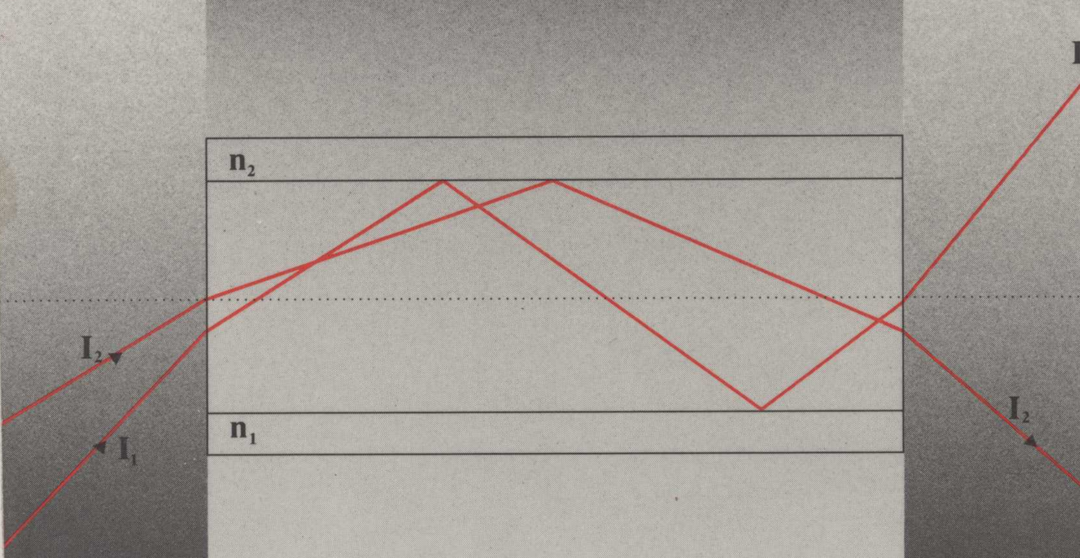
Application of

Lasers in Neurosurgery



Leonard J. Cerullo

APPLICATION OF LASERS IN NEUROSURGERY

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APPLICATION OF LASERS IN NEUROSURGERY

This book is dedicated to the founding members of the Laser Association of Neurological Surgeons International, to those who lit the light and kept it burning

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Preface

It is difficult to justify any technologic tool in surgery by quantifying results. If the instrument appears to have inherent value, a prospective study is morally difficult to design. There is no question, for instance, that the bipolar cautery is an invaluable addition to the neurosurgical armamentarium. On the other hand, there are few articles showing statistical validity to the superiority of the bipolar over monopolar coagulating methods. It is even more difficult to justify improvements on the theme, such as the "nonstick" bipolar. On the other hand, few would deny the major improvement that "nonstick" bipolar cautery has afforded both surgeon and patient. For these technologic advances, then, we are forced to borrow the legal term, "res ipse loquitor," the thing speaks for itself.

Few neurosurgeons who have had the opportunity to use laser in an appropriate fashion would deny the inherent value of the precision and gentleness afforded by this instrument. Accordingly, the use of laser has burgeoned in neurosurgery. Congresses, workshops, and other educational forums have been designed to instruct the neurosurgical community in laser from physics through application. Meanwhile, residency programs have incorporated laser training into their conventional educational program. Lasers, like microscopes and bipolars, have become an accepted part of the neurosurgeon's armamentarium.

This book, dedicated to the founding members of the Laser Association of Neurological Surgeons International, is designed to offer the practicing or training neurosurgeon fundamental information regarding laser physics, safety, application, and direction. The uses of laser are not limited, nor are the wavelengths limited, to those discussed in this brief treatise. On the other hand, it is hoped that this book will pique the imagination of the reader to develop further, to investigate further, and to capitalize further on the use of light energy in surgery.

The future of laser neurosurgery is limited only by the imagination of the surgeons.

LEONARD J. CERULLO, M.D.

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1 Prologue

THOMAS G. POLANYI, PH.D.

I am honored and delighted that Dr. Cerullo has asked me, a physicist, to write a prologue to this book. I am delighted because, twenty years after the discovery of the potential surgical utility of carbon dioxide (CO_2) lasers — an event that I witnessed in my laboratory and that has deeply affected my professional career ever since — the benefits to patients of this and other lasers are continuing to expand.

The role of lasers in the complex tasks of neurosurgery is still evolving. This becomes clear when reading the contributions to this book of the pioneering surgeons in this field. It also becomes clear that this role will become established through new ideas, new approaches, novel instrumentation, and much hard and dedicated work.

In what follows, I will attempt to evoke how lasers were introduced to operative (nonophthalmic) surgery, how cherished initial hopes had to be abandoned, and how slowly accumulating experiences in the field of laryngeal microsurgery benefited other fields, neurosurgery in particular.

The successful realization of the first laser — the ruby laser — by Maiman in 1960 created enormous excitement in the scientific world, including the medical world.

The pioneering work of G. Meyer-Schwickerath in the early 1950s sensitized opthalmologists to the use of light sources in producing therapeutic lesions in the retina. They were the first, in 1961, to experiment with this laser in surgery. Soon the advantage for retinal surgery of this new light source was established, and by 1964 hundreds of patients had been treated. Since that time the use of lasers in ophthalmology has continuously expanded. Currently, the practice of ophthalmology without lasers is inconceivable, and ophthalmologists are still the largest medical users of lasers.

Surgeons in other fields, including neurosurgeons, were also fascinated by the laser. One hope was that irradiating cancers with laser light would lead to more effective cancer therapy. However, these hopes were quickly dashed by the experimental work that followed. There was no reason then, nor is there any today, for this belief. Nevertheless, as later developments have shown, lasers have found a significant role in the treatment of selected cancers, albeit in an entirely different usage. Indeed, it can be anticipated confidently that the association of lasers with the ever-advancing methods of intraoperative real-time diagnosis will lead to a further expansion of laser use in cancer surgery. But this is the future.

The early history of the use of ruby and neodymium (Nd)-in-glass lasers in neurosurgery, which ended in 1967, was summarized in 1974 by Stellar et al., who participated in this early work and who later pioneered the introduction of the CO_2 laser into neurosurgery:

> When ruby laser pulses of a few joules were first applied to tissues, it was found that no effect occurred unless the radiation was focused to a small spot. If a focused spot of either ruby or neodymium lasers was used, small volumes of tissue of about 1 mm were damaged by conversion of the radiation into heat. Small vessels less than 0.5 mm in diameter in the path of the beam were coagulated, while larger ones would be ruptured with obviously potentially disastrous consequences, e.g., in the brain. . . . High-energy pulses focused on tissues created more violent tissue destruction with ejection of disrupted material in the form of a plume created by sudden steam formation. At still higher energies and using larger focal spots, 1/2 to 1 cm, veritable shock waves were created that in experimental animals led to rapid fatalities. . . .
>
> It soon became apparent that to destroy cancers, high-energy pulses focused to a small spot of 1 sq mm had to be used and that each impact made little impression on a neoplastic mass just a few centimeters in diameter. Hundreds of impacts, even thousands, are necessary to destroy such a mass completely, a thing necessary for cure. . . . In addition, it was found that at the required energy levels viable cancer cells could be disseminated by the pulse and/or the shock wave with obvious severe danger of internal transplantation. These various effects have been studied and reported by several authors. Stellar, Fox et al. and Lampert describe experiments in which brain tissue of animals such as mice, cats, and dogs has been driven into cranial openings by ruby laser pulses, hemorrhages have occurred, and the impacts have been followed by immediate death or severe neurological damage. . . .
>
> Transillumination of the tumor by the red beam of the ruby laser of 0.69 μm was thought to alter the enzyme systems of the neoplastic cells with the result that their metabolic processes were reversed and the cells died and were resorbed . . . Regression did not occur in our own series of transplantable ependymoblastomas and melanomas in mice similarly treated with the ruby laser. Some of these were cured, but only if the tumor was small and visibly destroyed by large numbers of laser impacts. . . .
>
> It became obvious that pulsed ruby and neodymium lasers as used were not suitable tools either for cancer therapy or for operative surgery.[1]

The discouragement concerning the use of lasers in operative surgery was caused by the characteristics of the lasers available to these early workers, the ruby and the Nd-in-glass. Electromagnetic energy at the wavelength of these lasers, 0.69 and 1.06 μm, respectively, is poorly absorbed by biologic tissues. In addition, these lasers operate only in short pulses. The discouragement with lasers for surgery lasted a long time, continuing into the period when more suitable lasers had been discovered, particularly the CO_2 laser discovered by Patel in 1964. By 1965, various means had been found to increase the power output of this laser, which operated in the continuous mode at 10.6 μm to the unprecedented level of hundreds of watts.

At that time, I was directing the gas laser research and development work of Laser Inc., a subsidiary of the American Optical Corporation. Early in 1966, Dr. William Z. Yahr called me asking whether he could do an experiment with the CO_2 laser I had operating in the laboratory. Dr. Yahr was then a fourth-year surgical resident at Montefiore Hospital in New York. He had been trying for some time to perfect a nonocclusive side-to-end vessel anastomosis and was searching for an optimal means to create the passage between the common walls of efferent and afferent vessels joined by a glue. He thought that he might use a laser for this purpose. He tried this repeatedly with an Nd-in-glass laser in another facility of the American Optical Corporation in Southbridge, Mass., where this laser had been discovered. He had encountered difficulties in this work and he realized that these were caused by the lack of absorption by tissues of the energy of the Nd laser. He thought that by staining the tissues with copper sulfate he would overcome the problems. However, a new problem presented itself at the power and energy levels necessary to create the desired passage: the glued common wall was disrupted by the impact of the beam. With the help of physicists at Southbridge, Dr. Yahr explored the absorption characteristics of biologic tissues and concluded: "Briefly, tissues are almost perfect black bodies for the molecular nitrogen–carbon dioxide laser and relatively good black bodies for the argon ion laser." This was the background to Dr. Yahr's call to me.

Our CO_2 laser was a typical physics laboratory laser; in particular, the focused beam was stationary. After preliminary trials, Dr. Yahr brought anesthetized dogs to the laboratory, and soon numerous surgical operations were performed by slowly moving the anesthetized animal under the fixed focused beam. With growing enthusiasm, Dr. Yahr and his senior colleague Dr. J. K. Strully used the focused CO_2 laser beam to make skin incisions, cut through muscle and fascia, perform laparotomies, and resect liver lobes. It seemed miraculous to see that not only did tissues part, as if by a steel scalpel, by invisible "immaterial" energy, but tissue bleeding was minimal. These were my first contacts with the surgical world and the first operations at which I had ever assisted. When the liver resection was made, I thought that there was much bleeding, and I must confess that my "inner man" was not quite well for 24 hours. I was assured, however, that the bleeding I had seen was nothing compared with the same operation performed with a steel scalpel.

The enthusiasm of Yahr and Strully for this new potential surgical instrument was obvious and infectious. It led to the development of the first CO_2 laser system for surgery. This was a self-contained, movable system with beam delivery through a hand-held focusing system, later named the focusing hand piece, attached to the distal end of an articulated arm. The point of impact of the movable beam was marked by a set of white light cross hairs. It became available for surgical research in spring of 1967. In an article that appeared at the end of 1966, Yahr and Strully 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. Leaving

the realm of arterial surgery one may consider some of the following uses. . . . Many brain tumors, and some congenital defects, block the reflow of 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] fracture stones blocking important biologic duct systems. . . . It appears probable that the nitrogen carbon-dioxide laser will find a place to make rapid skin incisions, divide certain organs without blood loss, and to anastomose vessels as an adjunct to standard techniques.[2]

In March 1967, American Optical's CO_2 laser system for surgery with an articulated arm was exhibited at the meeting of the American College of Surgeons in New York City. The news spread rapidly; already in 1967, Dr. R. Edlich, in the laboratory of Prof. O. H. Wangensteen at the University of Minnesota, Minneapolis, showed that with the unfocused beam of the CO_2 laser the parietal cells could be devitalized without damage to the lamina muscularis mucosae. In the same laboratory, Drs. R. Gounzalez and R. L. Goodale used the defocused beam to obtain hemostasis of subcapsular superficial lesions of the liver and of deep gastric erosions. They found that hemostasis was obtained much more rapidly than with electrocoagulation.

Many other short- and long-range investigations were soon started. Apart from Dr. Edlich's investigation, which might be described loosely as functional surgery, the majority of these investigations were motivated by the ancient and recurring dream of bloodless surgery. One of these investigations indirectly had an important bearing on the introduction of the CO_2 laser to neurosurgery. This was the extensive investigation on burn débridement started in 1968 by Dr. James Fidler, who was associated with the laser laboratory of Dr. Leon Goldman and the Shriner's Burn Institute of the University of Cincinnati. Dr. Fidler reported his initial results at the Gordon Research Conference on Lasers in Medicine and Surgery in summer 1968. Participating in the conference was Dr. Stanley Stellar. He recognized the profound differences between the effect of this laser beam on tissues and those of the ruby and Nd-in-glass lasers with which he had worked until then. Immediately following the conference, he came to our laboratory and performed a variety of surgical experiments on cat scalp, dura, brain, and spinal cord. He was extremely encouraged, and this was the start of his extensive, classic experimental investigations on the use of the CO_2 laser in neurosurgery, first at St Barnabas Hospital in Bronx, N.Y., and later at St Barnabas Hospital in Livingston, N.J.

In the first article on this subject in 1970, we wrote:

The ability of the CO_2 laser beam to cut tissue effectively was readily apparent from the outset and virtually all tissues yielded to it without difficulty. Haemostasis was excellent in cats, rabbits and mice. . . .

Tumours could be made to disappear by vaporization directly to a gas or they could be incised in the same manner as ordinary tissue. . . .

> To see a cancer disappear in smoke within a matter of a few minutes is remarkable. . . .
> Minimal lesions of a predetermined size could be made quite easily, suggesting that functional neurosurgical procedures might well be developed with this new technique. . . .
> Spinal cord pathways such as those subserving pain can also be easily destroyed, whenever they can be reached surgically. Whether the laser will compete effectively with current cryosurgical or radio-frequency methods cannot be predicted at present. . . .
> Haemostasis with the CO_2 laser is good in all tissues since capillaries, veins and small arteries are readily coagulated if the power output is a few watts or more using a focused beam. Larger vessels will be perforated with resultant bleeding but experiments are now in progress in our laboratory to determine which parameters, particularly high intensity and defocusing, will prevent perforation of vessels before coagulating them. . . .
> Computer control, with automatic scanning resulting from a suitable feed-back mechanism, might reduce the operating time for large tumours provided the neurosurgeon over-rides the instrument whenever necessary.[3]

With light and electron microscopic histologic studies, we showed the characteristics and the limited range of the tissue damage produced with the CO_2 laser. We summarized the advantages of the laser as follows:

> (1) Ability to deliver a high intensity, directed, easily controllable beam of energy for the rapid and effective cutting, drilling or vaporization of tissue. (2) The lack of forced impact and, hence, gentleness of action on surrounding tissue. (3) A restriction of action when properly controlled to a distance of less than 1 mm from the edge of the beam. (4) The ability to destroy micro-organisms and to sterilize tissues during its application.[3]

In 1969, Dr. Stellar performed his first operation on a human. This was the first neurosurgical operation with a CO_2 laser and the first clinical use of the CO_2 laser on man. In the same 1970 article, we wrote:

> One human brain tumour, a primary malignant glioblastoma multiforme, was treated surgically by means of the carbon dioxide laser on 26 May 1969. Previous conventional surgery and radiotherapy had already failed to help. This case showed the technical feasibility of using this laser in patients, since the neoplastic tissue was readily vaporized with no visible impact or other harmful effect on the surrounding brain. The clinical recovery from the operation during the early post-operative period was unusually good with lessening of the pre-existing neurological abnormalities. No attempt was made, because of the unfavourable location of the tumour in the dominant motor and speech area, to perform a radical destruction of neoplasm. Application of this method to the treatment of additional otherwise hopeless human brain tumours is now warranted.[3]

The way for further studies and clinical applications of the CO_2 laser in neurosurgery appeared to have been opened. But the use of this laser in neurosurgery remained dormant for many years.

As mentioned earlier, most of the initial investigations in surgery were based on the hoped-for hemostatic properties of the CO_2 laser. This search continued for most of the 1970s, even in the face of experimental evidence that the hemostatic properties of this laser were limited. The real surgical utility of the CO_2 laser emerged slowly from the work of Dr. Geza J. Jako, an otolaryngologist, which started in 1968. This led to combining the CO_2 laser beam with an operating microscope and to controlling the position of the focal spot in the visual field of the microscope by means of a micromanipulator. The first laryngeal operation with this instrumentation was performed in 1971 by Drs. M. Stuart Strong and Geza Jako of the Boston University Medical School. Recognition of the advantages of this new surgical modality for numerous operations in the aerodigestive tract spread rapidly, and soon it became the method of choice in many hands. Today, the CO_2 laser–operating microscope combination is universally recognized as an essential adjunct in laryneal microsurgery.

What makes the CO_2 laser modality so valuable in surgery of the aerodigestive tract are the following characteristics: (1) precise removal of tissues from a distance; (2) the ability to remove minimal tissue volumes with minimal adjacent tissue damage; (3) the ability to operate in restricted areas, and by the use of mirrors in areas not accessible to direct vision; (4) the lack of encumbrance by solid instruments of the restricted visual space available when operating in deep cavities; (5) lack of bleeding from capillaries and small vessels, which preserves the improved tissue diagnosis capability of the operating microscope; (6) the generally benign tissue reaction and uneventful healing of laser wounds.

I firmly believe that the more one or more of these characteristics are vital in an operation, the greater is the potential applicability of the CO_2 laser as a primary or adjunctive surgical modality. Gynecologic microsurgery, today one of the more extensive applications of CO_2 lasers in surgery, is based on these characteristics. It was inspired directly by the larnygeal work; indeed, the first gynecologic operations in 1974 took place in the operating rooms of laryngeal surgeons.

Investigation of the applicability of the CO_2 laser to neurosurgery was taken up in summer 1975 by Dr. Peter W. Ascher and his chief, Dr. F. Heppner, at the University Hospital in Graz, Austria. Building on the work of Stellar and encouraged by the expanding clinical applications of lasers, extensive animal experimentation was undertaken. Histologic studies with light, transmission, and scanning electron microscopy revealed a wealth of new information on tissue damage following application of laser energy, particularly to neural structures. On June 28, 1976, the first brain glioma operation was successfully performed in Graz. This was followed by an additional 69 operations in the short span of 9 months; at which time Dr. Ascher submitted for publication his monograph, *Der CO2-Laser in der Neurochirurgie*. The operations included treatment of 16 glioblastomas, 16 meningiomas, and other brain tumors, functional surgery, and spinal cord and peripheral nerve operations. In analyzing this work, Dr. Ascher pointed out the ability of directing the laser beam at any angle with mirrors, the noncontact action of the laser beam, and the avoidance of electrical stimulation of nervous tissue. He found the laser essential in removing firm central tumors. He also found that, in selected cases, shortened operating time and decreased postoperative morbidity may add up to an essential advantage. He foresees that, with the help of lasers, selected operations hitherto considered "major brain surgery" may become more routine. All but three of these operations were done "freehand." He noted that in the macroscopic approach, laser and conventional techniques have many similarities but that laser neuromicrosurgery with the micromanipulator is entirely new territory.

The operative momentum in Graz has continued. By 1985, 889 operations had been performed with lasers, 743 with the CO_2 laser and 146 with the Nd:YAG laser, discussed below. From these a wealth of experience, indications, contraindications, and partial indications have emerged.

Starting in 1977, Drs. Ascher and Heppner forcefully advocated the selective use of lasers in neurosurgery in numerous articles and lectures. This activity, and the support of Laser Industries, Ltd., Tel-Aviv, Israel, whose CO_2 laser instruments Drs. Ascher and Heppner used, stimulated the interest of many neurosurgeons in Europe, the Far East where efforts to apply the laser to neurosurgery had already been started, and the United States. In 1979, Prof. Aldo Fasano, a neurosurgeon, organized the first National Congress of the Italian Society for Laser Surgery in Torino, Italy. There a full session was devoted to the use of lasers in neurosurgery.

In the United States, neurosurgeons at different centers undertook basic experimenal and clinical investigations. Seminars and teaching courses were instituted. Dr. Leonard Cerullo established such a center of studies at Northwestern University Medical School in Chicago. Through his initiative, the first American Congress of Laser Neurosurgery was convened in October 1981. The three-day sessions were attended by over 100 neurosurgeons, and 20 papers were presented and discussed. Two more such conferences were held in Chicago in the following two years with increasing participation. Basic investigations, analysis, and exploration of the applications of lasers to neurosurgery had acquired the needed momentum.

During the time these developments were taking place, lasers other than the CO_2 laser started to play a significant role in neurosurgery. The most important of these for neurosurgery is the Nd:YAG laser. The output of this laser is continuous, contrary to the pulsed characteristics of the Nd-in-glass found so unsuitable for surgery in the early 1960s. Radiation of this laser at 1.06 μm penetrates deeply into tissues, millimeters as opposed to microns for the CO_2 laser. For this reason its hemostatic properties are excellent. The first use of this laser in medicine became a reality through the untiring efforts, started in 1975, of Dr. Peter Kiefhaber and Dr. Gunther Nath, a physicist. Dr. Nath developed the first fiber capable of transmitting high-power Nd:YAG radiation. Introducing this fiber in one channel of a gastroscope, Dr. Kiefhaber developed methods for the endoscopic coagulation of massive gastrointestinal hemorrhages. These obtained clinical success in 1977 and stimulated much additional work with this laser. The Nd:YAG laser used in this work was developed by Messerschmitt-Bolkow-Blohm Medizintechnik of Munich. Many investigations related to the use of the Nd:YAG in medicine were undertaken there owing to the support of the Gesellschaft fuer Strahlenforschung, a semiofficial institute for the study of laser radiation. There, Dr. K. K. Jain pioneered the work on sutureless microvascular anastomosis with the Nd:YAG laser.

Prof. Oskar J. Beck pioneered the use of the Nd:YAG laser in neurosurgery starting in 1976. By July 1979, the Nd:YAG laser had been used in 103 neurosurgical operations in the Neurological Clinic of the University of Munich, 51 of these on meningiomas.

The radiation of the Nd:YAG, owing to its deep penetration into tissues, cannot be used for dissection in proximity to sensitive functioning tissue, but other characteristics of this radiation are important in neurosurgical applications. In addition to hemostasis as already mentioned, it can be used for coagulating sizable volumes; also, this radiation is transmitted through cerebrospinal fluid with little attenuation. Flexible fibers are routinely available today that permit the development of very light hand-held accessories; endoscopic operations, as already undertaken by Dr. Ascher, are possible.

For many years, not surprisingly, a rivalry developed between proponents of the CO_2 and the Nd:YAG lasers. Today it behooves us to consider these lasers as complementary adjuncts to selected areas of surgery. Fasano has started using them in this way. Others select one or the other. Many of the early pioneers of surgery with lasers dreamed of the time when multiple-wavelength lasers would become available. Cooper LaserSonics now produces a surgical system delivering CO_2 and Nd:YAG laser radiations to explore areas of complementarity.

Through the work of Drs. J. Boggan, M. S. B. Edwards, and A. Fasano, the argon ion laser has also found specialized applications in neurosurgery, for example, to small arteriovenous malformations and in functional surgery. Earlier, this laser had been used only sporadically in experimental neurosurgery, by Dr. J. L. Fox for brain-tissue incision and by Dr. G. Maira for experimental aneurysm treatment.

The path to using lasers in neurosurgery has been tortuous. Expectations had to be modified and reduced, experience accumulated, approaches tried and discarded, new instrumentation developed, and many types of lasers tested. This work is continuing. No one surgical instrument or technique, or diagnostic method, is going to solve all the complex problems daily facing the surgeon. But all together, coordinated by the judgment and the skill of the surgeon, they will increasingly benefit patients, as discussed in the chapters of this book.