Endoscopic Laser Surgery Handbook

edited by
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Additional Volumes in Preparation

Preface

My interest in the application of lasers in medicine and, in particular, in otolaryngology began during my residency (1972-1975) at the Boston University Medical Center under the direction of my mentor, M. Stuart Strong. This was an exciting time for me because the CO_2 laser, introduced by Jako and Strong, was rapidly changing the practice of laryngology for both adults and children. Although not initially well accepted by the medical establishment, this precision laser has become the instrument of choice for the management of many laryngeal and some tracheobronchial disorders. Improvements in laser technology and delivery systems, as well as the discovery of new indications for laser applications, further advanced the use of lasers in many specialties. Because of the generous support of the Eleanor Naylor Dana Charitable Trust with the establishment of the Laser Research Laboratory at the Lahey Clinic Medical Center, my work has continued, particularly in endoscopic laser applications with medical fiberoptics.

Endoscopic therapeutics has become an important concept in otolaryngology, gynecology, gastroenterology, pulmonary medicine, and, recently, cardiovascular medicine and surgery. The endoscopic application of laser technology is a natural addition to diagnostic fiberoptic instruments that are now a mainstay in many specialties.

When Marcel Dekker, Inc., asked me to edit a textbook on lasers in medicine, my suggestion was to limit this endeavor to endoscopic applications with lasers. The extensive chapter on laser physics and soft-tissue applications by Fisher begins the text in a technical vein. It is a comprehensive, clear, definitive reference and an excellent source of information. Subsequent chapters, written by knowledgeable leaders in their respective specialties, are clinical presentations. Of particular interest is Isner's chapter on the cardiovascular applications of laser technology; this has become a major research effort worldwide. New concepts of cancer therapy, such as photodynamic therapy, are included because of the laser's endoscopic application. A discussion of potential complications and how to start a laser center are also included.

I wish to thank all of the contributors to this volume for their hard work in the preparation of their excellent chapters, representing the state of the art in the application of lasers in medicine. Special thanks go to Suzanne Setzer and Kaye Newman in our laser laboratory. Eileen Rahamim, our department secretary, was extremely helpful in organizing the project and in contacting the contributors. The cooperation of all other support services at the Lahey Clinic, especially the photographic department, is always appreciated. Most important, much appreciation is extended to my wife Ruth and to my children Sandy and Mara for their continuing support of all my efforts.

It has been an honor and a pleasure for me to edit this textbook on the endoscopic applications of lasers in medicine. I hope the reader will find this book useful, practical, and most of all, stimulating.

Stanley M. Shapshay

Foreword

This book, by experts in their fields, is concerned primarily with operative endoscopy utilizing lasers. The operating microscope has long been an integral part of surgical procedures in laryngology and some aspects of gynecology. Some physicians turned to lasers to improve the results of existing methods of treatment, others used lasers because traditional operative methods through endoscopic channels were inadequate to help their patients, and still others chose to transform open surgery into endoscopic surgery. Endoscopic removal or devitalization of tissue can be extremely demanding of the surgeon, but the benefits to patients of such minimally invasive surgery are great.

The energy emitted by lasers can be focused sharply at the distal end of narrow endoscopic tubes or transmitted through thin, flexible fibers. Lasers have not decreased the demands on the endoscopist; on the contrary, additional knowledge and skills are imperative. Improved medical care and major alleviation of human suffering are the compensations.

With the progressive availability of practical laser equipment in many wavelengths and a broad range of temporal characteristics, the perfecting of fibers and endoscopes, the development of new endoscopic diagnostic means, and the emergence of new ideas (touched on in several chapters of this book), the future for operative endoscopy with lasers is increasingly promising. I am sure this book will stimulate more endoscopists to participate in this exciting field. It is a great pleasure for me to write a short historical introduction to this book.

The discovery by Maiman in 1960 of the first laser light source, the ruby laser, caused great excitement in the scientific world, including the medical community. Ophthalmologists realized that this extraordinary light source might be useful in ophthalmic surgery, and by 1961 experiments were already under way. By 1964, hundreds of patients had been treated successfully. Of course, ophthalmologists already knew that light could be used to create therapeutic lesions in the retina due to the pioneering work of Meyer-Schwickerat in the early 1950s. In the following years, with the help of the Zeiss Company, he developed a retinal photocoagulator based on a high-power xenon arc light source. This photocoagulator was in worldwide use in the early 1960s. Xenon arc and ruby laser were later replaced by ion lasers. Today, the practice of modern ophthalmology without the benefit of laser technology is inconceivable; ophthalmologists are the largest medical users of lasers, the applications of which are still expanding.

Surgeons in other fields became interested in lasers, and soon numerous experimenters began to study the effect of laser radiation on various organs and on tumors grown in or implanted into animals. In these experiments, the ruby laser was used first and then the neodymium-in-glass laser, which had been discovered in 1961. The radiation of these lasers is poorly absorbed by nonpigmented biological tissue. To obtain appreciable effects on sizable tumors, the energy per pulse and the power of these lasers, which operated only in the pulsed mode, had to be increased to high values. High-energy, high-power pulses led to veritable tissue explosions that propelled viable cells into the surrounding area. This important finding, and the less-than-promising surgical results obtained, brought this line of research to an end (1).

Two lasers of great importance for use in surgery, the argon ion laser and the carbon dioxide (CO_2) laser, both operating in the continuous mode, were discovered in 1964. The first was used primarily in the laboratory, owing to its structural complexity. By 1969, however, basic experimental work with this laser in ophthalmic surgery had been accomplished, and soon argon ion lasers were universally used in this field. The power output of the CO_2 laser was at first measured in milliwatts. By 1965, with the addition of nitrogen and helium gases to carbon dioxide, the continuous-wave power output had reached the then unprecedented value of 50 W/m. My colleagues and I, in the research laboratories of the American Optical Corporation, had a CO_2 laser operating on a laboratory workbench. Early in 1966, Yahr, a senior surgical resident at Montefiore Hospital in New York, started surgical experiments with this laser and rapidly recognized its potential surgical utility. In 1966, Yahr and Strully (2) wrote: "Using a nitrogen carbon-dioxide laser . . . clean dry skin incisions which heal as well or better than scalpel controls were fashioned. Bone, liver, kidney, and lung can be cleanly divided . . . . The future medical applications of laser energy are many . . . . One may consider some of the following uses . . . . Many brain tumors, and some congenital defects, block the outflow of the cerebrospinal fluid . . . . A flexible bundle carrying both sight and laser could be introduced into one of the cavities . . . and a simple decompression . . . operation performed as an initial step in the patient's treatment . . . . Laser beams delivered through flexible bundles could be employed to eliminate or fracture stones blocking important biologic duct systems . . . . It appears probable that the nitrogen carbon-dioxide laser will . . . make rapid skin incisions, divide certain organs without blood loss, and . . . anastomose vessels as an adjunct to standard techniques." That was two decades ago. Yahr's and Strully's visions of the many potential uses of lasers in surgery appear uncannily prophetic. What impressed us most at the time was that a "light scalpel" had been found and that surgery with this scalpel seemed "bloodless."

The findings and the enthusiasm of Yahr and Strully led to the development of the first CO_2 laser system for surgery. It became available to surgical experimenters early in 1967. It was a self-contained, movable system requiring connections to a standard electrical power outlet and the water main for cooling the laser tube. An articulated arm with seven mirrors located in rotary joints conveyed the laser beam to a focusing handpiece, freely movable in space (3). Soon numerous surgical investigations were started with this type of system. These studies were all centered on applications where blood loss per se was a major problem: gastric ulcers, debridement of burns, and surgery of the liver, kidney, and brain. Much as the alchemists' search for the philosophical stone contributed immensely to chemistry, so these researchers revealed many important characteristics of the interaction of CO_2 laser beams with biological tissue. With the focused beam of this laser, the surgeon could do everything that could be done with a scalpel and more, such as vaporizing tissue volume, making incisions in tissues without manipulating them, and removing by vaporization thin tissue layers with minimal damage to the underlying tissue. Wound healing was studied, and the often benign nature of the surgical wound was established. However, when the transition was made from small laboratory animals to larger ones or to humans, the hoped-for dramatic hemostatic properties did not materialize. Hemostasis with the CO_2 laser beam was "relative," limited essentially to capillary bleeding. These studies continued well into the 1970s.

In 1967, Jako used the focused CO_2 laser beam to produce a discrete lesion on the vocal cord of a cadaver larynx. This use appeared so promising that he urged my group to develop a device that would permit him to expose the canine vocal cord in vivo to the laser beam. The device developed by Bredemeier in our laboratory was an approximately $6'' \times 6'' \times 6''$ box attached to the distal end of the articulated beam-manipulating arm. The laser beam was deflected by 90° in this box and focused at the distal end of a metal tube 30 cm long with a 1-cm diameter. From the opposite side of the box to which the tube was attached, the effects of the focused laser beam could be observed with ×2 or ×3 magnification. Means were provided to align the axis of the beam to be collinear with that of the tube (4). After performing extensive surgical experiments on canine vocal cords with this device, Jako became convinced the focused CO_2 laser beam was a superior modality for endoscopic laryngeal microsurgery. Bleeding was absent or minimal when operating on the vocal cords and on most tissues of the oral cavity.

For clinical applications, the CO_2 laser was combined with the operating microscope (5). The laser beam was projected through the laryngoscope and focused on the vocal cords or some other region of the oral cavity. The focal point was positioned with precision within the field of view of the operating microscope by means of the fine motions of a mechanical micromanipulator (Bredemeier HC: Stereo Laser Endoscope, U.S. Patent 3,796,220, 1972; issued 1974). Clinical use of this instrumentation was undertaken in 1971 by Strong and Jako at Boston

University School of Medicine. With continued work, the advantages of this modality became apparent. Particularly dramatic was the improvement in treatment of juvenile papillomatosis. Soon the work at Boston University was confirmed by Andrews at the University of Illinois Medical School and by French at the Eye, Ear, Nose, and Throat Hospital in New Orleans.

In 1973, two of Strong's patients presented with peristomal papillomas and two with papillomas extending into the right main bronchus. The endoscopic attachment developed 5 years earlier for the first in vivo experiments on canine larynges, and never intended for clinical work, was brought into use and fitted with a standard ventilating bronchoscope 30 cm long with a 5-mm diameter in our laboratory at American Optical Corporation (Wallace RA, Pejchar J: Endoscopic Surgical Laser System, U.S. Patent 3,906,953, 1974; issued 1975). This instrumentation was successfully used to vaporize the lesions. Strong and colleagues (6) noted in a 1973 paper: "This application of the laser may prove to be useful to other lesions of the trachea and bronchi, such as adenomas, or for palliation of carcinoma causing obstruction at the carina." The obvious importance of this unique application of lasers led rapidly to the development of a more refined instrument for bronchial surgery, using the CO_2 laser (7).

By 1975, close to 1000 endoscopic laryngeal and bronchial laser operations had been performed at the three centers mentioned earlier. Strong (8) reviewed this combined experience in an address to a plenary meeting of the American Academy of Ophthalmology and Otolaryngology in September 1975 and concluded: "The advantages of laser surgery in otolaryngology are so significant that it can be recommended for continued usage. Many applications of this unique surgical instrument have been identified but others need to be explored in the future."

The favorable clinical results, which started to accumulate in laryngeal microsurgery and bronchial surgery, helped to clarify the role of the CO_2 laser in surgery—precision removal of tissue under the visual control of an operating microscope and tissue removal in remote body locations accessible through rigid endoscopic tubes. The application of the CO_2 laser to treatment of cervical and vaginal intraepithelial neoplasia, today the widest surgical application of this laser, was directly inspired by work in laryngeal microsurgery. Indeed, the first such operations were performed by Bellina and French in 1974 at Eye, Ear, Nose, and Throat Hospital in New Orleans (9), and by Cibley and Strong in 1975 at the University Hospital of Boston University School of Medicine.

In the early 1970s, the argon ion and the neodymium:yttrium-aluminum-garnet (Nd:YAG) lasers had become available commercially as practical devices. It was well known to physicists that, in principle, materials existed that were capable of being formed into flexible fibers that could transmit the radiation emitted by these lasers practically without attenuation. In practice, this was a major materials research project. It was undertaken by Nath, a physicist, and his colleagues at the Technical University in Munich, Germany. Nath was associated with Kiefhaber at the University of Munich, who was searching for improved means to treat gastric bleeding. This group was aware of the work in endoscopic coagulation of gastric bleeding with laser radiation undertaken by Goodale in 1969 at the University of Minnesota. Goodale used the CO_2 laser system with a rigid gastroscopic tube fitted to the same attachment first used by Jako in surgery of canine vocal cords. At the distal end of the endoscopic tube a retractable 45° mirror projected an unfocused laser beam at 90° to the axis of the gastroscope. The promising results of this work were published by Goodale's group in 1970 (10). At that time, however, rigid gastroscopes were no longer being used clinically, and flexible fibers to transmit the radiation of the CO_2 laser did not exist. Nath developed the flexible fibers capable of transmitting the high-power radiation of argon ion and Nd:YAG lasers. In 1973, Nath and his co-workers (11) demonstrated reliable transmission of up to 10 W of ion laser radiation through a 2.3 m fiber that could be threaded into the biopsy channel of an Olympus gastroscope (American Cystoscopic Makers, Inc., Stamford, Connecticut 06904). Experimental work on treating gastrointestinal tract bleeding with ion laser radiation was soon started by several groups in Germany and in the United States. Selected patients were treated, the first one by Dwyer in the United States.

Kiefhaber in 1975 compared the hemostatic properties of Nd:YAG and ion lasers in the gastrointestinal tract. The Nd:YAG laser system he used had been developed for medical applications by Messerschmitt-Bolkow-Blohm Corporation in Munich, Germany. He was able to obtain hemostasis of the most severe gastrointestinal tract bleeding with high-power Nd:YAG laser radiation. By the end of 1976 he had been able to control 131 of 140 bleeding episodes in 106 patients presenting for emergency endoscopy. He and his associates (12) published these results in 1977, and the technique was rapidly introduced into many centers.

Through Kiefhaber's work it became clear that the radiation of the Nd:YAG laser had hemostatic properties that were far superior to those of the CO_2 and ion lasers because the radiation of the Nd:YAG laser penetrates several millimeters deep into human tissue. Thus, it was also apparent that radiation from this laser could be used to coagulate sizable tissue volumes endoscopically. Soon this property of the Nd:YAG laser was utilized by other researchers, notably Brunetaud in France, Bown in England, and Dwyer and Fleischer in the United States, for the endoscopic coagulation of benign and malignant lesions in the entire gastrointestinal tract.

Endoscopic treatment of bronchial lesions with the Nd:YAG laser followed. At the meeting of the Société Français de la Tuberculose in December 1978, Toty (13) of the Foch Hospital near Paris reported the promising clinical results he had obtained in a small number of patients by endoscopic treatment of bronchial stenosis using radiation from a high-power Nd:YAG laser transmitted through a flexible fiber. He ended this early report by expressing the hope that his results would be as consistently favorable as those obtained with the CO_2 laser in the glottic region by Freche at the same hospital. [Freche (14) had introduced laryngeal microsurgery with the CO_2 laser into Europe.] Toty's hopes were fully justified, as shown by his subsequent work and that of other pioneers in this field: Dumon, Shapshay, and Unger.

Thus, the decade of the 1970s, which had opened with only a handful of investigators searching for nonophthalmologic medical applications of lasers despite disillusionment and failures, closed with legions of patients who had benefited from improved or unique forms of treatment based on use of lasers.

In the 1980s, more researchers became involved, and the indications were extended and the techniques refined. New laser devices, novel instrumentation, and new ideas, such as endoscopic photodynamic therapy and laser angioplasty, may lead to additional dramatic improvements in medical care by the end of this decade. Even the dream of bloodless surgery may become reality. As the medical historian Castiglione (15) so beautifully stated, "the past is never past, but continues and is very active in every form and every manifestation of the present."

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Introduction

The routine application of laser technology in medicine and surgery has gradually become an accepted therapeutic modality over the past 15 years. The application of various lasers to different specialities has stimulated research into newer laser wavelengths and delivery systems. The *Endoscopic Laser Surgery Handbook* is specifically directed toward endoscopic application because in my opinion this is one of the most important applications of laser technology in medicine. The use of lasers in ophthalmology, although of great importance, has been excluded from discussion because this application requires separate handling and is not considered to be of an endoscopic nature. Endoscopy is strictly defined as examination of the interior of a canal or hollow viscus. Laser applications in dermatology and plastic surgery are dealt with in other texts.

I. THERAPEUTIC ENDOSCOPY

The term therapeutic endoscopy, a buzzword of the 1980s, has taken on special importance for medical specialists in particular. With the development of flexible fiberoptics for endoscopy in gastroenterology and pulmonary medicine, more sophisticated endoscopy could be performed on an outpatient basis with the patient under local anesthesia and with less morbidity. For example, bronchoscopy carried out with the rigid instrument was the domain of bronchoscopists, such as otolaryngologists trained in the Chevalier Jackson School of Endoscopy (Temple University School of Medicine, Philadelphia) and thoracic surgeons. Similarly, endoscopy of the esophagus was usually performed by surgeons using rigid esophagoscopes, usually without any telescopic magnification. With the introduction of the flexible fiberoptic endoscopes, procedure-oriented internists began to flourish. Endoscopic application of electrocautery and cryosurgery probes became commonplace. In addition, flexible forceps for use in specialized diagnostic