April 1988
Volume 207, Number 4

Annals of Surgery

What's New In General Surgery

Current Laser Applications in General Surgery

JOHN A. DIXON, M.D.

From the University of Utah Department of Surgery Laser Institute, and the Laser Section, Salt Lake Veterans Administration Medical Center, Salt Lake City, Utah

THE POSSIBILITY of application of lasers as a surgical instrument has intrigued surgeons since the introduction of the first CO_2 medical lasers in 1967.[1] Laser surgery has been characterized by a great amount of basic research and clinical application in nearly every surgical specialty. Like most new instruments, procedures, or medications, laser surgery has gone through the usual cycle of abundant optimism and expansive claims, followed by complications and criticisms, followed by a gradual transition into realistic expectations and utilization. Fortunately, much of media hype and sensationalism regarding lasers in medicine has subsided and been replaced by careful evaluation and comparison with the established modalities and techniques. In some situations, such as endoscopic laser control of gastrointestinal (GI) bleeding, a reasonable number of prospective controlled randomized trials have been carried out. In many other instances, such as endoscopic laser pancreatic cystogastrostomy, however, the number of cases in which lasers have been employed are few and results almost anecdotal. Maturity in each specialty of each procedure must be evaluated.

A discussion of laser applications in general surgery must first approach the difficult task of defining general surgery. For the purpose of this paper, the American Board of Surgery description, which includes "general processes involving wound healing, hemostasis, neoplasia, and surgery of endocrine system, hernia, vascular system, gastrointestinal tract, abdominal organs and endoscopic principles and applications," will be utilized.[2] Lasers are employed relatively infrequently for limited indications by the traditional surgeon using incisional techniques. When one considers, however, the disease processes being treated by endoscopic laser techniques that would have formerly been managed by the general surgeon, a great impact on this specialty is evident.

Reprint requests: John A. Dixon, M.D., 50 North Medical Drive, Salt Lake City, UT 84132.

Submitted for publication: November 5, 1987.

Laser Fundamentals and Instrumentation

The principles necessary for the formation of the concept of lasers were noted as early as the 19th century with the presentation of Bohr's theory of optical resonators. In 1917 Einstein proposed the concept of stimulated emission of light.[3]

An extensive discussion of subsequent developments in laser physics is not consistent with this clinical review. In general, however, an atom, molecule, or ion in its resting energy state or ground state is excited to a higher energy state by the absorption of thermal, electric, or optical energy. After energy is absorbed, an atom, mole-

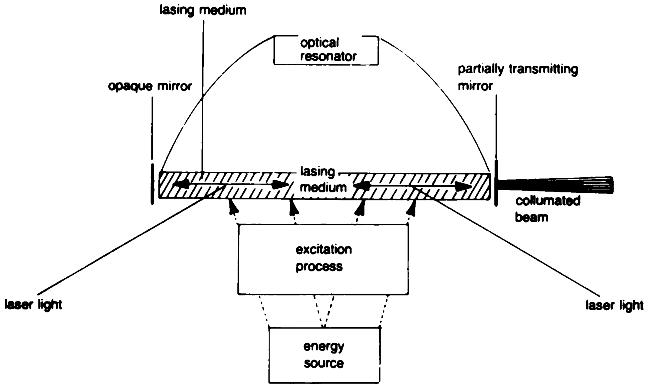


FIG. 1. Outline of laser operation. Energy source produces excitation process with excitation of lasing medium. Photons from lasing medium reflect off mirrors and are released through partially transmitting mirror (*right*).

cule, or ion spontaneously returns to a ground state and thereby liberates absorbed energy as a photon. The energy so created emerges as light that is coherent, of one wavelength, and in temporal and spatial phase (Fig. 1). This allows the beam to be focused, made divergent, or collimated (directed in parallel fashion, not focused or divergent). Such coherent light then may be focused on mirrors or flexible quartz rods (fiber) transmission.

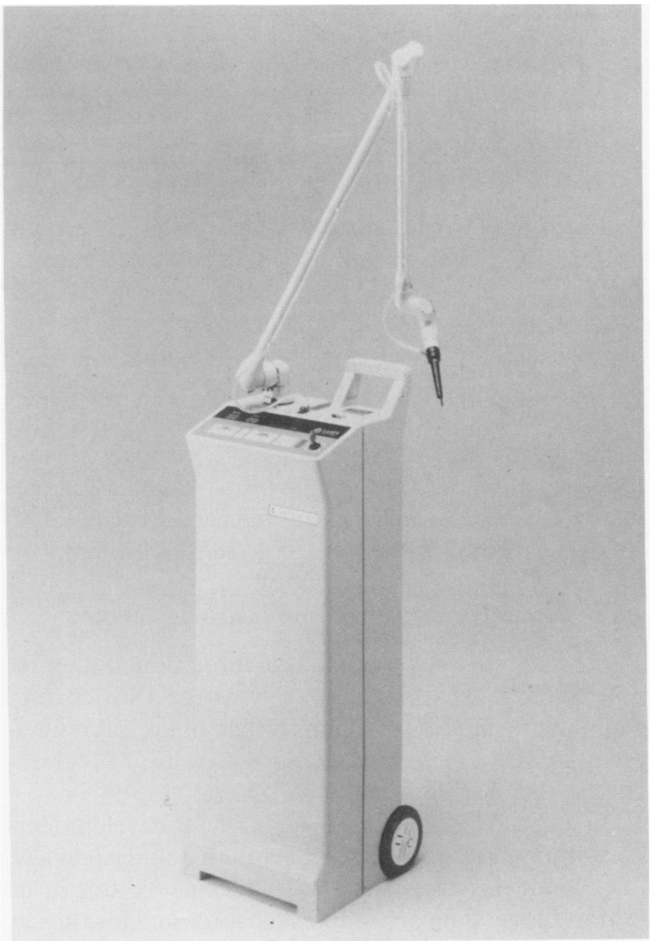


FIG. 2. Compact, portable 30 watt CO_2 laser with articulating arm for general surgical use (Sharplan Model 1020).

As laser light impinges upon tissue it may be reflected, absorbed, scattered, or transmitted.[4] The amount of absorption is determined by substances called chromophores. Two of the most common chromophores in tissue are hemoglobin and water.

Lasers in common use are the CO_2, argon, and neodymium YAG (Nd:YAG) lasers. Carbon dioxide laser energy (10.6 μm) is ideal for cutting and vaporization because it is heavily absorbed by water.[5] Unfortunately, CO_2 energy transmission requires a series of mirrors and an articulating arm for transmission. Although digital control of handpieces and articulating arms is fairly good, this method is still awkward in abdominal and other applications. Because of absorption by water, thermal injury from a given amount of energy from this laser is relatively superficial, ranging from 50 to 100 μm in depth. Small portable laser devices are available (Fig. 2).

Argon laser light (458–515 nm) is very heavily absorbed by hemoglobin and is especially useful in nonbleeding vascular lesions when precision and minimal depth of penetration (about 1 mm) are required.[6] Although heavily absorbed by blood, argon laser energy can be transmitted readily through water, gastric fluid, urine, *etc.*

The Nd:YAG laser (1.06 μm) has less specific absorption by water and hemoglobin than the preceding two lasers.[7] This results in a depth of thermal injury of approximately 3 mm in most tissues, which is useful for coagulation of large volumes of tissue such as in palliative coagulation of esophageal and colonic carcinomas.

While most laser applications are made using a noncontact technique, there has been recent introduction of a variety of sapphire or ceramic contact tips for handheld or endoscopic use, which allow for application of pressure to bleeding vessels or highly focused laser energy on the tip of a laser scalpel to minimize diffusion and laser tissue injury (Fig. 3).[8]

Unlike many surgical devices, the laser may harm surgeons and operating personnel as well as patients.[9] Goggles or appropriate eye wear with filters capable of protecting against the wavelength in use must be worn at all times. Access to the operating suite must be controlled so that individuals without appropriate eye wear do not enter. Surgical instruments in the field must be of a nonreflective type. Operating room drapes must be moistened or inflammable. Endotracheal tubes must be either metal or wrapped with reflective tape to prevent ignition or melting.[10]

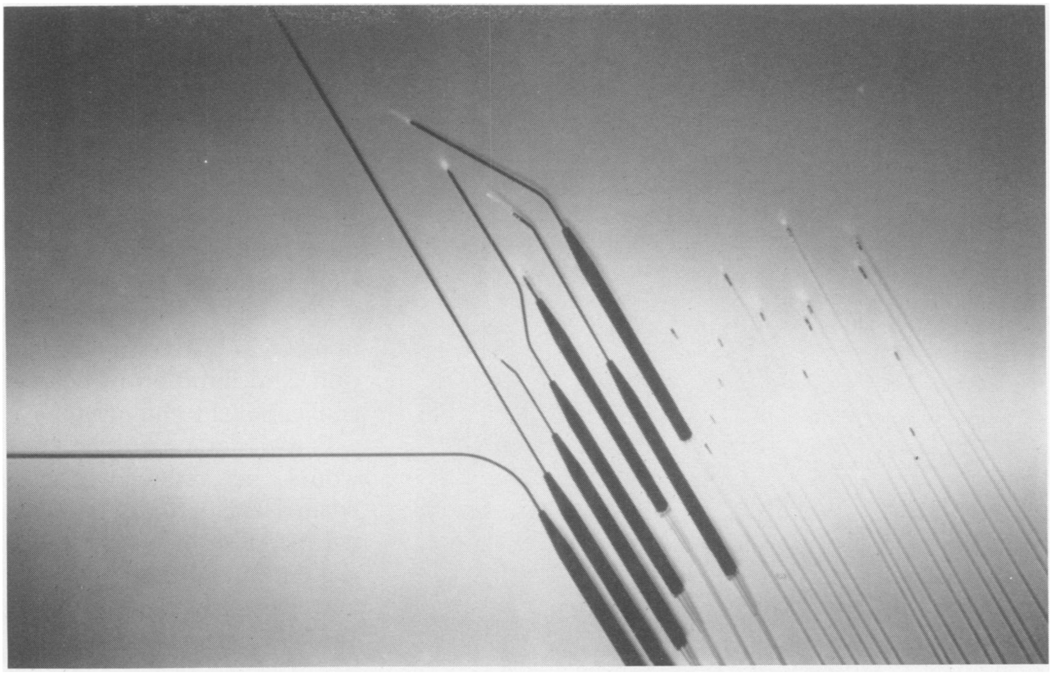


FIG. 3. Variety of handheld (left and endoscopic right) sapphire tips for operative and endoscopic use (Surgical Laser Technologies).

Where lasers are to be widely utilized, it is necessary to have a central organization to provide for laser safety, scheduling, maintenance of laser devices, fiber preparation, credentialing of users, and in-service training of personnel. The complexity of this organization depends upon the number of lasers and frequency of usage. Such units are usually managed by a part-time director and laser safety officer, with an advisory committee made up of representatives of the specialties using the laser. Shared use of lasers can greatly reduce cost per patient.[11]

Basic Surgical Processes

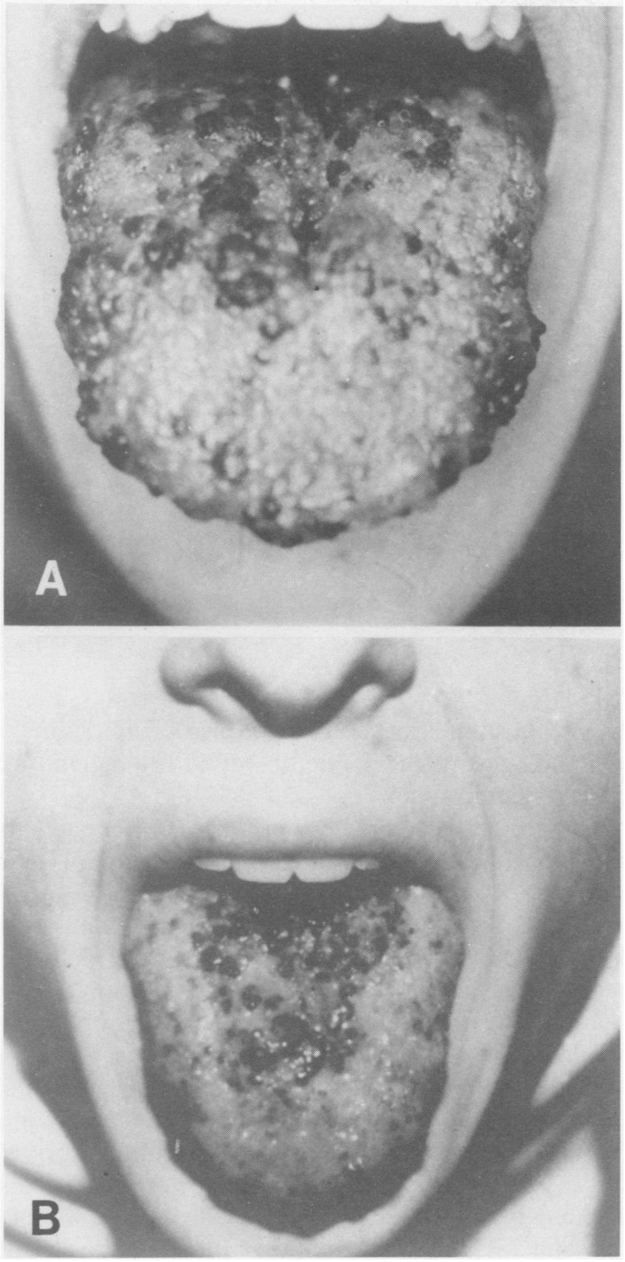
As compared with the scalpel, laser cutaneous incisions demonstrate delayed epithelial migration, prolonged period of wound phagocytosis, and decreased tensile strength up to 7–28 days.[12] This is probably due to thermal damage from the laser. After that period wound healing as measured by tensile strength is similar with both laser and scalpel.[13] The clinical significance of these findings is obscure at this time. The most practical recommendation is that cutaneous sutures remain in for an additional 3–5 days in laser incisions to allow for the more prolonged healing processes described.

Several authors suggested that low energy "soft or cold" lasers may result in biostimulation with acceleration of the rate of healing of wounds.[14,15] Mester and Mester reported that phagocytosis by leukocytes increases in response to helium-neon or argon laser at 0.5 J/cm^2 and that an accelerated growth of fur on mice occurs in response to exposure to low energy radiation.[16] Kana irradiated skin wounds in rats with the helium-neon laser at 45 mw/cm^2 and reported a statistically significant stimulating effect on collagen synthesis in the wound as measured by rate of wound healing and hydroxyproline content.[17]

The very considerable experience of the Mester's in patients with cold laser stimulation of healing in indolent leg and decubitus ulcers is interesting and merits continued observation. The application of argon laser at 4 J/cm^2 twice a week in over 1300 patients resulted in healing in a variety of lesions that were resistant to conventional treatment.[18] However, the problem of documentation in this area is great and statistical analysis difficult. So little is known of this type of laser/tissue interaction that one should be careful concerning premature acceptance or dismissal of biostimulatory effects. As is the case with many therapeutic agents, dosage may be critical with one energy dose being stimulatory and a slightly different one of the same wavelength being inhibitory or destructive.

Laser energy, especially at wavelengths in the hemoglobin absorption peaks, ruptures red blood cells, damages platelets, and activates clotting cascades with thrombus formation.[19] Endothelial damage, protein denaturation, shrinkage, and perivascular edema likewise contribute to vessel closure. Each laser, however, has limitations as to the size of vessels that can be controlled. The defocused CO_2 laser can coagulate vessels up to approximately 0.5 mm; the argon laser up to 1 mm; and the Nd:YAG laser up to 3 mm.[20]

Despite numerous anecdotal clinical references to decreased blood loss with laser surgery, statistical evidence is not readily at hand. One controlled study on burn excision in pigs showed a significant reduction in blood



FIGS. 4A and B. *A*. Lymphangioma of tongue with recurrent bleeding. *B*. Three months following Nd:YAG laser therapy. Marginal 3 cm of tongue treated by spot technique. Central portion of tongue untreated.

loss when experimental burns were excised with the argon laser as compared with electrosurgery.[21] There are several reports of reduced blood loss in experimental and clinical hepatic resections utilizing the CO_2 or Nd:YAG laser.[22,23] On the other hand, a controlled study using the Nd:YAG laser in canine experiments failed to show a statistically significant reduction on blood loss when the laser was employed for hepatic surgery in a noncontact fashion.[24] Decreased blood loss was recorded in experimental partial splenectomy[25] and clinically in mastectomy.[26]

One important area of laser hemostasis involves emergency surgery in patients with hemophilia, thrombocytopenia, or other coagulopathies. Due to vessel closure by thermal factors, it is reported that bleeding can be controlled by lasers during urgent procedures in such individuals. Kiefhaber stated that a platelet count of 25,000 is the minimum necessary for laser hemostasis in the GI tract.[105] A recent study involving the use of the CO_2 laser in surgery in hemophiliac patients undergoing synovectomy of the knee noted a significant reduction in blood loss, necessity for blood factors, time of operation, and duration of hospitalization compared with conventional techniques.[27]

Early reports suggested that infection in laser wounds would be reduced due to high temperatures created with bacterial "sterilization."[28] Shultz et al. studied the effect of Nd:YAG laser energy on three bacterial strains: *Staphylococcus aureus, Escherichia coli,* and *Pseudomonas aeruginosa.*[29] Energy fluence of 1667–3333 J/cm^2 resulted in a 2–8 log decline in a number of viable bacterial colonies. *P. aeruginosa* was the most sensitive to the Nd:YAG laser.[29] A study employing the CO_2 laser with *E. coli* and *S. aureus* also showed a dramatic reduction of bacteria.[30] It appears that lasers may reduce bacterial colonization at the time of incision, but experimental laser wounds subsequently contaminated have a higher incidence of infection.[31] Sterilization by laser is unlikely, but reduction of bacteria in necrotic infected wounds is probable.

It is evident from experimental and clinical studies that tumors can be coagulated or vaporized using the thermal effects of the laser.[32] Controlled studies in the bladder[33] and gastric cancer are in progress to determine comparative efficacy of endoscopic laser and conventional treatment. Sealing of lymphatics by lasers in tumor surgery is still uncertain. Frishman et al. reported a reduction in pulmonary metastasis when the CO_2 laser was used to excise experimental subcutaneous fibrosarcomas.[34] Oosterhuis et al., in a careful study of Cloudman melanoma cell dispersion, reported that CO_2 laser was "no worse than the conventional scalpel" in dissemination of cells from the incised tumor.[35] In a recent experimental study comparing the effect of circumferential Nd:YAG laser and electrocautery applications around the dome of the urinary bladder in restricting lymphatic migration of carbon particles, there was a statistically significant lesser degree of particulate migration through the laser barrier as compared with electrocautery.[36] Lanzafame et al. found that wound recurrence of experimental tumors in Fisher rats was significantly reduced by CO_2 laser excision.[37] Viable tumor cells were not found in the smoke plume during tumor vaporization with the CO_2 or Nd:YAG laser.[38,39]

Possible carcinogenic effects of lasers must be consid-

FIG. 5. Vascular infiltrative neurofibroma of abdominal wall being excised with CO_2 laser (center, gauzed-wrapped). Two previous attempts with conventional excisional methods failed due to severe hemorrhage.

ered. Goldman observed a group of human volunteers subjected to repeated low power argon cutaneous applications; no tumor formation was noted.[40] Apfelberg et al. carried out an *in vitro* study of fibroblast cultures irradiated with argon laser; no mutagenic effects were observed.[41]

Clinical Applications

Current clinical applications of lasers in general surgery are presented in two sections. The first section deals with conventional incisional surgical access laser techniques. The second section deals with the vast and rapidly growing endoscopic access laser surgical techniques, or minimally invasive endoscopic gastrointestinal laser surgery.

Coagulation and Excisions of Masses and Tumors

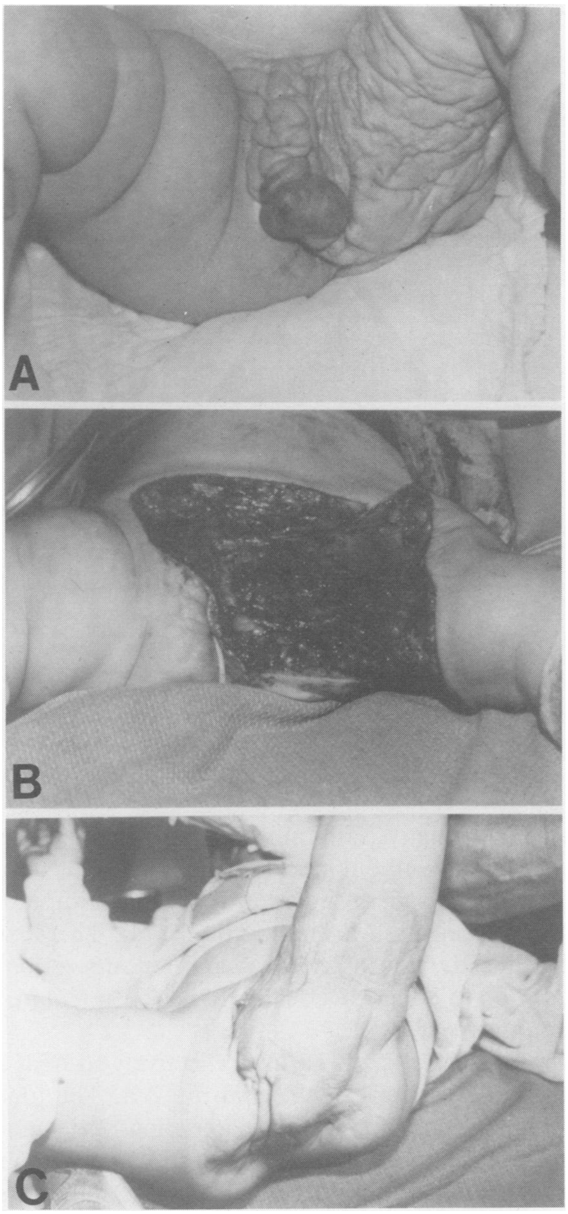
With its rich vascular supply, the tongue has been a difficult organ for the general surgeon to incise using standard techniques. With masses that are rather small and localized, excision with the CO_2 laser may be accomplished quickly and with minimal blood loss.[42] Due to rapid reparative processes of the tongue, thermal injury of laser does not result in significant delay in healing.

A conservative palliative application for control of vascular lesions of the tongue with lasers is being utilized. Argon and Nd:YAG lasers have been used effectively in a palliative fashion to reduce bleeding and size of such lesions without loss of functional tongue mass in 13 patients. A spot coagulation technique without cutting or vaporization is employed (Fig. 4). This has resulted in reduction of bleeding and lesion size for periods of up to 3 years. Retreatment has been required as symptoms recur.[43]

The CO_2 laser has been used effectively to treat leukoplakia and lesions of the oral mucosa. The unique superficial vaporization of this laser allows for a precise microsurgical removal of the dysplastic tissue. If the lesions are extensive, resultant ulcerations may require several weeks to heal completely and be quite uncomfortable for the patient. The recurrence rate, however, is much less than that with other techniques.[44]

Excision of vascular lesions of the scalp may likewise be facilitated with use of the CO_2 laser. Smaller vessels in the skin may be readily photocoagulated and larger vessels exposed. These vessels can be controlled by clips, ligature, or electrocoagulation. The bed in such excisions readily accepts a graft without delay in graft take or healing.[45] Similar vascular lesions of the trunk, abdominal wall, and extremities may be excised with reduced blood loss (Figs. 5 and 6).

A number of reports indicate facilitation of excision of head and neck tumors with the CO_2 laser, indicating better exposure, less blood loss, and decreased operating time.[46] A more specific application was outlined by White and Adkins for excision and vaporization of lym-



FIGS. 6A–C. *A.* Lymphangiosarcoma in 3-week-old female infant. *B.* Immediately following excision with CO_2 laser; 120 mL blood loss. *C.* Two years following skin graft, no recurrence. External genitalia preserved.

phangiomas of the head and neck in children.[47] Multiple thin-walled small extensions of the tumor that were difficult to excise were ablated by a handheld CO_2 laser technique.[47]

Breast

Considerable experimental and clinical study has been made of the carbon dioxide laser in treatment of carcinoma of the breast. Lanzafame et al. compared local tumor recurrence following scalpel, electrocautery, and laser excision of R3230AC mammary tumors in rats.[48] A statistically significant ($p < 0.05$) reduction in recurrence was noted with laser excision as compared with scalpel excision.[48]

In a controlled trial involving 209 patients, Ansanelli compared CO_2 laser excision and scalpel excision of breast malignancies.[49] Transfusions required, postoperative wound drainage, and hospital stay were all less for inpatients where CO_2 excision was performed.[49]

Recurrent breast cancer in the thoracic wall with necrosis and ulceration is a difficult surgical problem. Hira et al. utilized CO_2 laser and vaporization for excision of such tumors with reduction in blood loss and local infection. In a 2-year follow-up, however, no difference in rate of local recurrence between the control or treated groups was noted.[50]

Abdomen

Stomach

The Nd:YAG laser is frequently used in Russia for excision of gastric lesions with a report of decreased infection and blood loss. Special devices have been constructed to allow uniform circumferential transsection of stomach and intestine. It is suggested that there is better sterilization, less tissue turn in, and reduced anastomotic complications using this technique.[51] Hira and Moore employed similar contact techniques in 30 intraabdominal anastomotic procedures and stated that the laser did not damage intestinal margins as much as other methods, and was especially useful in excising inflammed vascular neoplastic tissue.[52]

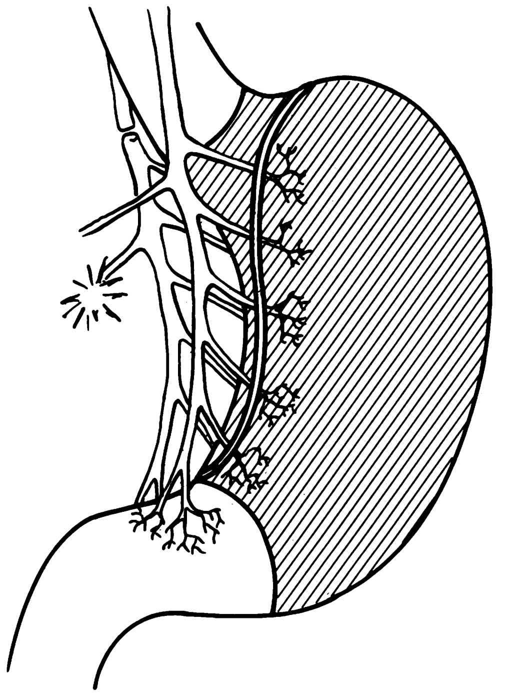


FIG. 7. Experimental laser vagotomy. Posterior truncal vagotomy followed by division of branches of anterior vagus along lesser curvature to nerve of Latarjet with either adjacent spot application or continuous sweep application of argon laser.

An unusual experimental gastric application has been suggested by Hunter et al. utilizing the argon laser plus vagotomy in dogs.[53] In this procedure, the posterior vagal trunk is divided. Following this, a laser myotomy is performed applying the argon laser along the anterior curvature from gastroesophageal junction to the nerve of Latarjet coagulating serosa and muscularis leaving muscosa intact. This procedure is designed to interrupt both the extramural and intramural branches of the left vagus nerve. Secretory studies indicating marked reduction in secretion are encouraging (Fig. 7).[53]

Pancreas

Excision of the pancreas has been performed using Nd:YAG laser in both experimental and clinical situations.[54] Donna utilized the Nd:YAG laser in order to preserve the duodenum with its blood supply in canine surgical procedures.[55] A statistically significant reduction in operating time and blood loss was reported.

Liver

The liver was early suggested as a site for laser applications for hemostasis or sublobar excisions.[56] Laboratory studies indicate that it is feasible to excise portions of the liver with CO_2 or Nd:YAG laser. Schroder et al. employed contact tip Nd:YAG excision combined with a flexible plastic strapper for canine liver resections with reduction in operating time and blood loss.[57]

It appears, however, that the present lasers may be most useful for hemostasis involving large oozing surfaces of the liver due to trauma. Standard surgical techniques will likely continue to be utilized in elective lobar resections to control major vascular and biliary structures. Sublobar resections and vaporization of scattered hepatic metastases, especially in tumors of endocrine origin, may be facilitated by the use of lasers.

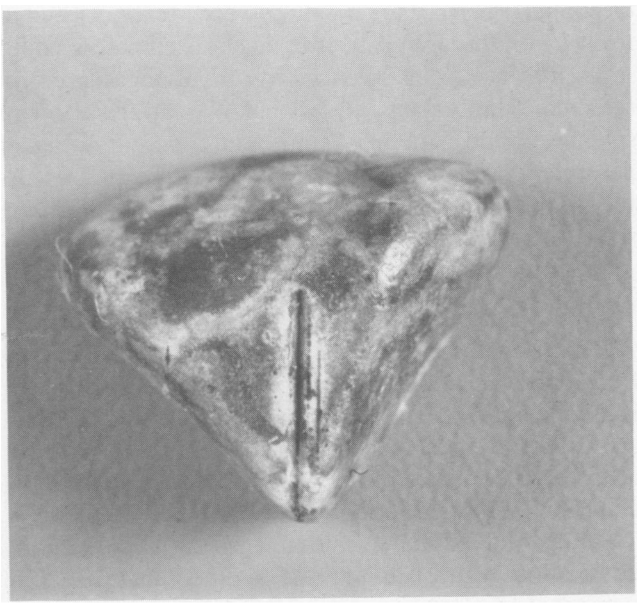
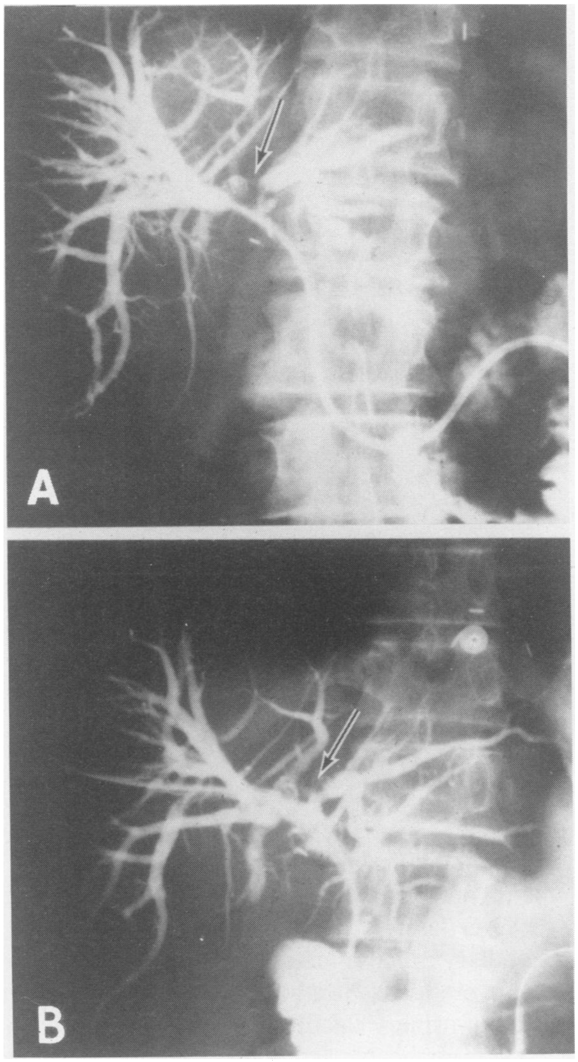


FIG. 8. Mixed calcium cholesterol pigment stone. Central incision made with free electron laser at 2.9 μm wavelength. Small incision on stone to right of center 20 μm width. No evidence of thermal damage.



FIGS. 9A and B. *A*. Cholangiogram of patient with Klatskin tumor. A percutaneous tube is draining the right hepatic duct system. The left remains obstructed (arrow). *B*. The same patient following endoscopic laser treatment of tumor required to control hemorrhage. The left hepatic duct system is no longer obstructed (arrow).

Biliary

Biliary calculi can be fragmented and removed using the Nd:YAG laser. The laser is guided by endoscopic means using a transampullary, percutaneous transhepatic, or tube tract approach.[58] Pigmented and mixed stones are readily reduced to smaller pieces. Pure cholesterol stones or heavily calcified stones are more difficult to reduce. Fragmentation is achieved by placing a fiber in contact with the stone and applying repeated brief impulses. Stones may then be removed by catheter or by grasping forceps. This technique may be especially

FIG. 10. Superficial capsular injury of spleen. Bleeding through microfibrillar collagen (*top*). Control of bleeding with multiple application of Nd:YAG laser, fiber at left (*bottom*).

useful in retained intrahepatic stones that cannot be removed by conventional techniques.[59]

A major problem with gallstone fragmentation with the Nd:YAG laser is the generation of heat that can damage biliary mucosa. The recent introduction of the flash lamp pumped dye (400–750 nm) laser for fragmentation of urinary calculi suggests this same technology may be applicable to biliary calculi.[60] The exact mechanism of stone fragmentation by this technique is not fully defined but may result from plasma formation and with photomechanical disruption. Dayton and Dixon measured *in vitro* thermal effects of gallstone fragmentation with Nd:YAG, copper vapor, and flash lamp pumped dye lasers.[61] Significant peripheral temperature elevations were noted during fragmentation with Nd:YAG and copper vapor but not with flash lamp pumped dye laser.[61] The free electron laser was utilized to photoablate gallstones by Dixon et al.[62] This high energy pulsed device allows precise incision and reduction in size of stone with minimal thermal effects (Fig. 8). These devices, possibly combined with ultrasonic fragmentation, suggest a future role for laser applications especially for intrahepatic, retained common duct calculi, and possibly even gallbladder stones.

A unique hepatobiliary endoscopic application of the laser involved percutaneous transhepatic insertion of an endoscope into dilated biliary radical above bleeding intrahepatic bile duct tumors. Utilizing the Nd:YAG laser fiber through a pediatric bronchoscope, bleeding from a Klatzkin tumor was controlled and symptomatic relief from obstruction provided (Fig. 9).[63] The Nd:YAG laser has also been used for endoscopic papillotomy where conventional techniques have failed.

Spleen

The Nd:YAG laser has been found to be effective in controlling experimental superficial splenic capsular bleeding (Fig. 10). Larger central vessels cannot be controlled with the laser. A technique has been described for segmental or partial splenectomy involving ligature of selected hilar vessels and Nd:YAG vaporization of splenic capsule, superficial sinusoidal tissue, and smaller peripheral vessels. Coagulated material is aspirated. As the hilum is approached, vessels larger than 1 mm are skeletonized, clipped, or suture-ligated. (Fig. 11).[64]

Anal and Regional

Laser hemorrhoidectomy is reported with increasing frequency but still remains controversial. The CO_2 laser is used in some techniques in conjunction with standard surgical ligation and excision. The laser is reported to be effective in elevating mucosal flaps with preservation of anoderm and reduction in pain.[65,66]

Sankar and Joffe devised a new technique of hemorrhoidectomy utilizing a Nd:YAG with contact tips as an excisional method.[67] A limited clinical trial indicated less blood loss, pain, urinary retention, and fewer healing complications as compared with conventional techniques.[67]

The removal of condylomata of the perianal region may be accomplished with CO_2, argon, or Nd:YAG lasers.[68] With all wavelengths, it is essential to remove all epidermis for at least 1 cm surrounding any active lesion since virus has been found in prickle cells for at least that distance. If the brush technique described by Baggish is not employed, the recurrence rate is much higher.[69]

Since live virus may be disseminated in the air during condylomata vaporization, gloves, masks, gowns, and other precautions are essential.[70]

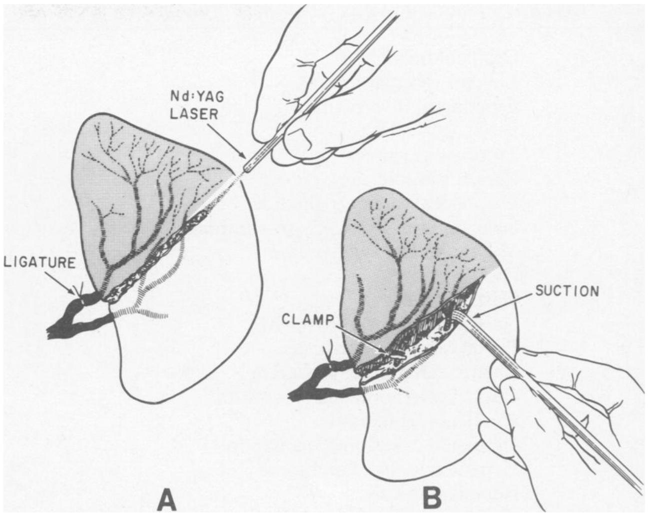
Pilonidal Cystectomy

CO_2 excision of pilonidal cyst has been reported. The hemostatic and bacteriocidal effects of the laser are utilized in tracing out and excising, or vaporizing, the numerous tracts of this troublesome lesion.[71]

Decubitus Ulcer

Excision of decubitus ulcers with the CO_2 laser has been described in reports of treatment of several thousand patients.[72] The ability of the laser to vaporize infected tissue is used, which allowed earlier grafting of the exposed site.

A controlled trial of laser *versus* conventional ulcer excision involving 66 patients was conducted by Juri et al.[73] Statistically significant differences in favor of the laser-treated groups were noted in operative blood loss, infection rate, and recovery rate. The sum of these factors resulted in a mean of 23 fewer hospital days per excisional procedure in laser-treated patients as compared with control patients (Fig. 12).[73]



FIGS. 11A and B. *A*. Ligation of segmental vessel with photocoagulation of capsule and parenchyma using Nd:YAG laser. *B*. Skeletonizing of large vessels in dry field using neurosurgical sucker. Clips applied followed by transection of vessels and completion of procedure with laser.

Infected Wounds

Primary closure of phlegmons, abscesses, and carbuncle following total excision with CO_2 laser was reported

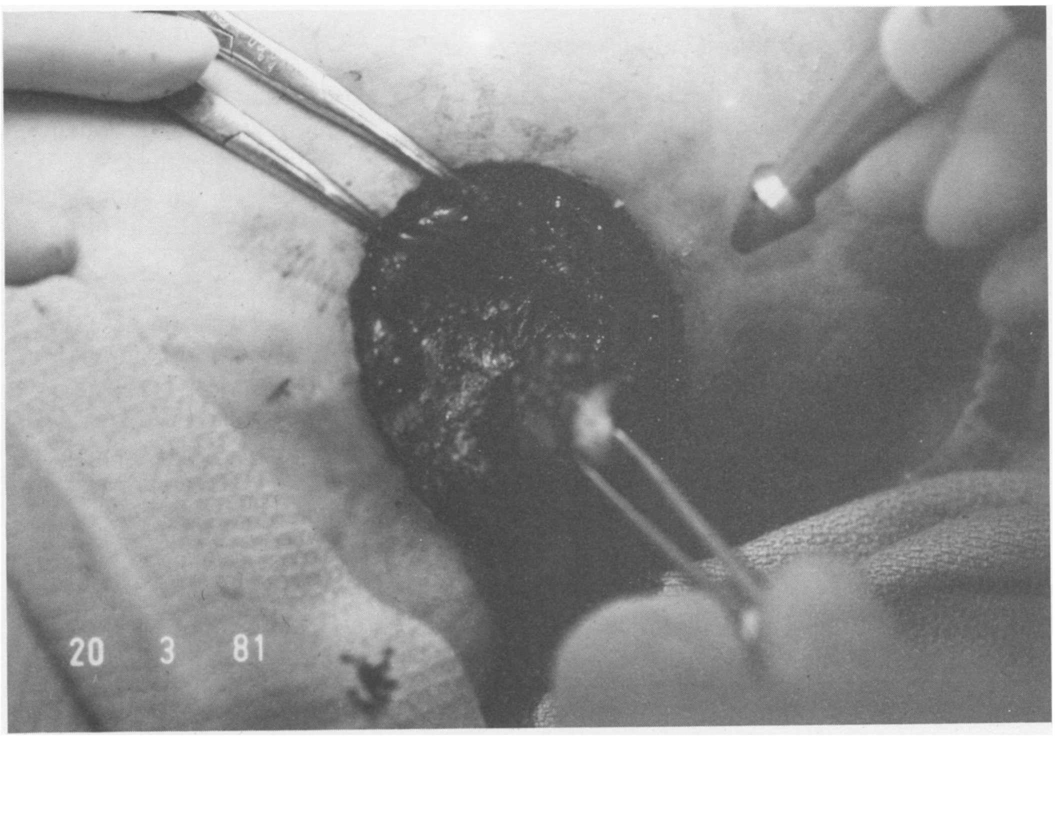


FIG. 12. Excision of decubitus ulcer with CO_2 laser. Necrotic base has been vaporized followed by circumferential excision of entire ulcer and bed (CO_2 laser handpiece, *upper right*).

TABLE 1. *Endoscopic Laser Treatment of Surgical Disease*

Oral leukoplakia
Lingual vascular lesions
Esophageal diverticulum
Esophageal web
Esophageal varices
Barrett's esophagus
Esophageal cancer (palliation)
Sutures, foreign bodies, granulomas
Mallory-Weiss syndrome
Gastric polyps
Gastric varices
Gastric telangiectasia, AVM
Peptic ulcer, hemorrhage
Gastric carcinoma, palliation
Gastric carcinoma, early, control
Duodenal leiomyoma
Duodenal carcinoma, palliation
Hepatic bile duct carcinoma
Hepaticolithiasis
Choledocholithiasis
Stricture of hepatic duct
Pseudocyst of pancreas
Ampullary stenosis
Carcinoma of ampulla
Polyps and AVM, intestine
Colon vascular lesions
Colon polyps
Colon cancer, palliation
Radiation proctitis, hemorrhage
Endometriosis, colon
Anastomotic strictures, stenosis, adhesions
Suture granulomas
Postsurgical anastomotic bleeding

by Chegin et al.[74] Tube drainage was frequently utilized; of 247 patients so managed, 233 did not require further incision or drainage.[74]

Endoscopic Gastrointestinal Laser Surgery

Remarkable advances in the endoscopic approach to intraluminal (and selected extraluminal) GI lesions have been made. Newer endoscopic devices provide excellent visualization of mucosal or submucosal lesions with ample operative channels for introduction of laser fibers or a variety of electrosurgical or heater probes. A partial list of endoscopic GI laser surgical procedures employed for treatment of general surgical disease processes appears in Table 1. Space limitations allow only briefest mention of representative applications in acute GI hemorrhage, vascular malformations, small benign mucosal lesions, GI malignancy, cysts, and stenoses.

Gastrointestinal Bleeding

A summary is available of nine prospective controlled randomized studies of endoscopic laser treatment of patients with acute upper GI hemorrhage (mostly peptic ulcers).[75] Three of the studies failed to show significant differences in long-term hemostasis or requirements for surgery or survival, although initial hemostasis was achieved in approximately 90% of laser-treated patients. A study by Rutgeerts et al.,[76] which included the largest number of patients, however, showed a statistically significant decrease in rebleeding rate, necessity for urgent surgery, and reduction of mortality rate in laser-treated patients. Laser therapy for active GI hemorrhage appears to be beneficial only in patients with actively bleeding peptic ulcer disease or with nonbleeding visible vessels in an ulcer crater. Lesions such as diffuse gastritis and those inaccessible endoscopically are not suitable for laser therapy.

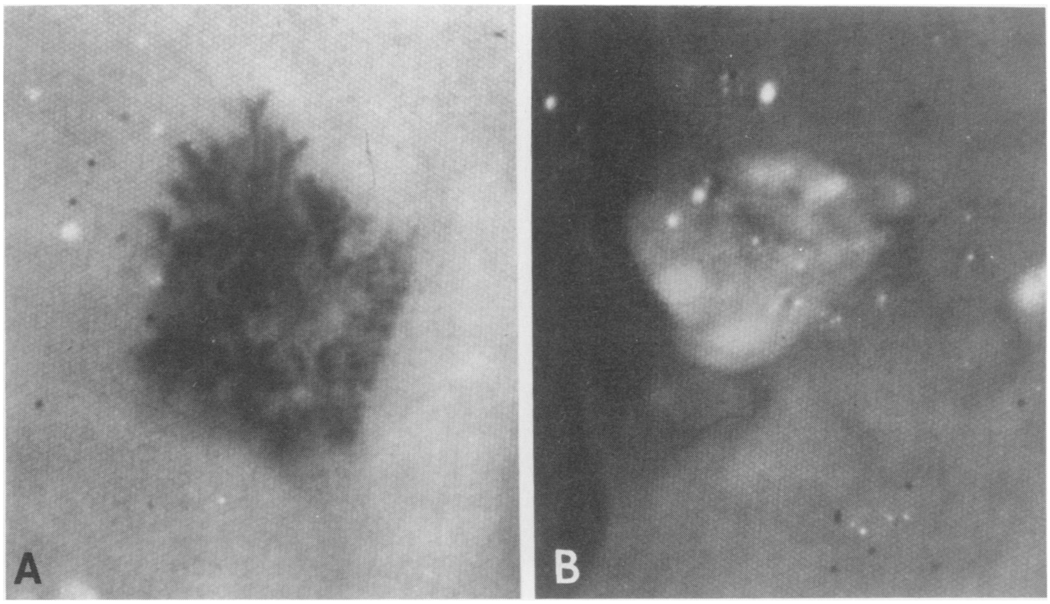
One of the greatest indirect contributions of the laser for endoscopic therapy has been the requirement for precise early identification of the bleeding lesion. This has resulted in new visual management criteria based upon the presence or absence of spurting lesions, visible vessels, or stigmata of recent hemorrhage.[77] Massively bleeding arterial lesions are recognized early and referred for surgery without further delay.. Endoscopic laser conversion from bleeding to stabilized patients, even for a brief period of time, may assist the surgeon in management of these difficult problems.

Vascular Malformations

These lesions are particularly suited to laser therapy since they are frequently limited to the mucosa or submucosa and heavily absorb light in the argon range (Fig. 13). The combined experience at the Universities of Utah and Lille now includes 80 patients with upper GI, 26 with colonic, and nine patients with upper and lower vascular lesions. Twenty had Osler-Weber-Rendu (OWR) syndrome. The overall results in these patients were similar to other reports with over 95% success in controlling blood loss in patients with sporadic vascular malformations and reduction in frequency of bleeding in patients with the OWR syndrome.[78] No perforations or major complications occurred. Rutgeerts et al. reported the treatment of 482 GI vascular lesions in 59 patients with Nd:YAG laser.[79] Overall results were good with only 17 patients rebleeding.[79] Buchi followed 44 patients for up to 3 years following laser treatment of vascular malformations and found a statistically significant reduction in frequency of bleeding, transfusion rates, and requirement for surgery.[80] The collective experience of various centers indicates that laser treatment of GI vascular malformations is safe and effectively terminates or markedly decreases frequency of bleeding.

Small Multiple Benign Mucosal Lesions

Dixon et al. studied endoscopic argon laser treatment in 34 patients with Gardner's syndrome with multiple polyps in residual rectum following subtotal abdominal colectomy.[81] Over 1100 polyps were removed without



FIGS. 13A and B. *A*. A 5-cm diameter superficial hemangioma of lesser curvature of the stomach with recurrent bleeding. *B*. Immediately following argon laser photocoagulation of hemangioma. No recurrence after 3 years follow-up.

complication (Fig. 14). A similar experience was noted by Brunetaud et al. at the University of Lille.[78] Other lesions successfully treated include gastric polyps, endometriosis coli, and localized lesion in Barretts' esophagus. The laser should not be used to remove pedunculated polyps since there is usually a central vessel that is difficult to control without the constrictive effects possible with electrocautery snares.

Villous Adenoma

The management of villous adenoma is more controversial. Lambert and Sabben reported complete laser destruction of 35 of 39 villous adenomas, with reduction of size of lesion in the remainder; four perforations were noted, but two did not require treatment.[82] Brunetaud recently reported treatment of 109 villous adenomas in this fashion; 19% had local recurrence, but all were successfully ablated with repeated laser treatment.[83] Five patients with invasive carcinoma were discovered in the course of treatment and referred for surgery.[83]

Gastrointestinal Malignancy

Palliative therapy of GI malignancy is one of the more appealing applications of endoscopic laser surgery. Neoplasms of the esophagus, stomach, duodenum, hepatobiliary tract, colon, and rectum have been managed in this fashion for control of bleeding, relief of obstruction, management of secretions, or to allow oral nutrition (Fig. 15).[84] Applications have been made in lesions that are incurable by surgical resection, recurrent lesions, in patients who cannot withstand a surgical procedure, or in preparation of a patient for surgery. Laser procedures have the advantages that they can be carried out with minimal or no sedation and generally on an outpatient basis, with potential reduction in complications, medical costs, and hospital stay.

Fleisher and Sivak[85] treated 68 patients with esophageal cancer with the Nd:YAG laser who were not candidates for surgery or radiation therapy, with relief of dysphagia in 92% and clinical improvement lasting 3–6 months. Five patients (12%) developed tracheoesopha-

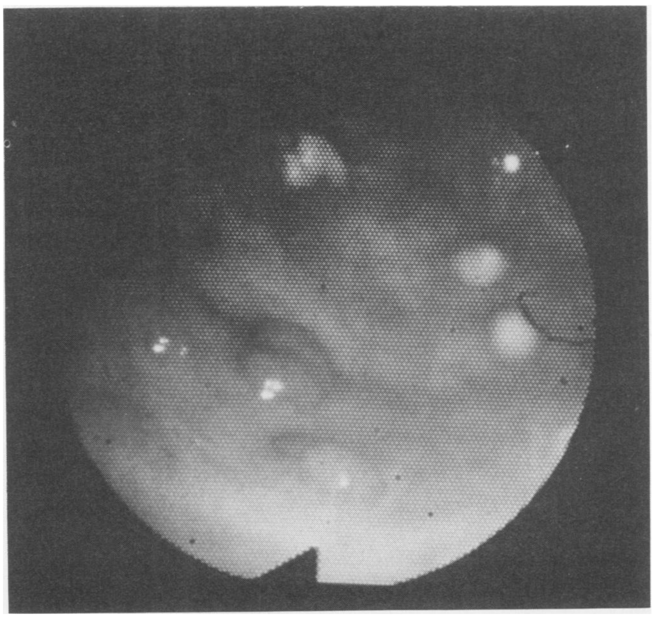
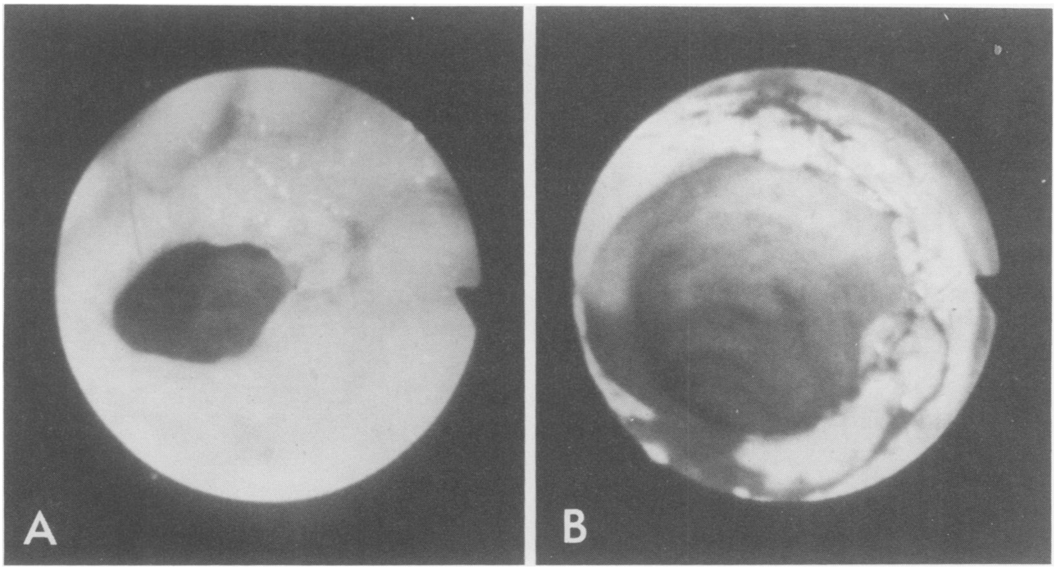


FIG. 14. Multiple polyposis of colon (Gardner's syndrome). Untreated polyps (*below*). White coagulated polyps treated with argon laser (*above*).



FIGS. 15A and B. *A.* Stenosis of low rectal anastomosis with recurrent malignancy at suture line in patient with distal metastases. *B.* Immediately following Nd:YAG incision of stenosis and vaporization of tumor. Patient died 13 months later without recurrence of stenosis or local tumor.

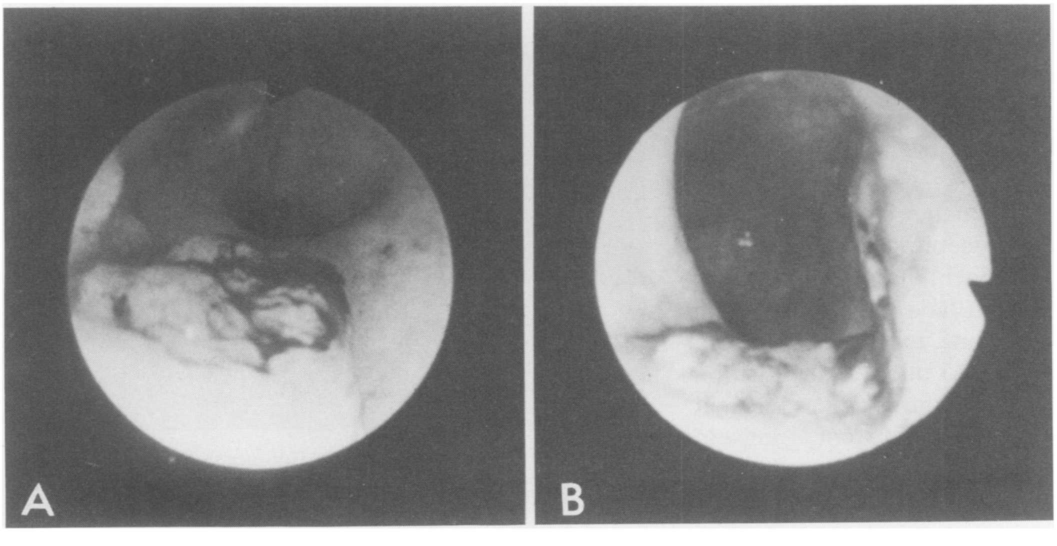
geal fistulae or perforation. Two of these were clearly laser-related, but the other three occurred up to 6 months after laser treatment. Patients managed in this fashion required retreatment as progression of the growth occurs.[85] As would be expected, no increased length of survival was noted.

Gastric and distal esophageal malignancy may be managed by endoscopic laser therapy with similar results. Thirty-four patients were treated at the University of Utah Laser Institute; 91% of patients were relieved of gastric or distal esophageal obstruction and 2% developed fistulae.[78]

In a cooperative study 118 patients were treated for surgical preparation or palliation of colorectal malignancies at the University of Utah and the University of Lille. Control of bleeding or relief of obstruction with the Nd:YAG laser was possible in all patients (Fig. 16). An average of three initial treatment sessions was required. Few complications were encountered.[78] Again, retreatment was necessary as tumor growth progressed.

Endoscopic Incisional

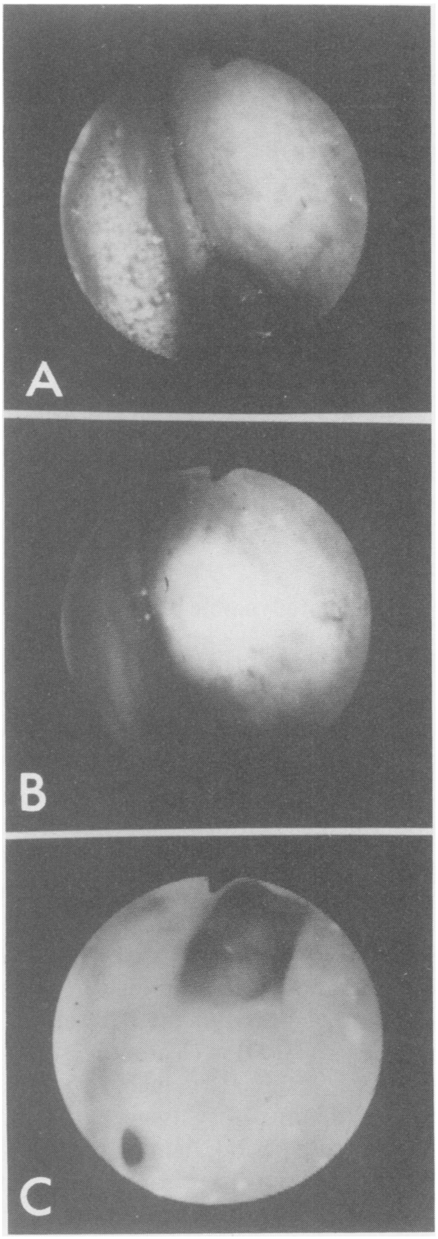
Increasing experience with endoscopic surgery has resulted in unique applications involving endoscopic incisional methods. This has been facilitated by the development of contact tips for laser fibers, which allow for precise laser application to such lesions. Potential procedures of this type are limited only by visualization of the lesion and endoscopic skills of the surgeon. Delmotte et al. utilized the argon laser to drain pancreatic and biliary cysts internally.[86] Buchi et al. employed the Nd:YAG laser to drain two symptomatic expanding



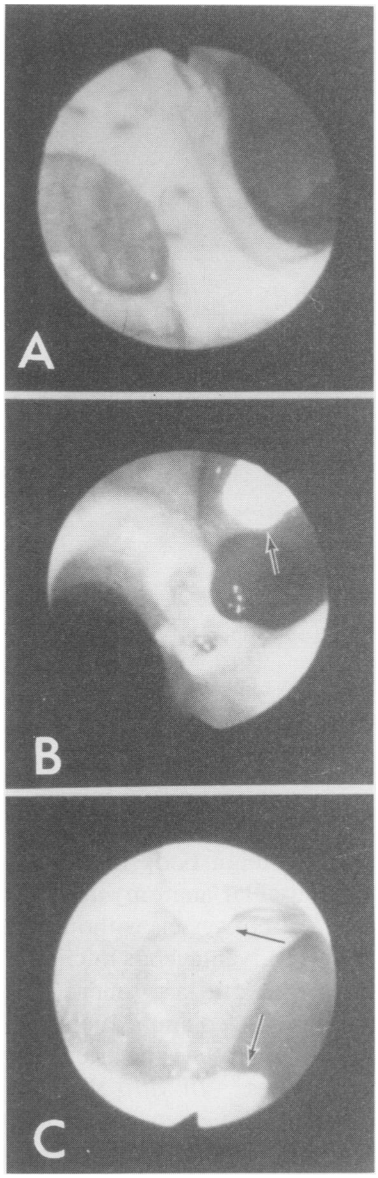
FIGS. 16A and B. *A.* Cancer of rectum with acute bleeding. *B.* Immediately following Nd:YAG endoscopic photocoagulation with control of bleeding. Patient was then treated surgically on elective basis.

traumatic pancreatic pseudocysts in patients who could not undergo operative cystogastrostomy.[87] An area of the gastric wall overlying the pseudocyst was heavily photocoagulated, and subsequent slough created a large pseudocystogastrostomy. No recurrence of cysts was noted in a 3-year follow-up (Fig. 17).[87]

A number of reports have described the use of lasers for successful incision and enlargement of postoperative stenosis of the esophagus and colon.[88] Peptic strictures,



FIGS. 17A–C. *A.* Displacement of posterior wall of stomach in critically ill patient with traumatic pancreatitis and pseudocyst, right. *B.* Immediately following endoscopic Nd:YAG photocoagulation of gastric wall and anterior wall of cyst. *C.* Five days following treatment with slough of gastric wall and wall of pseudocyst with effectively functioning pancreaticocystogastrostomy with drainage of cysts. No recurrence.

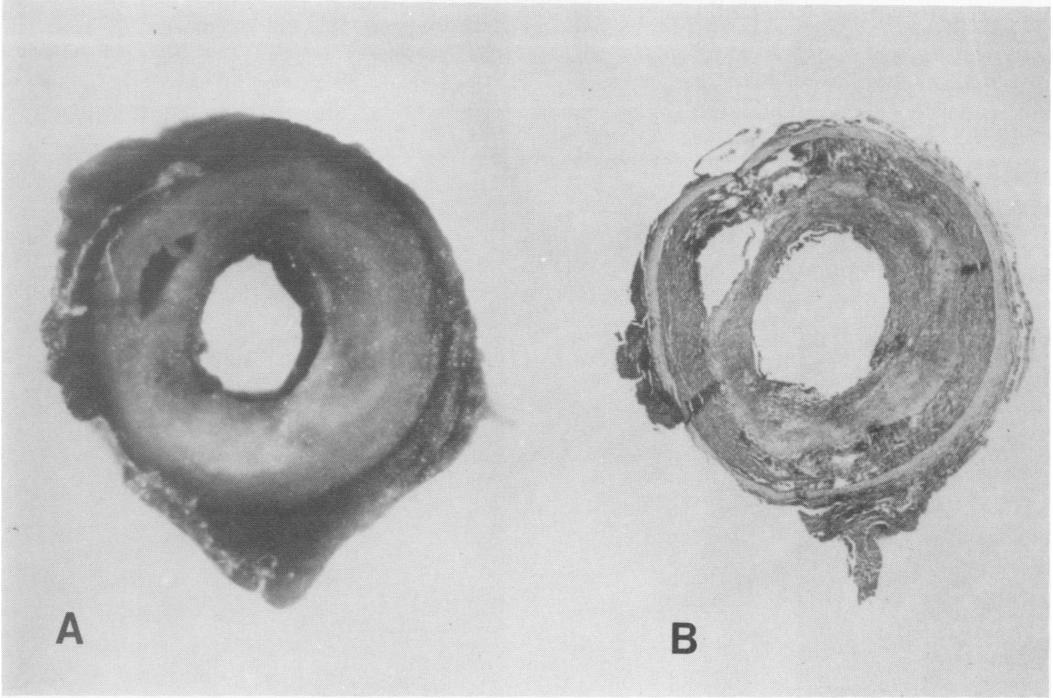


FIGS. 18A–C. *A.* Intraluminal side-to-side adhesion following ileal J-pouch construction with malfunction. *B.* Argon laser endoscopic division of vascular adhesion. Laser fiber (arrow). *C.* Immediately following argon laser division. Note that good retraction of adhesion ends with no bleeding.

congenital rings, and postoperative webs have likewise been incised and dilated (Fig. 18).[89] Innovative incisional applications are in the early investigative phase but promise to greatly influence the practice of GI surgery.

Vascular

Lasers have been employed experimentally and clinically in microvascular welding and recanalization of atherosclerotic vessels. In microvascular welding, vessels of 1 mm in diameter or less are joined using spot weld



FIGS. 19A and B. *A.* Autopsy specimen of atherosclerotic femoral artery. *B.* Immediately following argon laser vaporization of atheroma. Note the increase in luminal diameter but thermal injury, arterial wall.

techniques or by application of external supports of laser-coagulated collagen or blood.[90] Such techniques appear to reduce foreign body inflammatory action, preserve normal vascular anatomy and luminal diameter, and allow growth of vessels without stenosis, which may be particularly advantageous in children.[91]

The ability to transmit laser energy through small flexible fibers has suggested application use for recanalization of occluded atherosclerotic arteries by catheter or endoscopic techniques.[92] *In vitro* studies have shown that atherosclerotic plaque can be vaporized with various lasers, especially where the chief component is cholesterol (Fig. 19).[93] Calcified plaque is more difficult to ablate, however.[94] Several preliminary case reports are available utilizing either Nd:YAG or argon laser to recanalize occluded femoral arteries. Vessels in 16 patients studied in one series were recanalized with two perforations. No major hematomata occurred despite full anticoagulation with heparin.[95] In another series of 51 attempted femoral artery procedures using a thermal laser tip, nine were immediate failures due to either inability to recanalize the lesion or to thrombosis. Initial patency rate of 83% slowly dropped to 73.2% at the end of a 21-month period.[96]

Due to injury and perforation of arterial wall, selective ablation of plaque with or without the use of exogenous photosensitizers seems vital before advances can be made. The effect of the debris created by vaporization of plaque on the peripheral vascular bed has been studied and appears to be minimal in extremities.[97] The effect of such debris on critical peripheral beds such as brain, kidney, and myocardium have not been fully studied.

Photodynamic Therapy

Photodynamic therapy (PDT) is a new procedure involving known photobiologic principles that may be useful in the treatment of various tumors and disease processes.[98] Current laser applications depend upon absorption of laser energy by naturally occurring molecules in tissue such as hemoglobin or melanin (endogenous chromophores). It has been known since 1903 that various drugs could be introduced intravenously that would bind selectively to tumors or associated vascular beds.[99] Hematoporphyrin derivative (HPD) has been one of the agents most widely studied in this regard.[100] After a period of 24–48 hours after injection, much of the photosensitizer (HPD) is cleared from normal cells and organs but is retained in high concentrations in tumors, plaque, inflammatory tissue, and certain bacteria. After the clearing period, light of appropriate wavelength to activate the sensitizer is applied directly to the tumor by an interstitial fiber or by endoscopic techniques. While some thermal reaction may occur, this is minimal. The chief effect of the photosensitizer is to initiate a chemical reaction in target cells, which results in fluorescence and the formation of singlet oxygen with associated phototoxicity and selective tumor damage (Fig. 20).[101]

Much of the initial clinical work using photosensitization has been carried out in recurrent carcinoma of the breast with cutaneous metastasis. Carruth and Dougherty reported initial reduction in tumor size in 60–70% of patients so treated.[102] In carcinoma of the bronchus, Hayata et al. treated 35 patients with PDT where conventional surgery was not possible with good reduction in tumor mass or palliation reported in 30–40% of patients.[103] A summary of the literature of current clinical results appears in Table 2.

Another unique element in photosensitization is that photosensitizer can be activated to fluoresce when the appropriate wavelength light is applied (Fig. 21). This has been employed in the bronchoscopic identification of early tracheobronchial carcinoma.[103] These techniques might provide for early tumor diagnosis utilizing fluorescence followed by phototherapy to cause selective destruction of sensitized tumor cells.

Numerous new photosensitizers with greater potency and tumor selectivity are available and await appropriate preclinical studies and approvals.[104]

TABLE 2. *Summary of Response of Various Tumors to PDT (to 1984)*

Tumor Type	No. of Patients or (Sites)	Response CR	Response PR	Response NR	Longest Follow-up to Date (yr)
Skin (met. breast, basal cell, squamous, melanoma)	(219)	(147)	(29)	(43)	4
Endobronchial					
Late stage	262	106*	136	20	1.5
Early stage	32	17	10	—	4.5
Bladder, superficial	(70)	(38)	(16)	(13)	2
Head/neck, recurrent	49	9	26	14	2
Gynecologic, recurrent	11	4	5	2	2
Esophagus, advanced	17	0	11†	6	1

CR = complete remission; PR = partial remission; NR = no remission.

* Complete opening to wall of lumen following physical removal after PDT.

† Partial relief of obstruction.

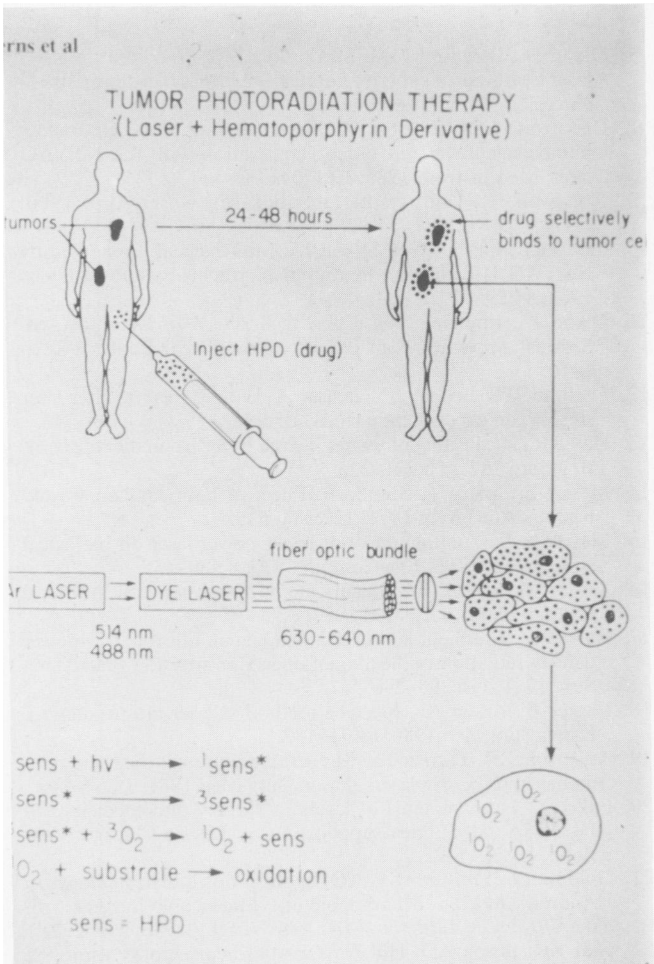


FIG. 20. Schema of PDT with hematoporphyrin derivative (after Dougherty).

Discussion

The entire field of applications of lasers in general surgery is dynamic and evolving, and it requires constant critical evaluation. The field has been plagued by an inordinate amount of media attention and the usual plethora of uncontrolled enthusiastic reports by early investigators. Fortunately, well-designed trials are now becoming available to provide tenable guidance relative to indications and contraindications for application of these devices. At this point however, certain observations seem warranted:

1. Laser applications in general surgery now have achieved limited but defensible indications for certain selected procedures.
2. The use of lasers as a surgical instrument employed through endoscopes has resulted in a number of GI applications that will impact conventional incisional methods. It appears inevitable that the general surgeons of the future will need skills in at least upper GI endoscopy, colonoscopy, and choledochoscopy to utilize minimally invasive laser and other techniques.
3. The utilization of photosensitizers to identify by fluorescence and treat various tumors by phototherapy opens interesting possibilities for primary management or adjunctive treatment in association with conventional surgery.

Technologic advances promise smaller, less expensive, more reliable lasers with improved delivery devices for handheld operative microscopes or for endoscopic

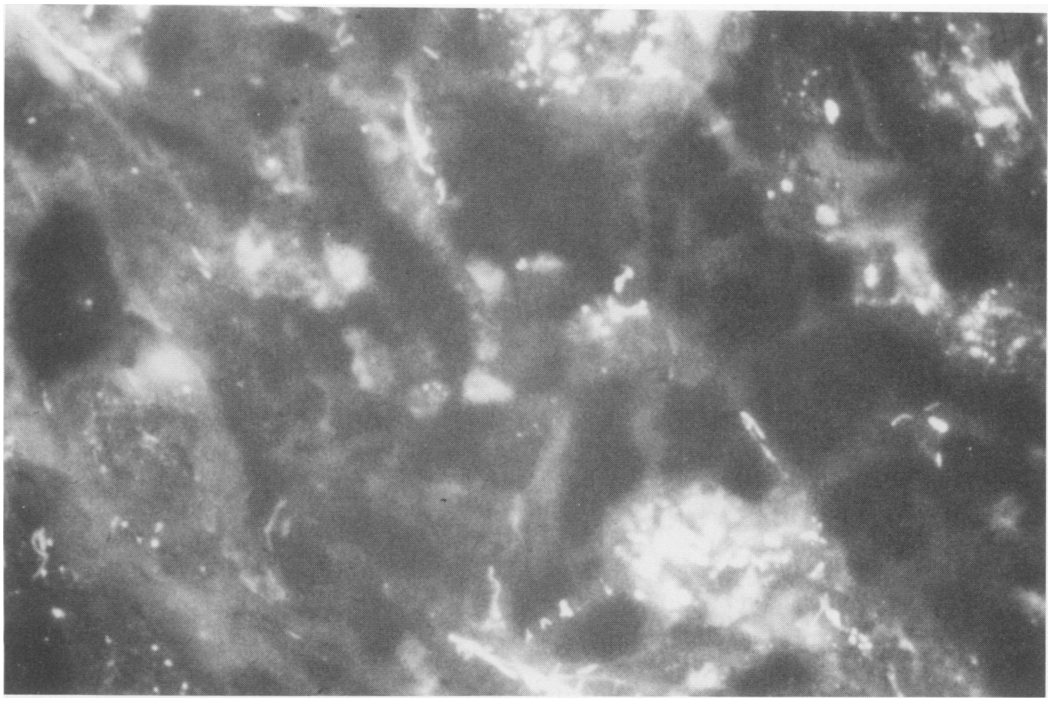


FIG. 21. Fluorescence of HPD-sensitized mouse tumor cells (scattered white spots) with 420 nm light; normal cells in background (dark areas).

use. New wavelengths and even tunable lasers will appear in the near future.

Despite the fact that membership in the American Society for Laser Medicine and Surgery recently passed the 1000 mark, not every surgeon should buy a laser. These expensive devices should be utilized only for specific indications where standard techniques are not available or are less efficacious. It is important, however, for every general surgeon to remain aware of developments in this field, which involve many new and intriguing aspects of photobiology and light tissue interactions that may prove to have surgical application.

Acknowledgments

The author acknowledges the use of illustrative material from Dr. Louis Morales, Dr. Peter Lawrence, Dr. John Bowers, Dr. Kenneth Buchi, and Dr. William Syme, all members of the Utah Laser Institute.

References

1. Ketcham AS, Hoye RC, Riggle GC. A surgeon's appraisal of the laser. Surg Clin North Am 1967; 47:1249–1263.
2. American Board of Surgery, Inc. Booklet of Information, July 1985–June 1986, Philadelphia.
3. Einstein A. Zur Quantentheorie Der Strahlun. Physiol Z 1917; 18:121–128.
4. Fisher J. Basic laser physics and interaction of laser light with soft tissue. *In* Shapshay SM, ed. Endoscopic Laser Surgery. New York: Dekker, 1987; 99–111.
5. Mihashi S, Jako GJ, Incze J, et al. Laser surgery in otolaryngology: interaction of CO_2 laser in soft tissue. Ann Sci 1976; 267:263–294.
6. Vallon AG, Cotton PB, Laurence BH, et al. Randomized trial of endoscopic argon laser photocoagulation of bleeding peptic ulcers. Gut 1981; 22:228–233.
7. Dixon JA, Berenson MM, McCloskey DW. Neodymium YAG laser treatment of experimental canine gastric bleeding. Gastroenterology 1979; 77:647–651.
8. Daikuzono MN, Joffe SN. Artificial sapphire probe for contact photocoagulation and tissue vaporization with the Nd:YAG laser. Med Instrum 1985; 19:173–178.
9. Rockwell JR. Controlling laser hazards. Laser Appl 1986; 5:9–12.
10. Casey KR, Fairfax WR, Dixon JA. Intratracheal fire ignited by Nd:YAG laser during treatment of tracheal stenosis. Chest 1983; 84:295–297.
11. Dixon JA. Implementing a new technology. *In* Dixon JA, ed. Surgical Applications of Lasers. Chicago Year Book: 1987; p 1–10.
12. Cochran JPS, Beakin JP, Creasey A. Wound healing after laser surgery: an experimental study. Br J Surg 1980; 67:740–743.
13. Hall RR. The healing of tissues incised by a carbon dioxide laser. Br J Surg 1971; 58:221–225.
14. Mester E, Spiery T, Szende B. Effect of laser rays on wound healing. Am J Surg 1971; 122:532–535.
15. Mester E. Stimulating effect of lower power laser on biological systems. Med Biol Eng Comput 1970; 8:430–435.
16. Mester AF, Mester E. Clinical data on biostimulation in wound healing. Lasers Surg Med 1987; 7:78–79.
17. Kana GS, Hutschenreiter G, Haina D, et al. Effect of low-power density radiation on healing of open skin wound in rats. Arch Surg 1981; 116:293–296.
18. Mester A, Mester AF. Mester's method of laser biostimulation. Lasers Surg Med 1986; 6:171–172.
19. Anderson RR, Parrish JA. Microvasculature can be selectively damaged using dye lasers. Lasers Surg Med 1981; 1:263–276.
20. Fuller T. Fundamentals of lasers in surgery and medicine. *In* Dixon JA, ed. Surgical Applications of Lasers. Chicago: Year Book, 1983; 11–27.
21. Goldman L, McBurney E. CO_2 applications in dermatology. *In* Andrews AH, ed. Microscopic and Endoscopic Surgery with the CO_2 Laser. Littleton, MA: John Wright, 1982; 290–292.
22. Hall RR, Beach AD, Hill DW. Partial hepatectomy using the carbon dioxide laser. Br J Surg 1973; 60:141–144.
23. Fidler JP, Hoefer RW, Polanyi TG. Laser surgery of the exsanguinating liver injury. Ann Surg 1975; 181:74–80.

24. Tranberg KG, Rigotti P, Brackett KA, et al. Liver resection—a comparison using the Nd:YAG laser and ultrasonic surgical aspirator in blunt dissection. Am J Surg 1986; 151:368–374.
25. Dixon JA, Miller F, McCloskey D, et al. Anatomy and techniques in segmental splenectomy. Surg Gynecol Obstet 1980; 150:516–520.
26. Hira N, Stegger AC, Moore KC. The use of Nd:YAG laser in breast cancer surgery. Lasers Surg Med 1987; 7:87–88.
27. Herrera RH, Mackey R, Hinshaw JR. Use of the CO_2 laser in surgery of the hemophiliac patient. Proceedings of the Sixth Congress. International Society for Lasers in Medicine and Surgery 1985; 48.
28. Fidler JP, Law P, MacMillen BG, et al. Comparison of carbon dioxide burns with other thermal knives. Proceedings of the First International Symposium on Laser Surgery. Israel 1975; 90–94.
29. Shultz R, Cabello F, Harvey G. Bacterial side effects of neodymium YAG laser. Lasers Surg Med 1986; 6:162.
30. Mullarky MB, Norris CW, Goldberg ID. The efficacy of the CO_2 laser in the sterilization of skin seeded with bacteria: survival at the skin surface and in the plume emissions. Laryngoscope 1985; 95:186–188.
31. Hooks WT. Use of CO_2 laser in sterilization. Oral Surg 1980; 49:263.
32. Polanyi TG, Bredemer H, Davis T. A CO_2 laser for surgical research. Med Biol Eng 1970; 8:554–557.
33. Smith JA Jr. Bladder Cancer in Lasers in Urologic Surgery. Chicago: Year Book, 1985; 52–62.
34. Frishman A, Gassner S, Kaplan I. Excision of subcutaneous fibrosarcoma in mice. Isr J Med Sci 1974; 10:637–641.
35. Oosterhuis JW, Verschueren RCJ, Oldhof J. Experimental surgery on Cloudman S-91 melanoma with carbon dioxide laser. Acta Chir Belg 1975; 74:422–429.
36. Zimmerman I, Stern J, Frank F, et al. Interruption of lymphatic drainage by neodymium YAG laser irradiation in right urinary bladder. Lasers Surg Med 1984; 4:167–169.
37. Lanzafame RJ, McCormick CJ, Rogers DW, et al. Mechanism of carbon dioxide laser reduction of tumor recurrence in experimental mammary tumors. Lasers Surg Med 1987; 7:87.
38. Bellina JG. Carbon dioxide laser in gynecology. Obstet Gynecol Annu 1977; 6:371–391.
39. Leckman SA, Dixon JA. The viability of cells in waste products of S-80 tumors in mice treated with the neodymium YAG laser. Lasers Surg Med 1987; 7:103.
40. Goldman L: Personal communication, 1981.
41. Apfelberg DB, Chadi B, Maser MR. Study of carcinogenic effects of in vitro argon laser exposure of fibroblasts. Plast Reconstr Surg 1983; 71:92–97.
42. Vaughan CW. Laser management of oral lesions. *In* Andrews AH, Polanyi TG, eds. Microscopic and Endoscopic Surgery with the CO_2 Laser. Boston: Wright 1982; 164–170.
43. Dixon JA, Gilbertson JJ, Davis RK. Laser treatment of vascular lesion of the tongue. Laryngoscope 1986; 96:537–541.
44. Verschueren RCJ, Oldhoff J: CO_2 laser in general surgery. *In* Andrews AH, ed. Microscopic and Endoscopic Surgery with a CO_2 Laser. Boston: Wright 1982; 356.
45. Glantz G, Korn A. The use of CO_2 laser in general surgery, in Kaplan I, ed. Laser Surgery, Vol. 3. Tel Aviv: Ot-Paz, 1979; 179.
46. Aronoff BL. The carbon dioxide laser in head and neck surgery, in Goldman L, ed. The Biomedical Laser. New York: Springer-Verlag, 1981; 240–245.
47. White BJ, Adkins WY. The use of the carbon dioxide laser in head and neck lymphangiomas. Lasers Surg Med 1986; 6:293–296.
48. Lanzafame RJ, Rogers GW, Naim JO, et al. The effects of CO_2 laser excision on local tumor recurrence. Lasers Surg Med 1986; 6:103–106.
49. Ansanelli VW. The CO_2 laser in axillary resection for breast cancer. Lasers Surg Med 1987; 7:87.
50. Hira N, Moore KC, Stegger A. The use of Nd:YAG contact laser in surgery. Lasers Surg Med 1987; 7:86.
51. Skobelkin OK, Breckov EI, Smoljininov MB. Resection of hollow abdominal organs with lasers. Lasers Surg Med 1987; 7:101.
52. Hira N, Moore KC. The use of the Nd:YAG contact laser in abdominal surgery. Lasers Surg Med 1987; 7:86.
53. Hunter JG, Becker JM, Dixon JA. Lesser curvature laser myotomy. Lasers Surg Med 1984; 8:362–363.
54. Joffe SN, Sankar MY, Salzer B. Preliminary clinical application of the contact surgical rod and endoscopic microprobes with the Nd:YAG laser. Lasers Surg Med 1985; 5:188.
55. Donna GD. Total pancreatectomy with the carbon dioxide laser. *In* Atsumi K, Nimsakul N, eds. Laser Tokyo '81. Tokyo: Inter-Group, 1981; 43.
56. Orda R, Ellis H. Experimental study of hepatic, renal and splenic wounds following laser and electrosurgery. Am Surg 1981; 47:447–453.
57. Schroder T, Sankar MY, Brackett AKM, et al. Major liver resection using contact Nd:YAG laser. Lasers Surg Med 1987; 7:89.
58. Orri H. Choledocholithotomy with endoscopy and Nd:YAG laser. Surgery 1981; 90:120–122.
59. Nishioka NS, Levins PC, Murray SC, Anderson RR. Tunable dye laser fragmentation of biliary calculi. Lasers Surg Med 1986; 6:191–192.
60. Watson GM. Laser fragmentation of urinary calculi. *In* Smith JA Jr, ed. Lasers in Urologic Surgery. Chicago: Year Book, 1985; 121–137.
61. Dayton MT, Dixon JA. Thermal effects of gallstone fragmentation with flash lamp pumped dye laser. Surg Res, in press.
62. Dixon JA, Straight RC, Dayton MT. Free electron laser fragmentation of biliary calculi. Lasers Surg Med 1987; 7:88–89.
63. Carpenter CM, Bowers JH, Dixon JA. Neodymium YAG laser treatment of hemobilia via percutaneous biliary catheter tract. Radiology 1983; 148:853–854.
64. Dixon JA, Miller F, McCloskey D, et al. Laser partial splenectomy. Surg Res 1980; 10:116–118.
65. Morselli M, Buttazi, Manenti A. Outpatient treatment of hemorrhoids by CO_2 laser. Lasers Surg Med 1985; 5:144.
66. Zadeh AT. Three hundred fifty hemorrhoidectomies using the carbon dioxide laser. Lasers Surg Med 1985; 5:145.
67. Sankar MY, Joffe SN. Hemorrhoidectomy by contact laser surgery. Lasers Surg Med 1987; 7:91–92.
68. Calkins JW, Masterson BJ, Magrina JF, et al. Management of condyloma accuminata with the carbon dioxide laser. Obstet Gynecol 1982; 59:105–107.
69. Baggish MS. Improved laser techniques for the elimination of genital and extragenital warts. Am J Obstet Gynecol 1985; 153(5):545–550.
70. Baggish MS. Improved laser techniques for the elimination of genital and extragenital warts. Am J Obstet Gynecol 1985; 153:545.
71. Korn A, Glantz GJ. The use of CO_2 laser in general surgery. Trans Sixth International Congress. Society of Lasers in Medicine and Surgery. Jerusalem, 1985; 7.
72. Khodair F. Use of carbon dioxide laser in surgical treatment of bed sores in paraplegic patients. *In* Atsumi K, Nimsakul N, eds. Laser Tokyo '81. Tokyo Inter-Group, 1981; 75–86.
73. Juri H, Obeide A, Young S. CO_2 laser in decubitus ulcers. Lasers Med Surg 1985; 5:143–144.
74. Chegin PM, Skobelkin OK, Breckov EI. Techniques of laser surgery for superficial infected wounds. Lasers Surg Med 1987; 7:90–91.
75. Buchi KN, Brunetaud JM. Endoscopic gastrointestinal laser therapy. *In* Dixon JA, ed. Surgical Applications of Lasers. Chicago: Year Book, 1987; 121.
76. Rutgeerts P, Van Trappen G, Broeckaert L, et al. Controlled trial of neodymium YAG laser treatment of upper digestive hemorrhage. Gastroenterology 1982; 83:410–416.
77. MacCleod IA, Mills PR, McKenzie JF, et al. Nd:YAG laser photocoagulation for major hemorrhage from peptic ulcers and single vessels: a single blind controlled study. Br Med J 1983; 286:345–348.
78. Brunetaud JM, Mordon S, Dixon JA. Techniques, indications et

resultats des lasers en gastroenterologie. Encyclopedie Medico-Chirurgicale (Paris) 1987; 7:1–4.
79. Rutgeerts P, Van Gompel F, Geboes K, et al. Long-term results of treatment of vascular malformations of the gastrointestinal tract by Nd:YAG laser photocoagulation. Gut 1985; 26:586–593.
80. Buchi KN. Argon laser treatment of vascular malformation of the gastrointestinal tract. Gastrointest Endosc, in press.
81. Dixon JA, Burt RW, Rotering RH, et al. Endoscopic argon laser photocoagulation of small sessile colonic polyps. Gastrointest Endosc 1982; 28:162–165.
82. Lambert R, Sabben G. Laser therapy in colorectal tumors: early results. Gastroenterology 1984; 84:1222.
83. Brunetaud JM. Endoscopic Nd:YAG laser treatment of villous adenoma. Gastroenterology, in press.
84. Fleischer DE, Sivak MV. Endoscopic Nd:YAG laser therapy as palliation for obstructing esophagogastric carcinoma. Lasers Surg Med 1983; 3:172.
85. Fleischer DE, Sivak MV. Endoscopic Nd:YAG laser therapy as palliation for esophagogastric cancer. Gastroenterology 1985; 89:827–831.
86. Delmotte JS, Brunetaud JM, Desurmont P, et al. Treatment of pancreatic and biliary cysts by endoscopic argon laser. Gastroenterology 1982; 82:1041–1042.
87. Buchi KN, Bowers JH, Dixon JA. Endoscopic pancreatic cystogastrostomy using the Nd:YAG laser. Gastrointest Endosc 1986; 32:112–114.
88. Chen PC, Wu CS, Chang-Chien CS, et al. YAG laser endoscopic treatment of an esophageal and sigmoid stricture after end-to-end anastomosis stapling. Gastrointest Endosc 1984; 30:258–260.
89. Sander R, Posl H, Spuhler A. Management of non-neoplastic stenoses of the GI tract—a further indication for Nd:YAG laser application. Endoscopy 1984; 16:149–151.
90. Quigley MR, Bailes JE, Kwaan HC, et al. Microvascular anastomosis using the milliwatt laser. Lasers Surg Med 1985; 5:357–365.
91. Frazier OH, Painvin GA, Morris JR, et al. Laser-assisted microvascular anastomosis: angiographic and anatomopathologic studies on growing microvascular anastomosis. Preliminary report. Surgery 1985; 97:585–590.
92. Abela GS, Normann S, Cohen D, et al. Effects of carbon dioxide, Nd:YAG, and argon laser radiation on coronary atheromatous plaques. Am J Cardiol 1982; 50:1199–1205.
93. Lee G, Ikeda RM, Herman I, et al. The qualitative effects of laser irradiation on human arteriosclerotic disease. Am Heart J 1983; 105:885–889.
94. Grundfest WS, Litvack F, Forrester JS, et al. Laser ablation of atherosclerotic plaque without adjacent tissue injury. J Am Coll Cardiol 1985; 5:929–933.
95. Ginsburg R, Wexler L, Mitchell RS, et al. Percutaneous transluminal laser angioplasty for treatment of peripheral vascular disease: clinical experience with 16 patients. Radiology 1985; 156:619–624.
96. Greenfield AJ, Sandborn TA, Guben JK. Long-term patency rates after laser thermal angioplasty. Lasers Surg Med 1987; 7:82–83.
97. Isner JM, Clarke RH, Donaldson RF, et al. Identification of photo-products liberated by in vitro laser argon irradiation of atherosclerotic plaque, calcified cardia valves, and myocardium. Am J Cardiol 1985; 55:1192–1196.
98. Gomer CJ, Dougherty TJ. Determination of hematoporphyrin derivative distribution in malignant and normal tissue. Cancer Res 1979; 39:146.
99. Spikes JD. The historical development of ideas on applications of photosensitized reactions in the health sciences. *In* Bensasson RV, Jori G, Land EJ, et al eds. Primary Photoprocesses in Biology and Medicine. New York: Plenum, 1985; 209–227.
100. Parrish JA. The scope of photomedicine. *In* Regan JD, Parrish JA, eds. The Science of Photomedicine. New York: Plenum, 1982; 3–10.
101. Straight RC. Photodynamic therapy in laser surgery and medicine. *In* Dixon JA, ed. Surgical Applications of Lasers, Chicago: Year Book, 1987; 320–345.
102. Carruth JAS, Dougherty TJ. Photodynamic therapy: state-of-the-art. Lasers Surg Med 1986; 6:404–407.
103. Hayata W, Kato H, Konaka C, et al. Photoradiation therapy with hematoporphyrin derivative in early stage I lung cancer. Chest 1984; 86:169–177.
104. Oseroff AR. Strategies for selective cancer photochemotherapy. Photochem Photobiol 1986; 43:1055–1057.
105. Kiefhaber P, Nath G, Moritz K. Endoscopic control of massive gastrointestinal hemorrhage by irradiation with a high power Nd:YAG laser. Prog Surg 1977; 15:140–155.