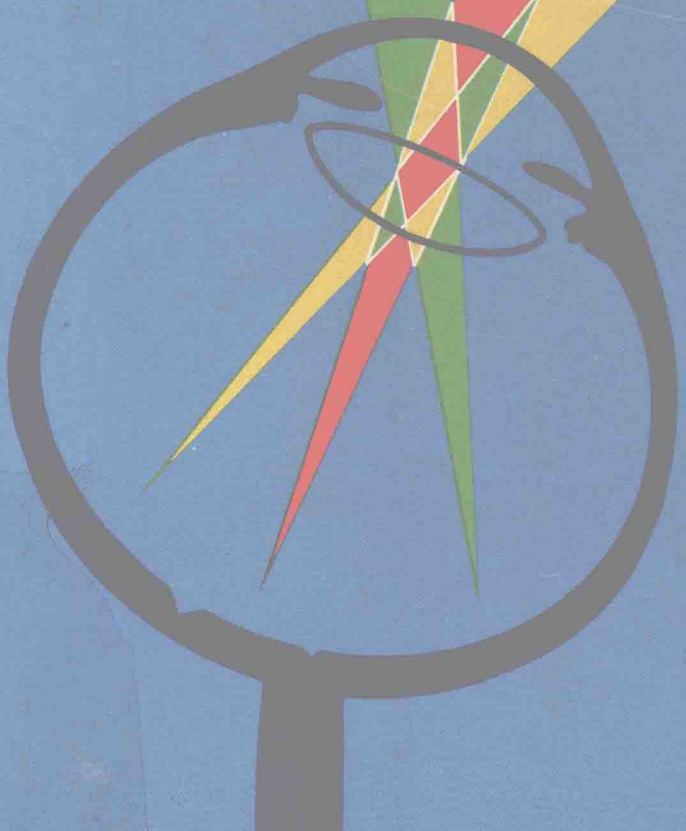
Francis A. L'Esperance, Jr.

OPHTHALMIC LASERS

Photocoagulation, Photoradiation, and Surgery

SECOND EDITION



OPHTHALMIC LASERS

Photocoagulation, Photoradiation, and Surgery

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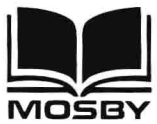
with **815** illustrations

Tone drawings by
Virginia Cantarella

The C. V. Mosby Company

ST. LOUIS • TORONTO • LONDON 1983



A TRADITION OF PUBLISHING EXCELLENCE

Editor: Eugenia A. Klein
Assistant editor: Jean F. Carey
Editing supervisor: Elaine Steinborn
Book design: Jeanne Bush
Production: Carolyn Biby, Barbara Merritt

SECOND EDITION

Previous edition (titled OCULAR PHOTOCOAGULATION: A STEREOSCOPIC ATLAS) copyrighted 1975

Printed in the United States of America

The C.V. Mosby Company
11830 Westline Industrial Drive, St. Louis, Missouri 63146

Library of Congress Cataloging in Publicatior Data

L'Esperance, Francis A., 1932-
Ophthalmic lasers.

Rev. ed. of: Ocular photocoagulation. 1975.
Bibliography: p.
Includes index.
1. Laser coagulation. 2. Eye—Diseases and defects—Radiotherapy. I. Title. [DNLM: 1. Eye diseases—Surgery—Atlases. 2. Lasers—Therapeutic use—Atlases. WW 17 L637o]
RE992.P5L47 1983 617.7'0631 82-7888
ISBN 0-8016-2823-7 AACR2

GW /CB /MV 9 8 7 6 5 4 01/C/069

To my wife
Ellen
and
Fran, Linda, and Laura
and to my dear
mother

Preface

The first edition of *Ocular Photocoagulation: A Stereoscopic Atlas* was undertaken in an effort to summarize and evaluate the response of various ophthalmic defects to photocoagulation. The first edition was designed to emphasize the important diagnostic and ophthalmoscopic aspects of chorioretinal diseases and was focused on the response of these diseases to the xenon-arc and the argon laser photocoagulation systems. Since the publication of the first edition, the krypton laser has become commercially available (although introduced in 1972), the carbon dioxide laser has moved from the experimental to the clinical phase in the treatment spectrum, the dye laser has been introduced as a multicolor laser with enormous potential in the field of photoradiation, the Q-switched neodymium-YAG laser has been introduced for the photoincision of transparent tissues, and even the argon laser has been reevaluated with reference to the potential tissue responses to the green or blue wavelengths. But perhaps more important than the introduction and commercialization of various new lasers and delivery systems to the eye has been the pioneering ingenuity of many investigators to manipulate existing lasers to control glaucoma, to substitute laser procedures for former surgical operations, and to become technically expert in the use of the enormous technologic precision that is inherent in ophthalmic lasers.

With the refinement of laser technology came a concurrent improvement in ophthalmic laser techniques, a clearer understanding of the potential for selective absorption of variously colored wavelengths by certain portions of the ocular tissues, and a greater degree of cooperation between physicists, bioengineers, and ophthalmologists. This book has been written for all ophthalmologists because it is anticipated that laser surgery will be practiced by ophthalmologists in all of the ophthalmic subspecialties from the orbital or plastic surgeon to the glaucoma expert.

With these preceding thoughts in mind, this book was designed to emphasize the leading laser systems available at this writing and the diseases they can partially or completely control or cure. It is hoped that the reader will gain a basic knowledge of lasers in the introductory chapters, which are concerned with the history and physics of lasers and laser surgery. Subsequent chapters emphasize clinically important subjects such as absorption potential and disease responses to the various laser beams. These basic technical considerations and some of the advantages and disadvantages of various lasers are immensely

important to the ophthalmologist in attaining a maximal benefit from laser intervention with a particular disease entity.

The second part of this book offers a brief description of specific diseases in some sections, the clinical symptoms and ophthalmoscopic appearance of the particular disease entity, the ancillary diagnostic examinations, indications for photocoagulation, and the particular photocoagulation approach recommended, as well as the complications occasionally incurred with photocoagulation. Part II is divided into peripheral chorioretinal diseases, macular diseases, and anterior segment diseases, which basically delineates the entire eye. Specific recommendations are made for photocoagulation techniques to be employed with the diseases encountered in those areas. Orbital and plastic surgery have not been included in the discussions, although the carbon dioxide laser and perhaps the hydrogen fluoride laser should have enormous impact on the treatment of various disorders in these particular ophthalmic subspecialties.

It has been my purpose to make laser photocoagulation and laser surgery as simple to understand and employ as possible. Diagrams, artists' illustrations, and photographs of disorders amenable to photocoagulation have been used as frequently as possible to illustrate a viewpoint visually, as well as to discuss it in the text. It is hoped that this book will serve as a comprehensive guide for the photocoagulation and laser surgical specialist for the proper and conservative therapy of the many ophthalmic diseases. I have attempted to describe and use the techniques employed by the ophthalmologists who have introduced various photocoagulation approaches, as well as represent recommendations in the text that form a consensus of the leading authorities using laser surgery on a particular disease entity. Therefore this book differs from the first edition because it represents the experiences and convictions of many great clinicians throughout the world, as well as some of my own clinical impressions. In this regard, I am greatly indebted to the many hundreds of ophthalmologists who have suggested new photocoagulation approaches or variations that have ultimately led to greatly improved care for all the patients who can truly benefit from the marvels of laser technology.

I am greatly indebted to the John A. Hartford Foundation for its generous support during the years 1966 to 1976. Its financial assistance made possible the design, construction, and clinical evaluation of the first argon, krypton, and frequency-doubled neodymium-YAG laser photocoagulations systems. Argon laser photocoagulation was used clinically for the first time on a human eye in February 1968; the krypton laser photocoagulation system was first used in April 1970; and the frequency-doubled neodymium-YAG laser photocoagulation system was first used in November 1970. I deeply appreciate the foundation's financial support during this time.

I was very fortunate to have the assistance of Arthur Vassiliadis, Ph.D., who wrote Chapter 2, which is concerned with the physical characteristics of the laser and which provides an understandable basis for photocoagulation therapy. I am deeply indebted to Virginia H. Cantarella for providing the sectional drawings and illustrations throughout the book. It would have been impossible to document many of the pathologic processes as beautifully and as accurately as she did, and I greatly appreciate her assistance.

I wish to acknowledge the inestimable help I have had from Eugenia A. Klein

who provided tremendous organizational support throughout the final stages in the production of this book. Her skill in interpretation and editing of all portions of the book was exceptional, and her unfailing cooperation and assistance were indispensable to the completion of this task.

I am particularly indebted to Lisa Barbera, M.D., an ophthalmologist who wrote the introductory sections in fluorophotometry, histoplasmosis, Eales' disease, Coats' disease, and Leber's miliary aneurysm. Her excellent clinical and photocoagulation therapy review of each of these diseases provide the reader with excellent reference material for further understanding of the disease process and the particular photocoagulation approaches that have been used. I am extremely grateful to her for completing the arduous task of assembling these introductory statements.

Gloria Spivacek, Paul McGuffin, and Fran Mues were indispensable for their artistic, photographic, and editorial assistance, respectively.

I am enormously indebted to Robert M. Ellsworth, Stuart L. Fine, Morton F. Goldberg, Lee M. Jampol, Arnall Patz, Irvin P. Pollack, Robert Ritch, Howard Schatz, Jerry Shields, and Lawrence A. Yannuzzi for their photographs illustrating the photocoagulation therapy of various diseases.

Finally I could not have written this book without the superb logistical and financial support of the Ophthalmic Research Foundation. The assistance of this organization made every aspect of this book possible.

Francis A. L'Esperance, Jr.

Contents

1. Argon laser radiation is five times more effectively absorbed by hemoglobin and vascular structures than is xenon-arc radiation.
2. The transverse electromagnetic mode (TEM_{00}) argon beam can be focused to a theoretical spot size at least 40% smaller than that produced by the ruby laser.
3. The blue-green beam has greater inherent energy per photon than does any other laser source considered for photocoagulation.
4. The argon laser produces radiation that is more highly collimated and directional than any other commercial photocoagulation beam. Argon laser radiation appears to be absorbed selectively at the pigment epithelium and at areas of hemoglobin concentration, as well as slightly at the nuclear layers and outer segments of the rods and cones.
5. The argon laser produces radiation that is seven to eight times more effectively absorbed by oxyhemoglobin and reduced hemoglobin than is ruby or red krypton laser radiation. Arterial systems have oxyhemoglobin primarily, whereas venous vessels are a mixture of reduced hemoglobin (primarily) and oxyhemoglobin.
6. Argon laser radiation creates no detectable adverse effects, other than thermal ones, on the ocular tissues, plasma proteins, or blood constituents. Nonlinear and acoustic effects have not been demonstrated during widespread investigations.

GRADATION OF VISIBLE CONTINUOUS-WAVE LASER PHOTOCOAGULATION LESIONS

Coagulations produced by the visible CW lasers can be graded on a simple system ranging from Grades 1 to 4 for coagulations of chorioretinal layers or ocular tissues other than the retinal vasculature (Figs. 4-23 and 4-24) and Grades I to IV for coagulations of vascular tissue (Figs. 4-25 and 4-26). Characterization of the coagulations is important for determining the proper end result when one is coagulating a particular abnormality. When appropriate, reference is made to these gradations throughout this text.

Chorioretinal coagulations

Grade 1	Barely visible, blanching of pigment epithelium
Grade 2	Hazy, mucoid, translucent, foggy
Grade 3	Opaque, dusky, gray, dirty white, off-white
Grade 4	Dense, chalk colored, hard-boiled egg white

Vascular coagulations

Grade I	Slight constriction of coagulated vessel
Grade II	Complete constriction and spasm of coagulated vessel
Grade III	Complete constriction and surrounding paravascular coagulum
Grade IV	Complete constriction, coagulum, and charring of coagulated vessel

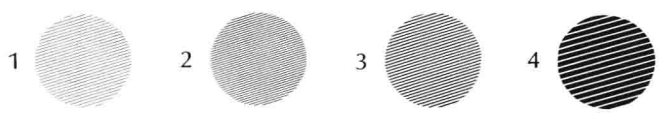


Fig. 4-23. Density of the coagulum in relation to the various chorioretinal coagulation gradations (Grades 1 to 4).

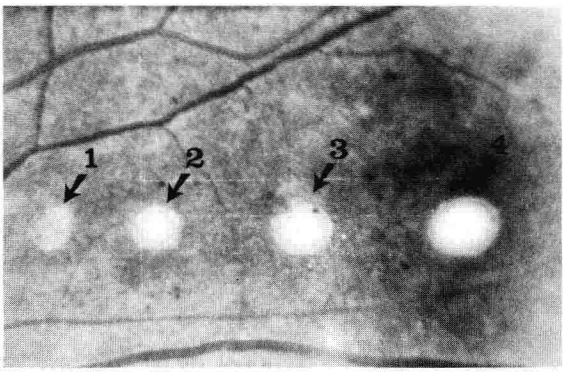


Fig. 4-24. Typical chorioretinal coagulation gradations (Grades 1 to 4).

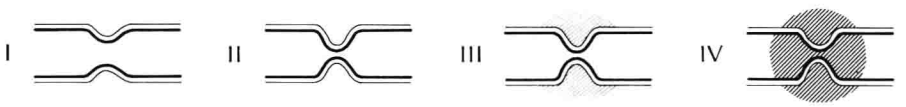


Fig. 4-25. Blood vessel and surrounding tissue with various degrees of vascular coagulation (Grades I to IV).

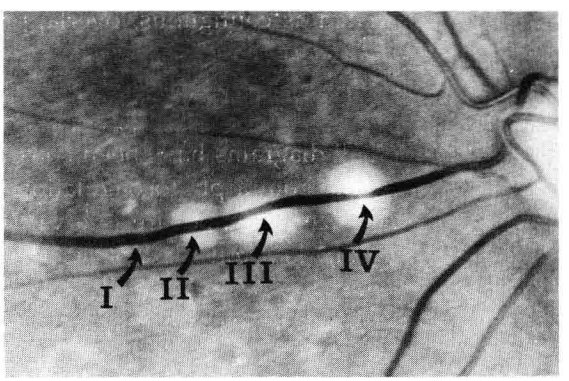


Fig. 4-26. Gradations of vascular coagulations (Grades I to IV).

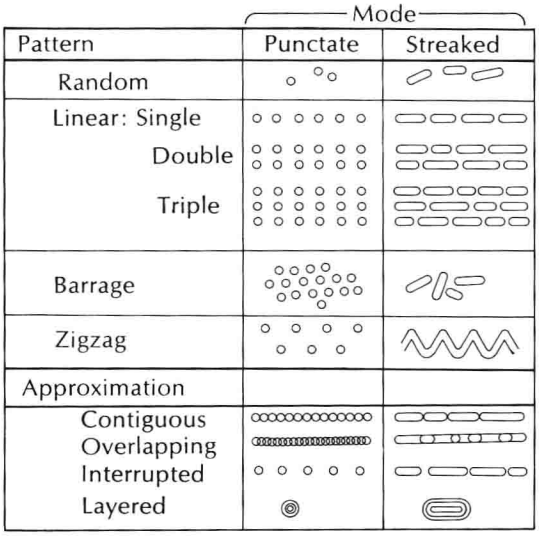


Fig. 4-27. Coagulation configurations, including the mode, pattern, and approximation of the ocular coagulations.

COAGULATION CONFIGURATIONS

One can describe a photocoagulation by defining its nature according to three categories: mode, pattern, and approximation (Fig. 4-27). The *mode* is concerned with delivery of the coagulation in a punctate, discrete, and solitary fashion or in a streaked, painted, and elongated manner. The *pattern* of the coagulation impacts is characterized as random; as single, double, or triple linear types; or as barrage or zigzag configurations. The *approximation* of one coagulation to another is further designated as contiguous, overlapping, interrupted, or layered.

PHOTOCOAGULATION PARAMETERS

Throughout this book all diagrams have been constructed in a manner that should be easily understood from a photocoagulation standpoint. The SEP at the side denotes the spot size (S), exposure interval (E), and power level (P) usually required with argon, krypton, or dye laser photocoagulation for the desired result for a particular disease under average conditions with clear media. When applicable, other laser photocoagulation parameters are discussed in each section.

MAINTENANCE OF POWER DENSITY

One of the most important concepts in photocoagulation is maintenance of the power density of the coagulating beam when it is directed on the diseased tissue. Usually the coagulation spot size can be predetermined for a particular lesion; the power setting and exposure interval are then carefully adjusted for production of the proper coagulation. When the proper coagulation energy (power intensity $\times$ exposure interval) has been determined, this dosage should

Table 4-1. Power increases necessary for various degrees of opacification

Area of opacification	Percentage of power increase required
Cornea	
1+ epithelial edema	5
2+ epithelial edema	15
1+ stromal haze	10
2+ stromal haze	35
1+ endothelial disruption	5
2+ endothelial disruption	25
Aqueous	
1+ flare	10
2+ flare	30
1+ cells	15
2+ cells	35
Lens	
1+ nuclear sclerosis	10
2+ nuclear sclerosis	25
3+ nuclear sclerosis	45
1+ cortical opacities	10 to 30
2+ cortical opacities	10 to 40
1+ posterior subcapsular opacities	15
2+ posterior subcapsular opacities	40
Vitreous	
1+ vitreous haze	15
2+ vitreous haze	35

be maintained while any changes in the exposure interval are being considered. It is quite advantageous in the performance of therapeutic photocoagulation to maintain the power density at the proper level. The energy transmitted to the retina can be considered in terms of energy per unit area or, with CW lasers such as the argon, krypton, or dye lasers, more appropriately as the power per unit area, or power density. If the spot size does not vary, the product of the exposure interval and the input power or power density should be kept approximately constant. This relationship is fairly linear and rather simple to maintain. However, if the spot size changes, the energy input must be decreased or increased with the decrease or increase in the diameter of the spot size (see Fig. 17-21).

ALTERATIONS IN PHOTOCOAGULATION INTENSITY, SECONDARY TO REFRACTIVE MEDIA OPACIFICATIONS

The approximate values for power density (SEP) expressed in each of the chapters are related to and dependent on ideal conditions. These conditions include an emmetropic eye that has a normally clear cornea, anterior chamber, lens, and vitreous humor. Any opacification of any of these parts of the ocular media can lead to reflection, scatter, or absorption of the argon laser beam; the effective energy impinging on the retinal surface would thus be decreased. Table 4-1 emphasizes the approximate energy increase necessary with the various degrees of opacification of the individual tissues. This table can serve only as a

rough guide; the appropriate power level must always be determined by increasing the power setting from a weak level to the ideal photocoagulation intensity for a particular disease. If the power increase necessary for a coagulation response far exceeds these listed values, one should search for other conditions or problems that are responsible for the ineffectiveness of the photocoagulation beam.

ATTENUATED RETINAL BEAM IMAGE

It is most important that one consider the appearance of the attenuated argon, krypton, or dye laser photocoagulation target beam on the retina when determining whether the total energy impinging on the cornea is being properly transmitted to the chorioretinal structures. The focus of the argon, krypton, or dye laser beam should appear as a circular spot of uniform intensity. Lenticular, corneal, or vitreal opacities can block portions of the incoming beam, producing a shadow in the circular spot area (Fig. 4-28). Cortical lenticular opacities can block out a wedge of the beam, and vitreous opacities can prevent a larger, more irregular portion of the beam from striking the retina. If the opacification is diffuse, such as that encountered with nuclear cataracts or vitreous cellular debris, the attenuated argon, krypton, or dye laser focus spot may be hazy and ill defined. The red krypton laser beam is transmitted more highly and scattered less by diffuse lenticular or vitreous opacities, particularly blood, and may be used more advantageously than lasers with shorter wavelengths (blue, green, or yellow beams). Occasionally a poorly delimited circular spot on the retina will indicate improper focusing of the laser beam. Large areas of the beam can be blocked if the incoming laser beam impinges on the borders of the iris, thereby

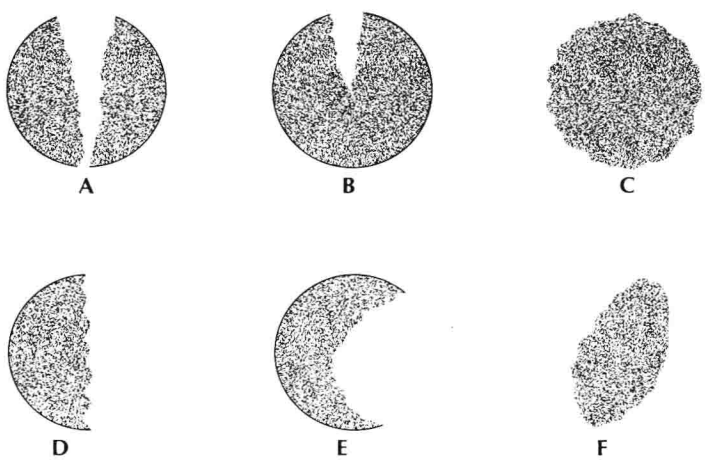


Fig. 4-28. Attenuation or distortion of the appearance of the attenuated argon, krypton, or dye laser photocoagulation target beam on the retina. **A,** Large cortical lenticular wedge opacification interferring with the laser beam. **B,** Short cortical lenticular spoke. **C,** Hazy, indistinct retinal image caused by ocular media haze. **D,** Disappearance of a portion of the retinal target beam spot because of impingement of the beam on the border of the iris. **E,** Loss of a portion of the argon laser beam image on the retina because of a large lenticular or vitreous opacity. **F,** Distortion and elongation of the retinal target spot because of lenticular astigmatism.

producing an eclipselike loss in the circular spot on the retina. In cases of high lenticular astigmatism the beam may be elongated, rather than circular, as it is projected on the retinal surface. To obviate these problems, the laser circular spot on the posterior structures of the eye should be evaluated carefully before photocoagulation.

LOCALIZATION OF THE FOVEA

The dimensions of the anatomic regions of the posterior pole (macula, fovea, foveola, and centrally located umbo) should be known. Fig. 4-29 illustrates the radii of the various anatomic regions as compared with the radius of the optic disc (750μ). The figure also compares the anatomic retinal areas with the frequently used clinical designations as follows: macular border (perimacular area), area between fovea and macular border (paramacular area), fovea (macular area), and foveola (foveal area). Knowledge of these dimensions permits the more precise evaluation of chorioretinal abnormalities in relation to their anatomic placement. It is common that practitioners will refer to the anatomic fovea as the macula and the anatomic foveola as the fovea. Although this practice has been acceptable, the designations in this book will refer to anatomic landmarks. Fig. 4-30 illustrates the foveolar avascular zone with the sloping clivus, central umbo, and inner retinal concentration of xanthophyll. These areas are extremely important because of the various absorptive pigments (xanthophyll and avascular zone), which respond differently to certain laser wavelengths.

It is sometimes extremely difficult to find the fovea before and during photocoagulation because of the presence of marked retinal edema, cystic changes, hemorrhages, or other disorganizing factors. It is most important that this region

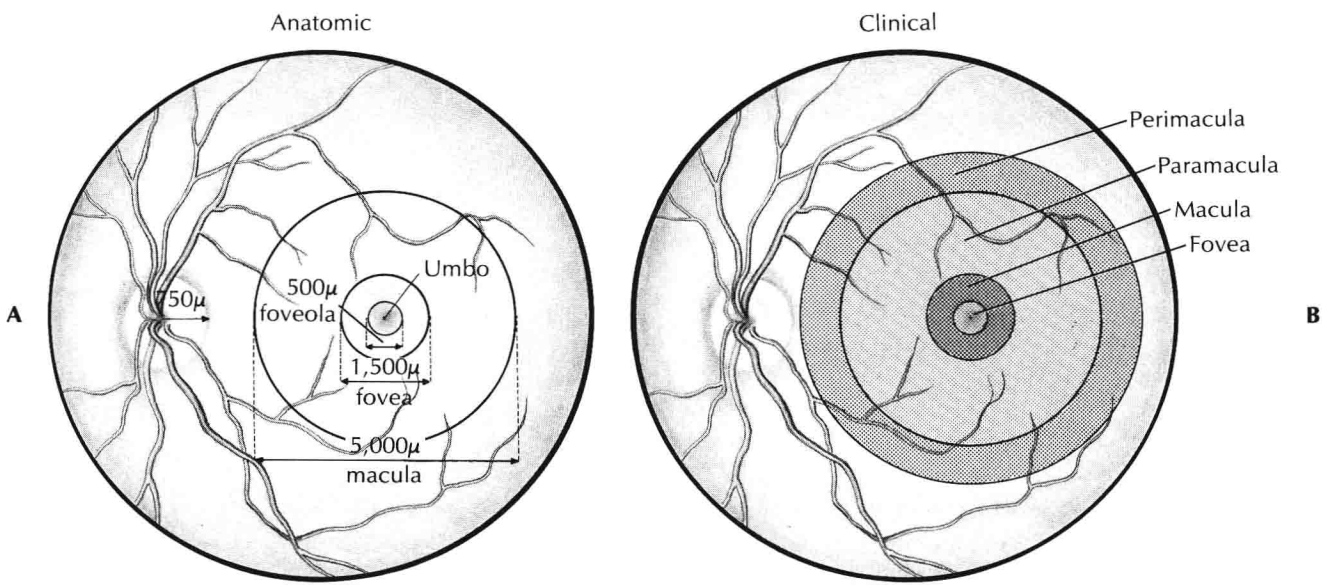


Fig. 4-29. A, Anatomic regions of the posterior retina and their respective dimensions. **B,** Relationship of the anatomic regions of the posterior retina to clinical designations.

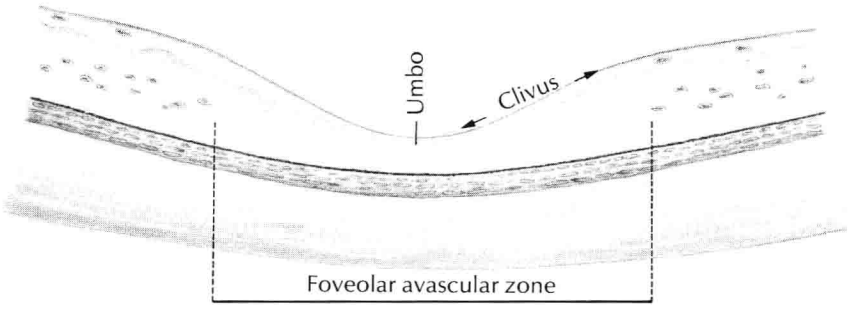


Fig. 4-30. Capillary-free or foveolar avascular zone (FAZ) surrounded by intraretinal superficial and deep vascular plexi. Note the sloping clivus, central umbo, and inner retinal concentration of xanthophyll pigment.

be located, so that the proper therapeutic approach to a disease may be determined and precise therapeutic photocoagulation impacts rendered. The following sequence has proved useful for the exact location of the fovea.

Prephotocoagulation evaluation

Following indirect ophthalmoscopy and contact lens biomicroscopy, it may be difficult for the patient to fixate on a target light or pointer accurately with his fovea because of retinal exhaustion resulting from the bright examination sources. The patient can be asked to look directly at the very small beam from the slit lamp during the initial examination; this procedure will usually demonstrate the foveal region somewhat accurately. If the fovea cannot be accurately located, it is advisable to proceed to the next step.

With his pupils dilated, the patient is asked to sit in a darkened room for approximately 20 min, until his retinal sensitivity is partially reactivated. He is then asked to sit before the biomicroscope and locate the very small spot of light from the slit lamp. The intensity of the light should be minimal, sufficient only for allowing the patient to fixate with his foveal region. This procedure may, however, be extremely difficult when advanced degenerative, edematous, or hemorrhagic conditions of the macular region are present. Once this estimation has been completed, the patient is moved to the photography room so that a permanent record can be made of the presumed fixation point.

With the illumination at its lowest value the patient is asked to locate the fixation pointer within the fundus camera (Fig. 4-31). The patient is directed to look at the end of the pointer, and some determination is made concerning the accuracy and overall ability with which the patient follows the pointer as it is moved in various directions. While the patient is fixating on the end of the pointer, a Polaroid or Kodachrome 35-mm picture is taken. This photograph is used for foveolar reference at the time of photocoagulation.

Any photography, indirect ophthalmoscopy, or examination using the bright light source on the biomicroscope will exhaust the retina sufficiently to cause an erroneous localization of the fovea, particularly in those patients with damaged maculas. Therefore localization of the fovea should always be done with

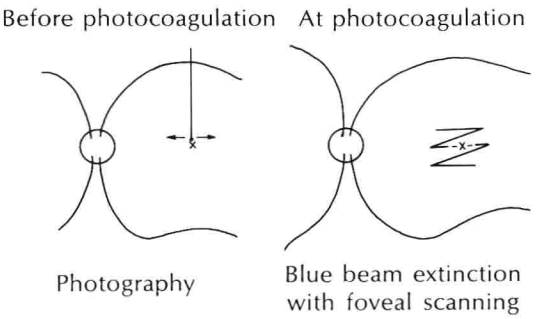


Fig. 4-31. Method of foveal localization with the fundus camera pointer during photography before photocoagulation and with extinction of the low-powered blue argon laser beam during foveal scanning at the time of photocoagulation.

reduced illumination and before any of the previously mentioned examinations involving a bright illumination beam.

Foveal localization during photocoagulation (scanning and extinction technique)

Particularly with those patients whose macula has been damaged, resulting in a decrease in macular function, the foveal region should be carefully located before indirect ophthalmoscopy or bright light biomicroscopy is done. The patient is seated before the photocoagulator slit lamp, and the contact lens is inserted on the patient's cornea. Under markedly reduced illumination, a very small spot is projected into the patient's eye, and the patient is asked to fixate on this small spot of white light. The geographic location of the fixation point, with regard to surrounding exudates, retinal folds, hemorrhages, or blood vessels, is then determined and documented by a small drawing, which is compared with the drawings and photographs made during the prephotocoagulation examination. If the fixation regions are identical, it can be assumed that the patient is using this particular retinal area for fixation and for his maximal visual function. His fixation point and his foveal region may not be the same, since his fovea may have been damaged sufficiently to cause him to fixate eccentrically in some other perifoveal or macular area.

When the fixation point has been determined, the attenuated target or marker argon laser beam can be used to locate the anatomic foveal region; a **100μ** diameter spot at a power of **25 mW** or less is placed in the macular region near the suspected foveal area. With the least dense attenuator filter in position and a rather bright, readily visible spot on the fundus, the very low-powered beam is brought across the suspected foveal region in a scanning, raster-type motion until the deep blue argon beam diminishes markedly in brightness because of its absorption by the xanthophyll pigment in the fovea (Fig. 4-31). This decrease in reflected intensity is quite noticeable, particularly if the argon beam is maintained at a very low power intensity, so that it contains energy predominantly composed of the blue (488.0-nm) wavelength. If the power intensity is increased, the less highly absorbed green (514.5-nm) wavelength appears in the beam, and the decrease in reflected intensity is not so pronounced. The argon laser beam is composed mainly of the blue (488.0-nm) wavelength at powers below 50 mW;