Glaucoma

Last major revision 2016–2017
The American Academy of Ophthalmology is accredited by the Accreditation Council for Continuing Medical Education (ACCME) to provide continuing medical education for physicians.

The American Academy of Ophthalmology designates this enduring material for a maximum of 10 AMA PRA Category 1 Credits™. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

CME expiration date: June 1, 2019. AMA PRA Category 1 Credits™ may be claimed only once between June 1, 2016, and the expiration date.

BCSC® volumes are designed to increase the physician’s ophthalmic knowledge through study and review. Users of this activity are encouraged to read the text and then answer the study questions provided at the back of the book.

To claim AMA PRA Category 1 Credits™ upon completion of this activity, learners must demonstrate appropriate knowledge and participation in the activity by taking the posttest for Section 10 and achieving a score of 80% or higher. For further details, please see the instructions for requesting CME credit at the back of the book.

The Academy provides this material for educational purposes only. It is not intended to represent the only or best method or procedure in every case, nor to replace a physician's own judgment or give specific advice for case management. Including all indications, contraindications, side effects, and alternative agents for each drug or treatment is beyond the scope of this material. All information and recommendations should be verified, prior to use, with current information included in the manufacturers’ package inserts or other independent sources, and considered in light of the patient's condition and history. Reference to certain drugs, instruments, and other products in this course is made for illustrative purposes only and is not intended to constitute an endorsement of such. Some material may include information on applications that are not considered community standard, that reflect indications not included in approved FDA labeling, or that are approved for use only in restricted research settings. The FDA has stated that it is the responsibility of the physician to determine the FDA status of each drug or device he or she wishes to use, and to use them with appropriate, informed patient consent in compliance with applicable law. The Academy specifically disclaims any and all liability for injury or other damages of any kind, from negligence or otherwise, for any and all claims that may arise from the use of any recommendations or other information contained herein.

AAO, AAOE, American Academy of Ophthalmology, Basic and Clinical Science Course, BCSC, EyeCare America, EyeNet, EyeSmart, EyeWiki, Focal Points, IRIS, ISRS, OKAP, ONE, Ophthalmic Technology Assessments, Ophthalmology, Preferred Practice Pattern, ProVision, SmartSight, The Ophthalmic News & Education Network, and the AAO logo (shown on cover) and tagline (Protecting Sight. Empowering Lives.) are, among other marks, the registered trademarks and trademarks of the American Academy of Ophthalmology.

Cover image: From BCSC Section 5, Neuro-Ophthalmology. Fundus photograph showing an arteriovenous malformation (racemose angioma) of the retina in a patient with Wyburn-Mason syndrome. (Courtesy of Mark J. Greenwald, MD.)

Copyright © 2017 American Academy of Ophthalmology. All rights reserved. No part of this publication may be reproduced without written permission.

Printed in the United States of America.
Basic and Clinical Science Course

Louis B. Cantor, MD, Indianapolis, Indiana, Senior Secretary for Clinical Education
Christopher J. Rapuano, MD, Philadelphia, Pennsylvania, Secretary for Lifelong Learning and Assessment
George A. Cioffi, MD, New York, New York, BCSC Course Chair

Section 10

Faculty
Christopher A. Girkin, MD, Chair, Birmingham, Alabama
Anjali M. Bhorade, MD, St Louis, Missouri
JoAnn A. Giaccone, MD, Los Angeles, California
Felipe A. Medeiros, MD, PhD, San Diego, California
Arthur J. Sit, MD, Rochester, Minnesota
Angelo P. Tanna, MD, Chicago, Illinois
Jonathan G. Crowston, MBBS, PhD, Consultant, East Melbourne, Victoria, Australia

The Academy wishes to acknowledge the American Glaucoma Society for recommending faculty members to the BCSC Section 10 committee.

The Academy also wishes to acknowledge the following committees for review of this edition:

Committee on Aging: Thomas A. Graul, MD, Lincoln, Nebraska
Vision Rehabilitation Committee: Paul I. Homer, MD, Boca Raton, Florida

Practicing Ophthalmologists Advisory Committee for Education: James A. Savage, MD, Primary Reviewer, Memphis, Tennessee; Edward K. Isbey III, MD, Chair, Asheville, North Carolina; Alice Bashinsky, MD, Asheville, North Carolina; David Browning, MD, PhD, Charlotte, North Carolina; Bradley Fouraker, MD, Tampa, Florida; Dasa Gangadhar, MD, Wichita, Kansas; Steven J. Grosser, MD, Golden Valley, Minnesota; Stephen R. Klapper, MD, Carmel, Indiana

European Board of Ophthalmology: Carlo Traverso, MD, Chair, Genoa, Italy; Gordana Sunaric Mégevand, MD, FMH, FEBO, Liaison, Geneva, Switzerland; Augusto Azuara-Blanco, PhD, FRCS(Ed), FRCOphth, Belfast, Northern Ireland; Anders Heijl, MD, PhD, Malmö, Sweden; Gabor Hollo, MD, PhD, DSc, Budapest, Hungary; Anja Tuulonen, MD, PhD, Tampere, Finland
Financial Disclosures

Academy staff members who contributed to the development of this product state that within the 12 months prior to their contributions to this CME activity and for the duration of development, they have had no financial interest in or other relationship with any entity discussed in this course that produces, markets, resells, or distributes ophthalmic health care goods or services consumed by or used in patients, or with any competing commercial product or service.

The authors and reviewers state that within the 12 months prior to their contributions to this CME activity and for the duration of development, they have had the following financial relationships:

Dr Browning: Aerpio Therapeutics (S), Alimera Sciences (C), Genentech (S), Novartis Pharmaceuticals (S), Pfizer (S), Regeneron Pharmaceuticals (S)

Dr Crowston: Alcon Laboratories (C, L), Allergan (C, L), Merck & Co (C, L), Pfizer (C, L), Polyactiva (C)

Dr Fouraker: Addition Technology (C, L), Alcon Laboratories (C, L), KeraVision (C, L), OASIS Medical (C, L)

Dr Giaconi: Allergan (C)

Dr Girkin: Carl Zeiss Meditec (S), Heidelberg Engineering (S), SOLX (S)

Dr Grosser: Ivantis (O)

Dr Heijl: Allergan (C, L), Santen (L), Zeiss (C, L, P)

Dr Hollo: Alcon (C, L), Allergan (L), Santen (C, L)

Dr Isbey: Alcon Laboratories (S), Bausch + Lomb (S)

Dr Medeiros: Alcon Laboratories (C, S), Allergan (C, S), Carl Zeiss Meditec (S), Heidelberg Engineering (S), Merck & Co (S), Reichert Technologies (S), Topcon (S)

Dr Savage: Allergan (L)

Dr Sit: AcuMEMS (S), Aerie Pharmaceuticals (S), Allergan (C), Glaukos Corporation (S), Sensimed AG (C), Sucampo Pharma Americas (C)

Dr Sunaric Mégevand: Alcon (C), Allergan (C)

Dr Tanna: Aeon Astron B.V. (C), Alcon Laboratories (C, L), Apotex (C), Merck & Co (L), Sandoz (C), Sucampo Pharmaceuticals (C), Watson Laboratories (C)

Dr Traverso: Alcon (C, L), Allergan (C), Santen (C, L), Théa (C)

*C = consultant fees, paid advisory boards, or fees for attending a meeting; L = lecture fees (honoraria), travel fees, or reimbursements when speaking at the invitation of a commercial sponsor; O = equity ownership/stock options of publicly or privately traded firms (excluding mutual funds) with manufacturers of commercial ophthalmic products or commercial ophthalmic services; P = patents and/or royalties that might be viewed as creating a potential conflict of interest; S = grant support for the past year (all sources) and all sources used for a specific talk or manuscript with no time limitation
The other authors and reviewers state that within the 12 months prior to their contributions to this CME activity and for the duration of development, they have had no financial interest in or other relationship with any entity discussed in this course that produces, markets, resells, or distributes ophthalmic health care goods or services consumed by or used in patients, or with any competing commercial product or service.

**Recent Past Faculty**
- Keith Barton, MD
- George A. Cioffi, MD
- F. Jane Durcan, MD
- Neeru Gupta, MD, PhD
- Jody R. Piltz-Seymour, MD
- Thomas W. Samuelson, MD

In addition, the Academy gratefully acknowledges the contributions of numerous past faculty and advisory committee members who have played an important role in the development of previous editions of the Basic and Clinical Science Course.

**American Academy of Ophthalmology Staff**
- Dale E. Fajardo, *Vice President, Education*
- Beth Wilson, *Director, Continuing Professional Development*
- Ann McGuire, *Acquisitions and Development Manager*
- Stephanie Tanaka, *Publications Manager*
- D. Jean Ray, *Production Manager*
- Kimberly Torgerson, *Publications Editor*
- Beth Collins, *Medical Editor*
- Naomi Ruiz, *Publications Specialist*
Contents

General Introduction ........................................... xiii

Objectives ......................................................... 1

1 Introduction to Glaucoma: Terminology,
Epidemiology, and Heredity ................................. 3
Definitions ....................................................... 3
   Open-Angle, Angle-Closure, Primary, and Secondary Glaucomas 3
   Combined-Mechanism Glaucoma ................................ 7
Epidemiologic Aspects of Glaucoma .......................... 7
   Primary Open-Angle Glaucoma ................................ 7
   Primary Angle-Closure Glaucoma ............................ 9
Genetics, Environmental Factors, and Glaucoma .......... 10
   Environmental Factors .................................. 10
   Genetic Testing ............................................. 11

2 Intraocular Pressure and Aqueous Humor
Dynamics .......................................................... 13
   Aqueous Humor Production and Composition ............. 13
      Suppression of Aqueous Formation ....................... 16
      Measurement of Aqueous Formation ...................... 17
   Aqueous Humor Outflow .................................. 17
      Trabecular Outflow ..................................... 17
      Measurement of Outflow Facility ....................... 19
      Uveoscleral Outflow ..................................... 19
   Episceral Venous Pressure .................................. 19
   Intraocular Pressure ....................................... 20
      Distribution in the Population and Relation to Glaucoma 20
      Factors Influencing Intraocular Pressure .............. 21
      Clinical Measurement of Intraocular Pressure .......... 22

3 Clinical Evaluation .......................................... 29
   History and General Examination .......................... 29
      Refraction ............................................... 29
      External Adnexae ....................................... 29
      Pupils .................................................. 30
      Biomicroscopy .......................................... 30
   Gonioscopy ................................................... 32
      Direct and Indirect Gonioscopy ......................... 33
      Gonioscopic Assessment and Documentation ............ 36
4 Open-Angle Glaucoma ........................................... 79
Primary Open-Angle Glaucoma .................................. 79
  Clinical Features ............................................. 79
  Risk Factors .................................................. 80
  Associated Disorders ........................................ 83
  Prognosis and Therapy ....................................... 84
Open-Angle Glaucoma Without Elevated IOP (Normal-Tension
Glaucoma, Low-Tension Glaucoma) ............................... 85
  Risk Factors and Clinical Features ............................ 85
  Differential Diagnosis ....................................... 86
  Diagnostic Evaluation ....................................... 87
  Prognosis and Therapy ....................................... 87
The Glaucoma Suspect ........................................... 89
Ocular Hypertension ............................................. 89
Secondary Open-Angle Glaucoma ................................ 91
  Pseudoxefoliation Syndrome ................................ 91
  Pigment Dispersion Syndrome ................................ 93
  Lens-Induced Glaucoma ...................................... 96
  Intraocular Tumors ......................................... 98
  Ocular Inflammation and Secondary Glaucoma .............. 100
Elevated Episcleral Venous Pressure ............................ 102
Trauma and Surgery ........................................... 103
Schwartz Syndrome (Schwartz-Matsuo Syndrome) ................ 109
Drugs and Glaucoma ........................................... 109

5 Angle-Closure Glaucoma ...................................... 117
Introduction ..................................................... 117
Pathogenesis and Pathophysiology of Angle Closure ............ 118
  Pupillary Block ............................................. 118
  Lens-Induced Pupillary Block Angle-Closure Glaucoma .......... 119
Angle Closure Without Pupillary Block .......................... 119
Iris-Induced Angle Closure .................................... 120
6 Glaucoma in Children and Adolescents ..................... 147
Classification .................................................. 147
Genetics ......................................................... 150
Primary Congenital Glaucoma .................................. 151
Juvenile Open-Angle Glaucoma ................................ 153
Developmental Glaucomas With Associated Ocular or Systemic
  Anomalies ....................................................... 153
  Axenfeld-Rieger Syndrome .................................... 153
  Peters Anomaly ............................................... 154
  Aniridia ....................................................... 154
  Sturge-Weber Syndrome ...................................... 155
  Neurofibromatosis ........................................... 156
Secondary Glaucomas ............................................ 156
  Aphakic Glaucoma ............................................ 156
Evaluating the Pediatric Glaucoma Patient .................... 157
  History ....................................................... 157
  Visual Acuity ................................................ 158
  External Examination ....................................... 158
  Anterior Segment Examination ............................... 158
  Tonometry ................................................... 158
  Pachymetry .................................................. 159
  Gonioscopy .................................................. 159
Primary Angle Closure ......................................... 120
  Risk Factors for Developing Primary Angle Closure ........ 120
Primary Angle-Closure Suspect ................................ 122
Acute Primary Angle Closure .................................. 123
Subacute or Intermittent Angle Closure ......................... 125
Chronic Angle Closure ......................................... 126
Plateau Iris Syndrome .......................................... 127
Secondary Angle Closure With Pupillary Block ................ 128
  Lens-Induced Angle Closure ................................ 128
Secondary Angle Closure Without Pupillary Block ............ 132
  Neovascular Glaucoma ...................................... 132
  Iridocorneal Endothelial Syndrome .......................... 136
  Tumors ....................................................... 138
  Inflammation ............................................... 138
  Malignant Glaucoma ......................................... 139
Nonrhegmatogenous Retinal Detachment and Uveal Effusions 141
Epithelial and Fibrous Ingrowth ................................ 141
Trauma ......................................................... 142
Retinal Surgery and Retinal Vascular Disease .................. 143
Nanophthalmos ................................................ 144
Persistent Fetal Vasculature ................................... 144
Flat Anterior Chamber ......................................... 144
Drug-Induced Secondary Angle-Closure Glaucoma ............. 145
169
Medical Management of Glaucoma

Prostaglandin Analogues .......................... 170
Mechanism of Action .............................. 170
Available Agents and Dosing Frequency ....... 170
Adverse Effects ................................. 175
Adrenergic Drugs ................................. 176
β-Adrenergic Antagonists ......................... 176
Adrenergic Agonists .............................. 177
Carbonic Anhydrase Inhibitors .................. 179
Mechanism of Action .............................. 179
Available Agents and Dosing Frequency ....... 179
Adverse Effects and Contraindications ......... 180
Parasympathomimetic Agents .................... 181
Mechanism of Action .............................. 181
Adverse Effects ................................. 181
Combined Medications ......................... 182
Hyperosmotic Agents ............................. 182
General Approach to Medical Treatment ...... 183
Long-Term Therapy ............................... 183
Therapy for Acute Intraocular Pressure Elevation 184
Administration of Ocular Medications ......... 184
Use of Glaucoma Medications During Pregnancy or by Breastfeeding Mothers ................. 185
Use of Glaucoma Medications in Elderly Patients 186
Generic Medications ............................. 186
Patient Adherence to a Medication Regimen .... 186

8 Surgical Therapy for Glaucoma ............... 187
Laser Surgery ..................................... 188
Laser Trabeculoplasty ......................... 188
Laser Iridotomy .................................. 191
Laser Gonioplasty, or Peripheral Iridoplasty . 193
Cyclodestruction ................................. 194
Incisional Surgery ............................... 196
Trabeculectomy .................................. 197
Combined Cataract and Trabeculectomy ...... 211
Cataract Extraction .............................. 213
Tube Shunt Implantation ....................... 213
Nonpenetrating Glaucoma Surgery ............. 217
General Introduction

The Basic and Clinical Science Course (BCSC) is designed to meet the needs of residents and practitioners for a comprehensive yet concise curriculum of the field of ophthalmology. The BCSC has developed from its original brief outline format, which relied heavily on outside readings, to a more convenient and educationally useful self-contained text. The Academy updates and revises the course annually, with the goals of integrating the basic science and clinical practice of ophthalmology and of keeping ophthalmologists current with new developments in the various subspecialties.

The BCSC incorporates the effort and expertise of more than 90 ophthalmologists, organized into 13 Section faculties, working with Academy editorial staff. In addition, the course continues to benefit from many lasting contributions made by the faculties of previous editions. Members of the Academy Practicing Ophthalmologists Advisory Committee for Education, Committee on Aging, and Vision Rehabilitation Committee review every volume before major revisions. Members of the European Board of Ophthalmology, organized into Section faculties, also review each volume before major revisions, focusing primarily on differences between American and European ophthalmology practice.

Organization of the Course

The Basic and Clinical Science Course comprises 13 volumes, incorporating fundamental ophthalmic knowledge, subspecialty areas, and special topics:

1. Update on General Medicine
2. Fundamentals and Principles of Ophthalmology
3. Clinical Optics
4. Ophthalmic Pathology and Intraocular Tumors
5. Neuro-Ophthalmology
6. Pediatric Ophthalmology and Strabismus
7. Orbit, Eyelids, and Lacrimal System
8. External Disease and Cornea
9. Intraocular Inflammation and Uveitis
10. Glaucoma
11. Lens and Cataract
12. Retina and Vitreous
13. Refractive Surgery

In addition, a comprehensive Master Index allows the reader to easily locate subjects throughout the entire series.

References

Readers who wish to explore specific topics in greater detail may consult the references cited within each chapter and listed in the Basic Texts section at the back of the book.
These references are intended to be selective rather than exhaustive, chosen by the BCSC faculty as being important, current, and readily available to residents and practitioners.

**Videos**

This edition of Section 10, *Glaucoma*, includes videos related to topics covered in the book. The videos were selected by members of the BCSC faculty and are available to readers of the print and electronic versions of Section 10. Mobile-device users can scan the QR code below (a QR-code reader must already be installed on the device) to access the video content.

---

**Study Questions and CME Credit**

Each volume of the BCSC is designed as an independent study activity for ophthalmology residents and practitioners. The learning objectives for this volume are given on page 1. The text, illustrations, and references provide the information necessary to achieve the objectives; the study questions allow readers to test their understanding of the material and their mastery of the objectives. Physicians who wish to claim CME credit for this educational activity may do so by following the instructions given at the end of the book.

**Conclusion**

The Basic and Clinical Science Course has expanded greatly over the years, with the addition of much new text, numerous illustrations, and video content. Recent editions have sought to place greater emphasis on clinical applicability while maintaining a solid foundation in basic science. As with any educational program, it reflects the experience of its authors. As its faculties change and medicine progresses, new viewpoints emerge on controversial subjects and techniques. Not all alternate approaches can be included in this series; as with any educational endeavor, the learner should seek additional sources, including Academy Preferred Practice Pattern Guidelines.

The BCSC faculty and staff continually strive to improve the educational usefulness of the course; you, the reader, can contribute to this ongoing process. If you have any suggestions or questions about the series, please do not hesitate to contact the faculty or the editors.

The authors, editors, and reviewers hope that your study of the BCSC will be of lasting value and that each Section will serve as a practical resource for quality patient care.
Objectives

Upon completion of BCSC Section 10, Glaucoma, the reader should be able to

• state the epidemiologic features of glaucoma, including the social and economic impacts of the disease
• list recent advances in the understanding of hereditary and genetic factors in glaucoma
• describe the physiology of aqueous humor dynamics and the control of intraocular pressure (IOP)
• describe the clinical evaluation of the glaucoma patient, including history and general examination, gonioscopy, optic nerve examination, and visual field
• list the clinical features of the patient considered a glaucoma suspect
• describe the clinical features, evaluation, and treatment of primary open-angle glaucoma and normal-tension glaucoma
• list the various clinical features of and therapeutic approaches for the secondary open-angle glaucomas
• state the underlying causes of the increased IOP in various forms of secondary open-angle glaucoma and the impact that these underlying causes have on management
• describe the mechanisms and pathophysiology of primary angle-closure glaucoma
• describe the pathophysiology of secondary angle-closure glaucoma, both with and without pupillary block
• describe the pathophysiology of and therapy for primary congenital and juvenile-onset glaucomas
• describe the various classes of medical therapy for glaucoma, including efficacy, mechanism of action, and safety

• state the indications for, techniques used in, and complications of various laser and incisional surgical procedures for glaucoma