Lasers in Surgery: A Return to Reason
Michael S. Kavic, MD
Editor-in-Chief

The announcement of laparoscopic laser cholecystectomy in 1989 sparked a widespread interest in lasers and laser technology. Early proponents of laparoscopic cholecystectomy described it as an operation to be performed with a laser, and available literature suggested that laser energy was necessary to accomplish laparoscopic gallbladder removal. Indeed, in those early days, it seemed that attempting laparoscopic cholecystectomy without a laser engendered significant malpractice exposure as published material stressed the use of lasers.

Teaching courses were quickly developed to meet the intense demand for instructing almost 30,000 classically-trained U.S. general surgeons in laparoscopic techniques. Included in each course was a series of lectures on laser physics and safety. The impetus to use lasers was further compounded by the desire of laser companies to sell their product and the public’s fascination with lasers as “Star Wars” technology.

A reasoned analysis of conditions during 1989-90 suggests that the intense pressure placed on classically trained general surgeons to adopt laparoscopic techniques precluded an objective appraisal of the true role of lasers in surgery. Lasers, as an energy source, were accepted uncritically and many hospitals purchased expensive units that few had the expertise to operate.

The blind acceptance of laser technology quickly turned to rejection of that technology when it became apparent that readily-available electrosurgical energy could perform equally well in a laparoscopic environment. The abrupt rejection of lasers was emotional and visceral as general surgeons felt misled by the laser companies and early advocates of laser usage. Laser energy became “persona non grata” after 1992 and the effect lingered for years.

Time and the application of scientific method, however, has begun to separate the facts of laser subcellular interaction from the fiction of uncritical application of laser power. An examination of just four areas of investigation into laser technology reveals that there is a sound basis for continued exploration of laser energy in the treatment of human disease.

1) Low Intensity Laser Irradiation:

There have been many reports over the past two decades of low intensity laser irradiation promoting tissue repair and wound healing. The biologic basis of the laser’s efficacy, however, has not been completely elucidated. Investigation into the precise biological processes involved in low intensity laser irradiation is ongoing and includes:

a) The effect of laser irradiation on oxidative metabolism of cells as evaluated by chemoluminescence measurements.

b) The ability of laser light-stimulated cells to incorporate tritiated thymidine as an indication of DNA synthesis. The use of these precise biological tools are now revealing that wavelength-specific laser energy can modulate tissue repair and wound healing.

2) Thrombolytic Therapy:

Arterial obstruction is usually due to a combination of plaque and thrombus. Some time ago, LaMuraglia showed that thrombus absorbed more laser light (400 - 600 nm) than vessel wall due to the presence of hemoglobin. Since the energy required to vaporize a clot in air is simple to determine, it seemed that choosing a laser of the appropriate wavelength would be sufficient to safely ablate thrombus. Laser ablation of a clot in a vessel containing flowing liquid, however, is not the same as vaporizing that clot in air. Early attempts at in vivo thrombus ablation not infrequently resulted in damage or perforation of the blood vessel.

Recently, there has been laboratory investigation that mirrors the physical environment of blood vessels to examine the underlying mechanics of thrombus ablation. One model utilizes gelatin impregnated with a photostable absorbing dye (to approximate the chromophore hemoglobin) which is placed in a tube under water. A pulsed dye laser at 577 nm is used to ablate the gelatin. This study has suggested that thermal ablation need not be the dominant mechanism in removal of a clot under liquid. Rather, at low energy settings, partial vaporization of the clot can occur and cause mechanical expansion or collapse of a vapor bubble. Mechanical action and not thermal vaporization, therefore, can be the dominant factor in mass removal under liquid. This model has also demonstrated that temperatures need not exceed 100 degrees centigrade to initiate the ablation process.

The ablation threshold for thrombus and vessel wall can be predicted at any wavelength. Radiant exposure can be chosen such that it is above the threshold for thrombus ablation, but below that which causes thermal damage to arterial plaque and vessel wall. More experimental work needs to be done, but the unique preciseness of laser energy to remove clot is being explored in a rational manner.

3) Photodynamic Therapy (PDT):

Essentially, photochemical cellular destruction of a malignancy is achieved by the combined action of a photosensitizer...
that accumulates in the tumor and light illumination in the presence of tissue oxygen. There must, of course, be a sufficient concentration of photosensitizer in the involved tissue and light of the appropriate wavelength and energy must be used to excite it.

Hematoporphyrin derivative or its purified ether/ester is one of the most frequently used photosensitizers. Prolonged skin photosensitization to this agent, however, can be debilitating to the patient. In addition, more than one layer of an organ may be sensitized, resulting in undesirable injury to healthy tissue. To minimize these effects, alternative methods to deliver the photosensitizer such as intratumoral or intravesical delivery techniques have been investigated.

5-aminolevulinic acid (ALA), is a naturally occurring photoinactive intermediary in the cellular biosynthetic pathway for the production of heme. During the production of heme, ALA is converted to protoporphyrin IX (PpIX) and in smaller amounts to coproporphyrin and uroporphyrin. Protoporphyrin IX can be photosensitive.

Excess exogenous ALA instilled in a closed space such as the urinary bladder can result in temporary excess accumulation of PpIX. PpIX, which is photosensitive, can be stimulated by light of the appropriate wavelength to cause photochemical destruction of tumor.

Intravesical delivery of photosensitizer avoids, in part, the build up of photosensitizer in adjacent tissues. In the case of urinary bladder tumors, this method of delivery has been shown to cause selective urothelial ablation without lamina propria or detrusor muscle damage. This technique represents a significant refinement in the precise application of laser energy to selectively destroy malignant tumor cells.

4) Tissue Welding:

Tissue welding using laser energy has been around for almost 20 years. The potential benefits of this technique are many and include the possibility of shorter operating time, reduced foreign body reaction and scar, and the potential to anastomose very small caliber vessels.

Laser tissue welding, however, has not been widely adopted. The main reasons for its lack of acceptance have been the difficulty in predicting when tissue welding has occurred and low weld strength during the initial healing phase.

Tissue welding is a result of thermal coagulation of tissue rather than a photochemical response. Laser irradiation causes a disruption of cell membranes with leak of cellular protein. A thermal degradation of the protein’s disulfide and hydroxyl bonds occurs which forms new molecular bonds upon cooling, somewhat analogous to boiling an egg.

During laser exposure, collagen is denatured and undergoes swelling and reorganization of its fibrils in one direction. Protein that has leaked from the cells forms a micro solder that, along with denatured collagen, forms a coagulum. This coagulum results in tissue adhesion.

Typically, the surgeon looks for a change in tissue color or blanching to signify an end point for weld completion. This parameter is highly subjective and lacks reproducibility in predicting the end point of tissue welding.

Recently, the two main disadvantages of laser welding techniques have been addressed in unique ways. First, it has been shown that efficient laser tissue welding occurs at a surface temperature of 70 degrees centigrade. Using a closed feedback loop consisting of an infrared thermometer for tissue surface temperature measurement, and a computer to manage temperature data acquisition and laser power control, surface temperature can be maintained at a constant value during tissue welding. Secondly, it has been found that human albumin solder can be used as a vehicle for delivery of a biologically active recombinant growth factor which is stable at the temperature necessary for tissue welding. This growth factor, transforming growth factor B1 (TGF-B1), has been shown to significantly accelerate wound healing.

The use of temperature-controlled laser delivery techniques affords a high degree of reproducibility and can be used to prevent significant thermal degradation of the growth factor. The use of nonimmunogenic, inexpensive human albumin permits the delivery of a single dose of growth factor which can be held at the wound site for extended periods and increase weld strength.

Conclusion:

Emotional overreaction of the general surgical community to commercial exploitation of lasers in laparoscopic cholecystectomy has begun to subside. Laser energy is no longer technology in search of a need, but rather a tool that the scientist-surgeon can use in a precise and often times subtle manner. The examples of investigational activity cited demonstrate that the unique effects of laser energy on human tissue are being explored in a sensible and rational manner. The continued investigation of laser energy holds promise for even more novel therapies to manage disease.

References:

1. Reddick EJ, Olsen D, Daniell J, et al. Laparoscopic laser cholecystectomy. Laser Med Surg News Adv. 1989(Feb.):38-40.

2. Southern Surgeons Club. A prospective analysis of 1518 laparoscopic cholecystectomies. N Engl J Med. 1991;324:1073-1078.
3. O’Kane S, Shields TD, Gilmore WS, Allen JM. Low intensity laser irradiation inhibits tritiated thymidine incorporation in the hemopoietic cell lines HL-60 and U937. Lasers Surg Med. 1994;14:34-39.

4. Callaghan GA, Riordan C, Gilmore WS, McIntyre IA, Allen JM, Hannigan BM. Reactive oxygen species inducible by low-intensity laser irradiation alter DNA synthesis in the haemopoietic cell line U937. Lasers Surg Med. 1996;19:201-206.

5. Yu W, Nairn JO, Lanzafame RJ. The effect of laser irradiation on the release of bFGF from 3T3 fibroblasts. Photochem Photobiol. 1994;59:167-170.

6. LaMuraglia GM, Anderson RR, Parrish JA, Zhang D, Prince MR. Selective laser ablation of venous thrombus: Implications for a new approach in the treatment of pulmonary embolus. Lasers Surg Med. 1988;8:486-493.

7. Sathyam US, Shearin A, Chastenev EA, Prahl SA. Threshold and ablation efficiency studies of microsecond ablation of gelatin under water. Lasers Surg Med. 1996;19:407-412.

8. Chang SC, Buonaccorsi G, MacRobert AJ, Brown SG. 5-aminolevulinic acid (ALA)-induced protoporphyrin IX florescence and photodynamic effects in the rat bladder: an in vivo study comparing oral and intravesical ALA administration. Lasers Surg Med. 1997;20:254-264.

9. Jain KK, Gorish W. Repair of small blood vessels with the neodymium-YAG laser. A preliminary study. Surgery. 1979;85:864.

10. Menovsky T, Beek JF, vanG MJC. Laser tissue welding of dura mater and peripheral nerves: A scanning electron microscopy study. Laser Surg Med. 1996;19:152-158.

11. Stewart RB, Benbrahim A, LaMuralglia GM, et al. Laser assisted vascular welding with real time temperature control. Lasers Surg Med. 1996;19:9-16.

12. Poppas DP, Massicotte JM, Stewart RB, et al. Human albumin solder supplemented with TGF-B1 accelerates healing following laser welded wound closure. Lasers Surg Med. 1996;19:360-368.