHER AND W. L. FORD

58 Human leukocyte subpopulations
P. BEVERLEY

59 Lymphokines
J. KAPPLER AND PHILLIPA MARRACK

60 Natural killer cells
H. WIGZELL AND U. RAMSTEDT

61 Genetics and cell distributions of mouse cell surface alloantigens
LORRAINE FLAHERTY AND J. FORMAN

Lymphocyte responses

62 Overview: Lymphocyte responses
G. J. V. NOSSAL

63 Lymphocyte responses to polyclonal B and T cell activators
EVA SEVERINSON AND EVA-LOTTA LARSSON

64 Assays for immunoglobulin-secreting cells
D. W. DRESSER

65 Limiting dilution analysis of effector cells and their precursors *in vitro*
M. ZAUDERER

66 *In vitro* evaluation of human lymphocyte function
H. C. LANE, GAIL WHALEN AND A. S. FAUCI

67 Assay for *in vivo* adoptive immune response
G. M. IVERSON

68 Analysis of cytotoxic T cell responses
ELIZABETH SIMPSON AND P. CHANDLER

69 T cell lines and hybrids in mouse and man
C. G. FATHMAN AND E. G. ENGLEMAN

70 B cell growth factors
MAUREEN HOWARD

Immunoregulation

71 Overview: Helper and suppressor T cells
K. OKUMARA AND T. TADA

72 Overview: Ir genes
B. BENACERRAF

73 Overview: Idiotypic regulation
K. RAJEWSKY

74 Overview: Epitope-specific regulation
LEONORE A. HERZENBERG

75 Overview: T cell clones
H. CANTOR

76 Subtractive cDNA hybridization and the T-cell receptor genes
M. M. DAVIS

77 Detection of suppressor cells and suppressor factors for delayed-type hypersensitivity responses
S. D. MILLER AND M. K. JENKINS

78 Detection of suppressor cells and suppressor factors for antibody responses
C. WALTENBAUGH AND B. S. KIM

79 Contrasuppressor T cells: a practical guide to the identification of contrasuppressive effects in immunoregulatory systems
D. R. GREEN

80 Antigen-specific suppressor molecules produced by T cells
M. TANIGUCHI AND T. TOKUHISA

81 Immunosuppressive agents
D. J. G. WHITE AND J. F. L. SHAW

82 Studies of autoimmune diseases
ELIZABETH S. RAVECHE AND A. D. STEINBERG

83 Primary immunodeficiencies: definitions and diagnosis
F. S. ROSEN

84 Studying immune regulation with protein and peptide antigens
N. SHASTRI AND E. E. SERCARZ

VOLUME 1
IMMUNOCHEMISTRY

Antigens

1 Overview: Antigens
M. SELA

2 Preparation of synthetic antigens
M. SELA AND SARA FUCHS

3 Haptens and carriers
O. MÄKELÄ AND I. J. T. SEPPÄLÄ

4 Isolation and identification of bacterial antigens
I. R. POXTON AND C. CAROLINE BLACKWELL

5 Preparation of viral antigens
C. J. BURRELL

6 Antigens of parasites
T. W. PEARSON AND M. W. CLARK

7 Fungal antigens
JOAN L. LONGBOTTOM AND P. K. C. AUSTWICK

8 Immunization of experimental animals
D. W. DRESSER

9 Carbohydrate antigens in higher animals
S. HAKOMORI AND R. KANNAGI

10 The chemistry and standardization of allergens
S. DREBORG, R. EINARSSON, JOAN L. LONGBOTTOM

Immunoglobulins: Purification and characterization

11 Overview: The quest for antibody homogeneity: the *sine qua non* for structural and genetic insights into antibody complementarity
E. A. KABAT

12 Immunochemical analysis of human and rabbit immunoglobulins and their subunits
D. R. STANWORTH AND M. W. TURNER

13 Purification and characterization of monoclonal antibodies
R. R. HARDY

14 Preparation and purification of active fragments from mouse monoclonal antibodies
P. PARHAM

15 Determination of the three-dimensional structures of immunoglobulins
A. B. EDMUNDSON AND KATHERYN R. ELY

16 Immunoadsorbants
SARA FUCHS AND M. SELA

17 Two-dimensional crystals of immunoglobulins
J. REIDLER, E. E. UZGIRIS AND R. D. KORNBERG

18 Sources of myeloma proteins, and M-components
M. POTTER

Mammalian cell membrane antigens

19 Overview: Mammalian cell surface antigens
R. D. KORNBERG

20 Membrane and secretory immunoglobulins: structure, biosynthesis and assembly
J. W. GODING

21 Class I MHC antigens of mouse and humans
J. E. COLIGAN AND T. J. KINDT

22 Glycoprotein antigens of the lymphocyte surface and their purification by antibody affinity chromatography
A. F. WILLIAMS AND A. N. BARCLAY

23 Immunofluorescence methods to study cell surface and cytoplasic proteins, and their dynamics
E. R. UNANUE AND J. BRAUN

24 Measurement of lateral diffusion by fluorescence photobleaching recovery
N. O. PETERSEN, S. FELDER AND E. L. ELSON

Antibody interaction with soluble and cellular antigens

25 Overview: Introduction to methods used to study the affinity and kinetics of antibody-antigen reactions
M. W. STEWARD

26 Radioimmunoassays and related methods
A. E. BOLTON AND W. M. HUNTER

27 Enzyme immunoassays: heterogenous and homogeneous systems
R. M. NAKAMURA, A. VOLLER AND D. E. BIDWELL

28 Preparation and use of fluorochrome conjugates
G. D. JOHNSON AND E. J. HOLBOROW

29 Flow cytometry and fluorescence activated cell sorting (FACS)
D. R. PARKS, L. L. LANIER AND L. A. HERZENBERG

30 Data analysis in flow cytometry
W. A. MOORE AND R. A. KAUTZ

31 Purification and coupling of fluorescent proteins for use in flow cytometry
R. R. HARDY

32 Immunodiffusion and immunoelectrophoresis
Ö. OUCHTERLONY AND L.-Å. NILSSON

33 Passive cutaneous anaphylaxis
Z. OVARY

34 Solid-phase radioimmune assays
C. J. NEWBY, K. HAYAKAWA AND LEONORE A. HERZENBERG

35 Immunological techniques for the identification of antigens and antibodies by electron microscopy
G. A. ANDRES, K. C. HSU AND BEATRICE C. SEGAL

36 Affinity targeting and fusion of vesicles to cells
W. GODFREY, J. GUYDEN AND L. WOFSY

37 Immunotoxins
OLIVIA MARTINEZ AND L. WOFSY

38 Kinetics of antibody reaction and the analysis of cell surface antigens
D. W. MASON AND A. F. WILLIAMS

Complement

39 Complement technology
R. A. HARRISON AND P. J. LACHMANN

40 Complement fixation by monoclonal antigen-antibody complexes
R. R. HARDY

VOLUME 3
GENETICS AND MOLECULAR IMMUNOLOGY

Molecular approaches to immunology

85. Overview: Introductory comments on molecular immunology
D. BALTIMORE

86 Construction and screening of recombinant DNA libraries in bacteriophage lambda
P. W. TUCKER

87 The major histocompatibility complex of the mouse
L. SMITH, M. STEINMETZ AND L. HOOD

88 The murine immunoglobulin heavy chain constant region gene locus
N. M. GOUGH AND SUZANNE CORY

89 The Igh-V genes of the mouse
R. RIBLET AND P. H. BRODEUR

90 Classification of mouse V_H sequences
RENATE DILDROP

91 Transfection for lymphocyte cell surface antigens
PAULA KAVATHAS AND L. A. HERZENBERG

92 Lymphoid cell gene transfer
SHERIE L. MORRISON AND V. T. OI

Immunoglobulin genetics

93 Overview: Allotypes
H. H. FUDENBERG

94 Human immunoglobulin allotypes
M. S. SCHANFIELD AND ERNA VAN LOGHEN

95 New methods for human allotyping
D. ZELASCHI, M. J. JOHNSTON, C. J. NEWBY AND LEONORE A. HERZENBERG

96 Gm and disease
Y. NAKAO AND T. SASAZUKI

97 Mouse immunoglobulin allotypes
MARILYN PARSON, LEONORE A. HERZENBERG, A. M. STALL AND L. A. HERZENBERG

98 Rat immunoglobulin allotypes
G. A. GUTMAN

99 Rabbit immunoglobulin allotypes
ROSE G. MAGE

Genetics of the major histocompatibility complex

100 Overview: The murine MHC
D. B. MURPHY

101 The MHC of the laboratory rat, *Rattus norvegicus*
G. W. BUTCHER AND J. C. HOWARD

102 Human HLA genetics and disease associations
GLENYS THOMSON

103 Common assays for identifying immune response genes
C. WALTENBAUGH AND S. D. MILLER

Resources

104 The mouse linkage map
MARGARET C. GREEN

105 Sonatic cell genetics and the human gene map
M. E. KAMARCK AND F. H. RUDDLE

106 Inbred, congenic, recombinant-inbred and mutant mouse strains
R. W. MELVOLD

VOLUME 4
APPLICATIONS OF IMMUNOLOGICAL METHODS IN BIOMEDICAL SCIENCES

Monoclonal antibodies

107 Overview: Monoclonal antibodies
C. MILSTEIN

108 Schemata for the production of monoclonal antibody-producing hybridomas
T. J. KIPPS AND L. A. HERZENBERG

109 Hybridoma immunoglobulin isotype switch variant selection with the fluorescence activated cell sorter
T. J. KIPPS AND L. A. HERZENBERG

110 Isotype switch variants
A. RADBRUCH

111 Growing hybridoma and producing monoclonal antibodies *in vivo*
K. OKUMURA AND S. HABU

Applications: Monoclonal Antibodies

112 Neurobiology
JANET WINTER, KAREN L. VALENTINO AND L. F. REICHARDT

113 Monoclonal antibodies in the study of parasites and host-parasite relationships
E. HANDMAN AND G. F. MITCHELL

114 Application of monoclonal antibodies in bacteriology
C. CAROLINE BLACKWELL AND F. P. WINSTANLEY

115 Applications of monoclonal antibodies in virology
W. GERHARDT AND T. BACHI

116 Special applications of tissue section immunologic staining in the characterization of monoclonal antibodies and in the study of normal and neoplastic tissues
R. V. ROUSE AND R. A. WARNKE

117 Monoclonal antibodies directed to carbohydrate antigens
R. KANNAGI AND S. HAKOMORI

118 Macrophages
J. C. UNKELESS AND T. A. SPRINGER

Applications: Immunological methods

119 Application of immunological techniques in bacteriology
F. P. WINSTANLEY AND C. CAROLINE BLACKWELL

120 Application of immunological methods in virology
E. J. STOTT AND D. A. J. TYRRELL

121 Applications of immunological methods in mycology
JOAN L. LONGBOTTOM

122 Applications of immunological methods in protozoology
E. H. R. LUMSDEN

123 Applications of immunological methods in helminthology
W. J. L. SOULSBY AND SHEELAGH LLOYD

124 Immunological aspects of human pregnancy
J. A. MACINTYRE AND W. PAGE FAULK

125 Applications of immunological techniques to the study of the tumour-host relationship
G. J. DOUGHERTY, C. A. ALLEN AND NANCY M. HOGG

Additional clinical applications of immunological methods

126 Tests of immune function
S. J. URBANIAK, M. C. MCCANN, A. G. WHITE, G. R. BARCLAY AND A. B. KAY

127 Provocation tests and measurements of mediators from mast cells and basophils in asthma and allergic rhinitis
O. CROMWELL, S. R. DURHAM, R. J. SHAW, JUDITH A. MACKAY AND A. B. KAY

128 Methods for detecting immune complexes in biological fluids
M. H. KLEIN AND K. SIMINOVITCH

129 Immunohistochemistry in pathology
EADIE HEYDERMAN, I. STRUDLEY AND T. C. RICHARDSON

130 Quantification of IgE and IgG4 both as total immunoglobulins and as allerge-specific antibodies
T. G. MERRETT

General methods for immunologic studies

131 Statistical aspects of planning and design of immunological experiments
R. A. ELTON AND W. H. MCBRIDE

132 Guidelines to statistical analysis
W. LUTZ

133 Laboratory animal techniques for immunology
W. J. HERBERT, F. KRISTENSEN, with RUTH M. AITKEN, M. B. ESLAMI, ANNE FERGUSON, KATHLEEN G. GRAY, W. J. PENHALE

Index to Volume 2 xix

Chapter 41
Overview: the function of receptors in phagocytosis

S. D. WRIGHT & S. C. SILVERSTEIN

The attachment step, 41.1
Receptors function independently of one another, 41.3
Engulfment, 41.3
Cytoskeletal proteins, cell motility, and the energetics of phagocytosis, 41.5
Transmembrane signals, 41.6
Fc receptors are constitutively active, 41.6
Some problems and strategies in the study of the roles of receptors in phagocytosis, 41.9

Mononuclear phagocytes together with polymorphonuclear leucocytes comprise the most numerous classes of phagocytic cells in higher organisms. Rabinovitch has termed these cells 'professional' phagocytes because they have made a full-time occupation out of eating. Leucocytes are not the only 'professional' phagocytes in the body. The pigmented epithelial cells of the retina phagocytose the fragments of rod outer segments that are shed daily by the rod cells [1]. Thus being a professional phagocyte is not a unique property of motile cells of haematopoietic (mesenchymal) origin.

A role for phagocytosis in antimicrobial defence has been recognized since the time of Metchnikoff [2]. Less widely appreciated is the role phagocytosis plays in homoeostatic functions such as the turnover of surfactant in the lung [3], and the removal of senescent erythrocytes [4]. In each of these instances, the material to be removed is specifically and selectively phagocytosed without apparent injury to neighbouring cells and tissues. The authors believe that this specificity is a consequence of receptor–ligand interactions that govern the ingestion process.

Macrophages have on their plasma membranes binding sites for more than forty ligands (Table 41.1). Receptors of defined molecular weight and subunit composition have been identified for a few of these ligands (e.g. IgG [5], complement [6,7]). The presence of specific receptor proteins for the remaining ligands is inferred by their specific and saturable binding to leucocytes and by the inability of other ligands to compete for binding.

At present, only a few of these receptors (i.e. those for IgG, complement, oligosaccharides) are known to promote ingestion of particles. It seems unlikely that the remaining receptors play a major role in phagocytosis since their ligands are soluble and bind poorly to micro-organisms or other particulate matter. (Fibronectin is a special case and will be discussed later in this chapter.) For this reason, the authors have focussed on mechanisms by which IgG, complement, and oligosaccharides promote phagocytosis. Implicit in their discussion is the assumption that uptake of all particulate materials by phagocytic leucocytes, be they latex beads or IgG-coated bacteria, is governed by receptor–ligand interactions; and that the general principles established in studies of the uptake of IgG-, complement-, or oligosaccharide-coated particles will be broadly applicable to other receptor–ligand systems.

The attachment step

Phagocytosis can be divided both conceptually and experimentally into a series of processes that culminate in the total engulfment of a particle. The first step in this series is the attachment of the particle to the phagocyte's surface [8]. In general, attachment occurs over a broad temperature range and independently of the expenditure of metabolic energy by the phagocyte. Engulfment, on the other hand, is strictly dependent on cellular metabolism and is entirely halted at temperatures below 18–20 °C [9,10]. Particles coated with some ligands (e.g. complement) bind more efficiently to their corresponding receptors at 37 °C than at 4 °C; particles coated with other ligands, such as IgG, bind with roughly equal efficiency at both temperatures.

Attachment *per se* does not predestine the particle for ingestion. Erythrocytes or smooth encapsulated bacteria can be bound to the surfaces of phagocytic leucocytes with concanavalin A [11], $F(ab)_2$ antibody fragments [12], fibronectin [13], or complement [14,15], and will remain on the phagocyte's surface for

Table 41.1. Receptors on the surface of macrophages[1]

Ligand	Name of receptor (if different from ligand)	Comments	Reference
Receptors that constitutively promote phagocytosis			
IgG_{2a}	FcRI	Murine	[5]
$IgG_{1,2b}$	FcRII	Murine	[5]
IgG_3		Murine	[5]
IgG_1	$Fc_\gamma R_{hi}$	Human	[86]
Immune complexes	$Fc_\gamma R_{lo}$	Human	[86]
IgE			[87]
Mannose/GlcNAc-containing oligosaccharides			[88]
Galactose-containing oligosaccharides			[4]
Receptors that promote phagocytosis in a regulated fashion			
C3b and C4b	CR1	Also inhibits complement enzymes	[6]
C3bi	CR3		[7]
C3d and C3dg	CR2		[57]
Receptors for fast-acting regulators			
Fibronectin			[13]
Serum amyloid P component			[60]
'lymphokine'		Secreted by lymphocytes in response to a factor from phagocytosing macrophages	[58]
Insulin			[89]
Adrenalin			[90]
Histamine			[91]
Somatomedin			[92]
Calcitonin			[93]
Parathormone			[93]
Receptors for long-term regulators			
γ-Interferon (macrophage activating factor)			[94]
Colony stimulating factor			[95]
Receptors that mediate pinocytic uptake of ligands			
α_2Macroglobulin–protease complex			[96]
LDL			[97]
Acetyl-LDL			[97]
VLDL			[98]
Transferrin			[99]
(Receptors for Fc, C3, and oligosaccharides also mediate pinocytosis)			
Receptors for chemoattractants			
Formyl-methionyl-leucyl-phenylalanine			[100]
C5a			[100]
Thrombin			[101]
Miscellaneous receptors			
Elastase			[102]
Lactoferrin			[103]
Fibrin			[104]
Tumour cell		Presumed to exist because 'activated' macrophages bind tumour cells	[105]
C1q			[106]

[1] It should be noted that for each ligand there may be multiple distinct receptors. Additional surface proteins that may be receptors are described in Table 118.1 in the chapter by Unkeless & Springer.

several hours at 37 °C. That these particles can be ingested is evident when IgG directed against the surface of the particle is added to the cultures. Under these conditions the particles are ingested [16,17]. These results indicate that signals generated by the ligation of specific membrane receptors are required to promote internalization.

Receptors function independently of one another

Phagocytosis-promoting receptors diffuse freely in the plane of the plasma membrane [18,19] and function independently of one another in mediating particle ingestion. For example, macrophages that are functionally depleted of Fc receptors after spreading on IgG-coated surfaces still phagocytose via their receptors for C3 and for oligosaccharides; conversely, macrophages whose complement receptors have been depleted by spreading on a complement-coated surface or inactivated by treatment with proteolytic enzymes still phagocytose via their Fc receptors [18]. Moreover, signals generated via one class of phagocytosis-promoting receptors are not transmitted to other classes of phagocytosis-promoting receptors on the same cell. For example, ligation of macrophage Fc receptors does not stimulate complement receptor function [18]. Nevertheless, two receptors may complement one another if ligands for each are present on a single particle. Ehlenberger & Nussenzweig [20] reported that erythrocytes bearing complement and a limiting number of IgG molecules are phagocytosed to a greater extent than erythrocytes bearing the same number of IgG molecules alone. Under the conditions of their experiment, complement receptors were unable to promote ingestion. However, attachment is the rate limiting step in Fc-receptor mediated phagocytosis [21]. Thus ligands that enhance attachment such as complement thereby enhance the efficiency of interaction of ingestion-promoting ligands, such as IgG with their corresponding receptors.

Engulfment

Generation of a signal that promotes membrane internalization, as occurs when Fc receptors are ligated, produces a membrane response that is restricted to the segments of membrane in contact with the particle initiating the signal [16]. The advancing pseudopods adhere closely to the surface of the particle (Fig. 41.1), even to the point of enveloping each particle in a separate vacuole. These and other observations led Griffin *et al.* [16,22] to propose a general hypothesis (the 'zipper' mechanism) to explain these findings. Essentially, the 'zipper' concept predicts that movement of a phagocyte's plasma membrane along the surface of a ligand-coated particle is governed by the availability of receptors on the surface of the phagocyte and is guided by the distribution of ligands on the surface of the particle. Several lines of evidence support this hypothesis, the most compelling of which is an experiment in which B lymphocytes were coated circumferentially or hemispherically with IgG antibodies to membrane IgM and then incubated with macrophages. Lymphocytes coated circumferentially with IgG were engulfed. Lymphocytes coated on one hemisphere with IgG were bound to the macrophages via this IgG cap, but they were not engulfed. Ultrastructural histochemistry confirmed that the macrophage membrane extends over the surface of the IgG-coated capped lymphocyte only in the areas of the IgG cap [22]. Thus, engulfment requires the sequential and circumferential interaction of receptors on the surface of the phagocyte with corresponding ligands on the surface of the particle.

Scanning electron micrographs of the engulfment of IgG-coated erythrocytes by macrophages show that these phagocytes extend several broad, relatively flat pseudopods over the particle. As these pseudopods advance they form a smooth cup-like structure whose rim ultimately covers the entire particle. There is no evidence that these advancing pseudopods fuse with one another; rather, formation of the phagocytic cup involves considerable membrane flow and remodelling such that the final event in closure of the phagocytic vacuole is the fusion of membranes over a small hole (punctum) at the point where the advancing pseudopods meet [23]. Thus the extent of membrane fusion required to close a phagocytic vacuole may be no greater than that required to close a pinocytic vesicle.

Within a span of 15–30 min macrophages can ingest sufficient particles to cause the interiorization of 30–40% of their total surface area. These cells have large internal stores of plasma membrane (perhaps as much as two-fold the amount of the surface [24,25]) and the authors presume that these internal membrane stores are inserted into the cell surface to replace plasma membrane interiorized with the ingested particles. Such redistribution of membrane from internal stores to the cell surface has been shown to accompany phagocytosis in amoebae [26,27] and in leucocytes [28], and may explain the constancy of plasma membrane composition in phagocytosing leucocytes suggested by the experiments of Tsan & Berlin [29] over a decade ago.

Cohn, Hubbard, Steinman and their associates [10,30,31] have made imaginative use of lactoperoxidase (LPO) catalysed surface iodination to examine the surface proteins incorporated into the membrane of the phagosome. These investigators labelled the surface membranes of fibroblasts [31,32] and macro-