Advances and Technical Standards in Neurosurgery

Edited by

L. Symon, London (Editor-in-Chief)
J. Brihaye, Brussels
B. Guidetti, Rome
F. Loew, Homburg/Saar
J. D. Miller, Edinburgh
H. Nornes, Oslo
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Vol. 13

Springer-Verlag Wien New York

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Springer-Verlag
Wien New York 1986

With 77 partly colored Figures

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Library of Congress Catalog Card Number 74-10499

Printed in Austria

ISSN 0095-4829
ISBN 3-211-81885-5 Springer-Verlag Wien—New York
ISBN 0-387-81885-5 Springer-Verlag New York—Wien

Sponsored by the
European Association of Neurosurgical Societies

Preface

As an addition to the European postgraduate training system for young neurosurgeons we began to publish in 1974 this series devoted to Advances and Technical Standards in Neurosurgery which was later sponsored by the European Association of Neurosurgical Societies.

The fact that the English language is well on the way to becoming the international medium at European scientific conferences is a great asset in terms of mutual understanding. Therefore we have decided to publish all contributions in English, regardless of the native language of the authors.

All contributions are submitted to the entire editorial board before publication of any volume.

Our series is not intended to compete with the publications of original scientific papers in other neurosurgical journals. Our intention is, rather, to present fields of neurosurgery and related areas in which important recent advances have been made. The contributions are written by specialists in the given fields and constitute the first part of each volume.

In the second part of each volume, we publish detailed descriptions of standard operative procedures, furnished by experienced clinicians; in these articles the authors describe the techniques they employ and explain the advantages, difficulties and risks involved in the various procedures. This part is intended primarily to assist young neurosurgeons in their postgraduate training. However, we are convinced that it will also be useful to experienced, fully trained neurosurgeons.

The descriptions of standard operative procedures are a novel feature of our series. We intend that this section should make available the findings of European neurosurgeons, published perhaps in less familiar languages, to neurosurgeons beyond the boundaries of the authors countries and of Europe. We will however from time to time bring to the notice of our European colleagues, operative procedures from colleagues in the United States and Japan, who have developed techniques which may now be regarded as standard. Our aim throughout is to promote contacts among neurosurgeons in Europe and throughout the world neurosurgical community in general.

We hope therefore that surgeons not only in Europe, but throughout the world will profit by this series of Advances and Technical Standards in Neurosurgery.

The Editors

List of Contributors

Epstein, Fred, M.D., Professor of Neurosurgery, Department of Neurosurgery, Division of Pediatric Neurosurgery, New York University Medical Center, 550 First Avenue, New York, NY 10016, U.S.A.

Tew, John M., Jr., M.D., Professor and Chairman, Department of Neurosurgery, University of Cincinnati, College of Medicine, 231 Bethesda Avenue, Cincinnati, OH 45267, U.S.A.

Tobler, William D., M.D., Department of Neurosurgery, University of Cincinnati, College of Medicine, 231 Bethesda Avenue, Cincinnati, OH 45267, U.S.A.

Wieser, PD Dr. med. H. G., Oberarzt Neurologie/EEG, Universitätsspital, CH-8091 Zürich, Switzerland.

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A. Advances

Present Status of Lasers in Neurosurgery

J. M. Tew, Jr., and W. D. Tobler

Department of Neurosurgery, University of Cincinnati, College of Medicine, Cincinnati, Ohio (U.S.A.)

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The application of laser technology to medicine and surgery has lagged behind industrial, recreational and military development. Acceptance has been slow in neurological surgery until refined technology was developed and skilled investigative surgeons recognized the potential for this new technology when applied with microscopic principles. Creative approaches, applications and remarkably improved results have been achieved. Yet we are probably only in an infantile stage of development of the potential of the myriad of applications of laser energy in Neurosurgery. In this chapter, we will review the currently accepted technology, applications and practical results which have been achieved.

History and Evolution of Laser Neurosurgery

The first laser was produced in 1960 by Maiman utilizing a ruby crystal[64]. Early investigators studied the effects of ruby laser energy on neurological tissues in experimental animals[12, 13, 26, 52]. Rosomoff used pulses of ruby laser energy in three patients with glioblastoma in 1966[53]. This laser was abandoned for the more powerful carbon dioxide laser developed in 1964 by Patel[45]. Stellar used the experimental carbon dioxide laser to define the characteristic histological lesions produced by various amounts of energy[56]. He reported the first application of the carbon dioxide laser in patients with glioblastomas in 1969[64]. In the same year, Takizawa began experimentation and development of carbon dioxide laser systems in Japan[60, 61]. Ascher and Heppner reported their first clinical experience with the carbon dioxide laser in 1976[3—5, 32] and Beck began experimentation and clinical application of the Neodymium:YAG laser in 1977[7, 8]. Laser neurosurgery education courses were initiated in the United States by Cerullo in 1980[11]. By 1984, the surgical laser had become an indispensible tool in many neurosurgery centres around the world[5, 7, 18, 28, 30, 33, 39, 40, 44, 51, 58, 62—64]. The carbon dioxide laser is now the most commonly used laser in neurosurgery. At the present time the Nd: YAG and argon lasers are not available for clinical neurosurgical use in the United States except by those individuals who have an investigational device exemption authorized by the Food and Drug Administration. Other lasers which are currently under experimental evaluation include tunable dye lasers and free electron lasers.

Principle of Laser Function and Application in Biological Tissues

Laser is an acronym which stands for Light Amplification by the Stimulated Emission of Radiation. Laser light is produced by electrical stimulation of the active medium, *i.e.*, carbon dioxide (gas), or Nd: YAG crystal (solid), which results in electron transitions to higher energy states in the molecules of the medium. These energized molecules spontaneously revert to an unenergized or ground state, in a decay process in which photons are emitted. These photons are captured, modified and form the laser beam (Fig. 1). The laser beam is transmitted either to the surgeon for free-hand application, or attached to the operating microscope where it can be manipulated by the surgeon or by a microprocessor[14]. The carbon dioxide laser has physical wavelength characteristics which currently proscribe transmission by a fibre-optic system. Thus the carbon dioxide beam is reflected via a series of interlocking hollow tubes and mirrors to the microscope. Inability to transfer the carbon dioxide beam is a practical

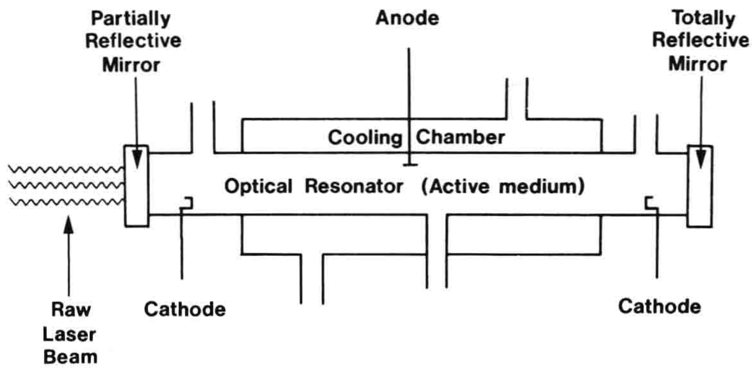

Fig. 1. Schematic illustration of gas laser. The active medium is contained within the optical resonator. High voltage stimulation results in molecular excitation. In the decay process these molecules emit photons and this process is called stimulated emission. The photons are captured and form the laser beam. (From Ref. 64)

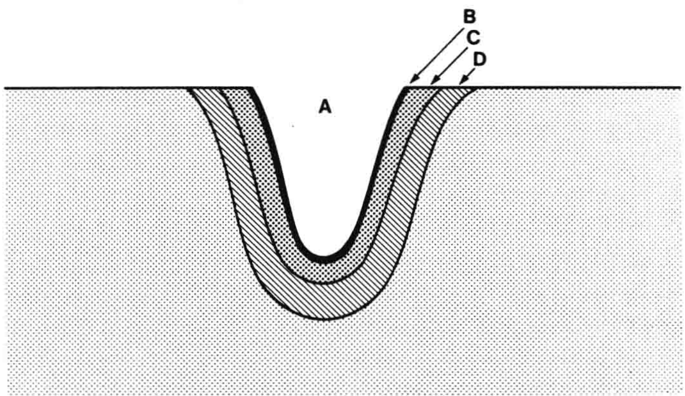

Fig. 2. Morphology of a laser lesion. *A* Central crater. *B* Charred mantle. *C* Dessication zone. *D* Oedema zone. The actual size and relative proportion of each zone varies according to power setting, mode of application, and laser. (From Ref. 64)

handicap which will probably be solved by the development of more efficient fibre bundles. The Nd : YAG laser and argon laser beams utilize quartz fibre-optic delivery systems[46–48, 55, 57].

Laser energy exerts its destructive effect on biological tissues by a thermal reaction created by excitation of vibrational and rotational levels of matter[46]. Concentric zones of tissue injury are formed by laser impact (Fig. 2). These include a central crater formed by the instantaneous superheating and vapourization of cellular contents where temperatures

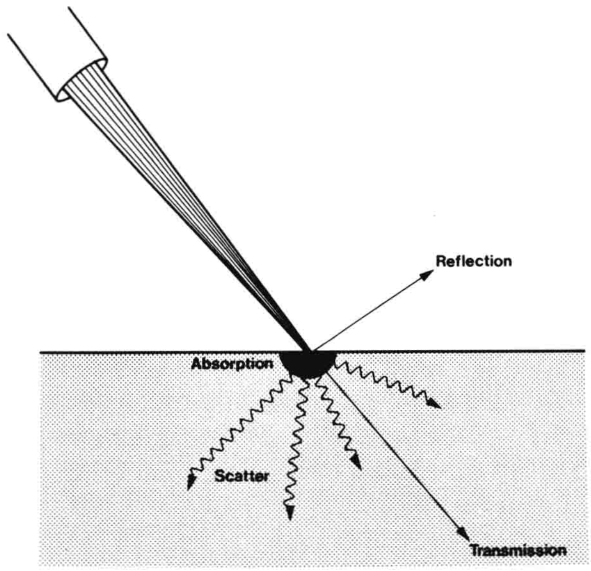

Fig. 3. Diagram of laser-tissue interaction. The tissue effect for the application of a specific laser will be one or a combination of reflection, absorption, scatter and transmission. The effect is determined primarily by the type of laser, and the biological properties of the tissue. The factors which influence tissue reaction are optical density, cellular composition, water content, temperature and pigmentation. (From Ref. 64)

reach several hundred degrees centigrade at the point of impact. The inner layer of damaged tissue consists of a charred mantle of cellular debris, surrounded by a zone of desiccated tissue, and the outermost zone consists of edematous but viable tissue[2, 6, 67]. Four characteristic reactions occur when laser energy is applied to biological tissue. These are reflection, absorption, scatter, and transmission (Fig. 3). The degree to which these effects occur varies with each laser and this characterizes the unique properties of the individual laser wavelength.

The nature of the lesion is also determined by the optical and biological properties of the target tissue. These properies are influenced by the cellular composition, water content, pigmentation and vascularity of the tissue. Current studies are evaluating the optical properties of pathological neural tissue[16, 20].

Neurosurgical Lasers

Carbon Dioxide Laser

Carbon dioxide laser energy has a wavelength of 10.6 microns which is located in the far infrared region of the electromagnetic spectrum (Table 1).

Table 1. *Characteristics of Commonly Used Neurosurgical Lasers*

	CO_2	Nd:YAG	Argon
Wavelength (microns)	10.6	1.06	0.488–0.514
Electromagnetic spectrum	far infrared	near infrared	visible (blue-green)
Power range (watts)	1–100	1–100	1–20
Pigment-dependent	no	yes	yes
Scatter (tissue)	low	high	medium
Absorption (tissue)	high	low	medium
Transmission (water)	no	yes	yes
Mode	CW, pulsed, super pulse	CW, pulsed, Q-switched	CW, pulsed
Delivery system	articulated arm micromanipulator	fiberoptic cables micromanipulator	fiberoptic cables micromanipulator

Therefore, the beam is invisible, and for clinical application these lasers must be equipped with a coaxial helium-neon pilot laser beam. Carbon dioxide energy is characterized by near total surface absorption, a fact which makes it a valuable instrument for ablative purposes (Fig. 4). The carbon dioxide laser is particularly applicable to neurosurgery because it efficiently vaporizes tissues. The effect is superficial; ablation is restricted to the tissue which the surgeon can directly visualize. Carbon dioxide laser energy is not selectively absorbed by pigmented tissue and therefore its biological effect is not enhanced by vascular or pigmented tissue. Because of superficial absorption of the carbon dioxide laser beam, it is rendered ineffective in a field flooded by water or blood. This property can be used to one's advantage to insure safe application of the laser. Water soaked cottonoids placed on important structures such as nerves and arteries serves to protect them while adjacent tissue is vapourized (Table 2).

The carbon dioxide laser beam can be focused by lenses to a fine point of 250 microns concentrating the energy to a very high power density (expressed in watts/cm^2). The focused beam then functions as a scalpel to sharply incise tissues to any desired depth. Defocusing enlarges the spot size, diffuses the power and converts the laser to an ablative instrument which vapourizes tissue mass. A further increase in spot size and subsequent

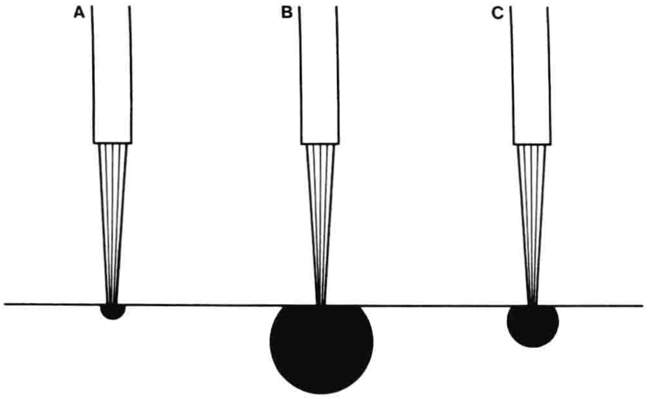

Fig. 4. Relative laser-tissue interaction. A) Superficial effects of absorption dominated, low scatter CO_2 laser. B) Deep tissue effect of the scatter-dominated low absorption Nd : YAG laser. C) Intermediate effects of the medium-absorption, medium-scatter argon laser. (From Ref. 64)

Table 2. *Advantages and Disadvantages of the Carbon Dioxide Laser*

Advantages	Disadvantages
High power for tissue ablation	lack of fibre-optic cables for beam transmission
No touch vapourization	non-transmission through water and blood
Precise microscopic control	requires co-axial pilot laser
Minimizes brain retraction	
Decreases blood loss	
Minimizes tissue manipulation	
No electrical interference with monitors	
Protective effect of water	
Micromanipulator attachment	

reduction in power density, enables coagulation of capillaries and small blood vessels. A finely focused beam at very low powers applied continuously, or intermittently, provides a precise microscopic tool capable of vapourizing minute fragments of tissue from vital nerves and vascular structures. Precise control of power density and manipulation of the beam is required to avoid undesired injury to critical structures. A power density that is too high may injure a vascular structure and cause uncontrollable haemorrhage. Considerable experience is required to develop a sense of stereoscopic control of the laser's potential destructive force. In neurosurgery, the principal application of the carbon dioxide laser is in microsurgical procedures where access is limited, the tissue is calcified, vascular, or entangled by eloquent tissue. Micromanipulators which contain focusing lenses attach to the microscope and provide cursor control of the visible coaxial helium-neon beam. These microscopic attachments adapt to any operating microscope and do not significantly encumber the function of the equipment. The most advanced systems contain an infinitely variable spot size, variable focal length and analog-computed power density[15]. A microprocessor can be programmed in a multi-dimensional configuration of the target and the laser will precisely ablate the delineated structure under microscopic stereotaxic control[14].

Milliwatt carbon dioxide lasers are capable of generating very small spot sizes, of 150 microns yet are capable of achieving enormous power density. These small units can be directly attached to the microscope for reconstructive welding and ultra-precise surgical feats[41]. The theoretical basis for tissue welding can be explained by lysis of intermolecular collagen bonds, which occurs at precisely controlled, low temperatures. On cooling new bonds are formed and welding of tissue surfaces may be accomplished[64]. Apposition of divided ends of a vessel may facilitate anastomosis with a minimum number of sutures. This process can coapt neural and dural tissues. Conventional large carbon dioxide lasers lack the fine power control necessary in the lower ranges of operation for welding. A milliwatt laser can be purchased as a separate unit, or an attachment can be added to the carbon dioxide laser. The theoretical advantages of these milliwatt systems for anastomosis have not been substantiated in practical application, thus no significant body of human experience has accumulated in the application of this laser. The clinical effectiveness of these new applications are ready for documentation.

Nd: YAG Laser

The Nd : YAG laser is a solid state laser which emits invisible light with a wavelength of 1.06 microns and is located in the near infrared region of the electromagnetic spectrum (Table 1). This wavelength is associated with tissue scatter and minimal absorption (Fig. 4). Because of this, Nd : YAG energy penetrates more deeply into the target tissue producing a deep thermal effect which results in shrinkage, coagulation, and necrosis of tissue 4 to 6 mm below the surface. The coagulation effect is enhanced by the preferential absoption of the laser energy by pigmented, especially heme-pigmented, tissues. These properties combine to make the Nd : YAG laser a potent coagulative device. It has some ablative effect, but is markedly less efficient in vapourizing tissue than the carbon dioxide laser. Nd : YAG energy is thoroughly transmissible through water, so that it can be used effectively in a fluid filled cavity. Nd : YAG energy is transmissible through thin quartz fibres which greatly enhances its delivery to the tissue surface.