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HIGH-POWER NEODYMIUM-YAG LASER SURGERY

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Abstract. A new high-output laser system, with the property of color absorption, the neodymium-YAG laser, with a special flexible fiber optics scalpel has been used for the first time for surgery in man. The skin was selected as the proper test model for the clinical investigative studies of this new laser. To establish color absorption, certain types of skin lesions were selected. Patients with tattoos, port-wine spots, blue-rubber-bleb syndrome (progressive angiomatosis) and skin malignancies, including basal and squamous cell types were used. The preliminary experiments, both with surgery in animals and an investigate laser surgery in twelve patients, indicate that this laser system, with its high output, can be used with precision because of its flexibility, effective arrest of hemorrhage from its high-power output and selective absorption and consequent increased coagulation necrosis in pigmented tissues through its differential color absorption. These initial experiments, then, establish the skin as a good test model system for studies on the surgical application of laser systems.

Advances in laser technology continue to produce new laser systems. For surgery, a high-power output is necessary. When high-power outputs are used, transmission systems are usually complex and cumbersome. For surgery, a laser beam which is continuous (CW) and can act like an optical knife, is preferred to the pulsed-laser system. Two systems are under study now, a CO_2 laser (10 600.0 nM) and the neodymium-Yttrium Aluminum Garnet, Nd-YAG (10 600 nM). With planned programs for safety, laser surgery may be done without danger to either subject or operator. The problem still remains to determine the true value of laser surgery over other modalities such as the scalpel, high-frequency electrosurgery, cryosurgery and for animal surgery (because of its hazards of gas embolism), the hot plasma scalpel. Multiple skin lesions continue to provide a good clinical model for controlled investigations of laser surgery.

In a previous report (4), the use of high-power CO_2 far infrared (10600 nM) laser for various surgical applications, including skin lesions, was detailed. Previous studies by other investigators had been done with low-output CO_2 lasers and are not related, as control studies, to our current research with high-power Nd-YAG lasers. Since our report in 1970, extensive animal experiments have been done in our laboratory with the high-output CO_2 laser in surgery of the stomach, liver, excision of burns, maxillofacial and bone surgery. In addition, CO_2 laser surgery has been done recently on patients with stomach stress ulcers by Goodale (5) and brain tumors by Stellar (8). There also has been an excision of a burn of the neck with the CO_2 laser. Excision of small deep burns by lasers with a bloodless base, receptive immediately for a graft replacement with good healing, should be of considerable interest to dermatologists as well as to surgeons. Studies in the laser treatment of burns in patients are continuing at the Shrine Burns Institute of the Medical Center of the University of Cincinnati. High-power CO_2 lasers (80–300 W) still require large laser equipment with bulky operating arms which are limited in flexibility and are difficult to sterilize. Although the absorption coefficient of tissues at the CO_2 laser frequency is at least 200 cm^{-1} (which affects total absorption of the beam in the outer 200 μm of the tissue surface), arrest of capillary hemorrhage is excellent and occlusion of vessels up to 2 mm is possible with this laser type. Previous studies with low-output CO_2 lasers had not shown such hemostasis. The technique of coagulation of blood vessels of 2 mm in diameter was elaborated by using the unfocused beam of an 80 W CO_2 laser to any area 10 m in diameter. The temperature of

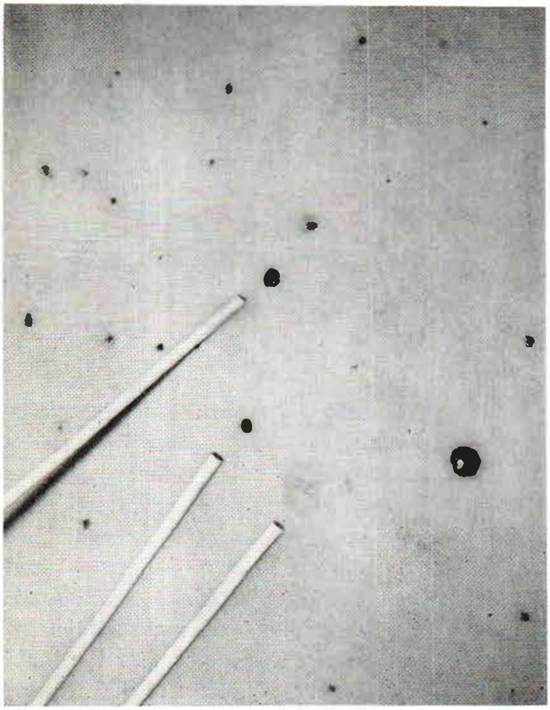

Fig. 1. Nd-YAG laser surgery, showing flexibility of the special fiber optics laser scalpel for the high-output Nd-YAG laser operation under local anesthesia on the back of a patient with progressive recurrent hemangiomatosis (blue-rubber-bleb nevus syndrome).

such soft tissue did not exceed 100°C and 2 mm from the line of excision of the focused beam, there was a temperature rise of only 15°C in a period of 2–3 sec. Current studies from our laboratory of the use of the CO_2 laser in exsanguinating experimental liver injury in dogs is being reported by Fidler et al. (1). As regards skin incisions, Hall (6) determined that in albino rats, CO_2 laser (12–15 W) incisions healed more slowly than scalpel incisions because of the necrosis of wound margins. This is true also with our high-output CO_2 lasers. As Hall (6) found, however, the abdominal wounds healed the same.

MATERIALS AND METHODS

In an effort to study effects at a frequency more transparent in tissues, a compact and more flexible laser operating unit employing CW neodymium YAG laser was used. Details for the dermatologist of the basic mechanisms of the Nd-YAG laser are given by Goldman & Rockwell (2). The laser system employed emitted up to 200 W at the near infrared 10 600 nm frequency. Tests on liver tissues indicated an absorption coefficient of approximately 12 cm^{-1}, hence, in comparison with the CO_2 laser, one would anticipate a much deeper penetration and a corresponding deep zone of thermal coagulation necrosis and, perhaps, the ability to arrest bleeding in larger vessels in a more rapid manner due to greater in-depth heating.

To provide for complete flexibility of the laser beam, a light-weight crystalline quartz type fiber optics transmission probe, developed by Nath & Schindler (7), was used. This specially constructed probe allowed transmission of 80% of the neodymium-YAG laser power while maintaining a divergence of less than 10 mrad in the exiting beam. The brightness of the beam exiting this special probe is higher by more than two orders of magnitude compared to conventional fiber optics bundles. Thus, high-power densities can be achieved by focusing the emergent beam. Using a lens with a 5 cm focal length, a focused power density up to 70 kW/cm^2 was produced in the focal plane. The size of the focused beam at this point was approximately 0.4 mm. The overall system provides a much more flexible delivery system for the surgeon than the cumbersome laser beam transmission arms of earlier laser surgical systems.

The Nath–Schindler fiber probe is completely sterilizable and, thus, is easilly adapted for use in the operating theater. To provide for precise and visual pre-localization of the Nd-YAG surgical beam, a helium-neon laser "aiming beam" was used. This beam was optically

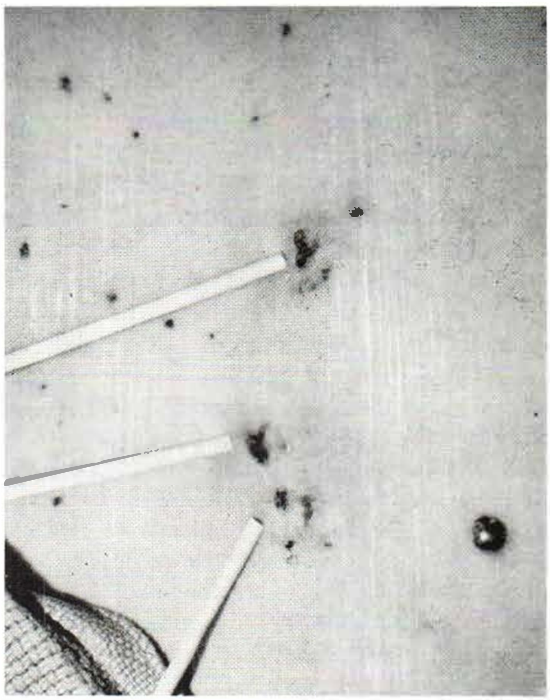

Fig. 2. The immediate effect on lesions with crusting and absence of any hemorrhage, 70 kW/cm^2 power density.

coupled into the beam pathway in a manner which reproduced the Nd-YAG laser characteristics. A krypton beam may also be used.

Eye safety is provided by goggles using Schott KG glass. This glass is highly transparent in most of the visible range of the optical spectrum and enables unobstructed vision during surgery.

Gloves were used for protection of the hands from reflected radiation and, where possible, specular reflectance was avoided from operating instruments. Surgery was best performed by maintaining a dry operating field with long cotton applicators. This dry field was necessary since blood absorbed the laser beam.

RESULTS

In this initial series of experiments, the operating neodymium-YAG laser was used on both animals and patients. Our previous experience with a CW 10-W Nd-YAG laser had shown that tissue reactions at this frequency displayed a color-selective absorption in selected areas of pigmented and tattoed skin of man. This low-output laser was not effective for extensive lesions of the skin.

To develop a critical evaluation of this higher power Nd-YAG laser system, experiments were done which paralleled those with the high-power CO_2 laser systems also being done in our laboratory (6). Surgery was done on dogs with the Nd-YAG to determine the efficiency of cutting of skin, soft tissue, liver, lung and bone. In brief, the results indicated that the CW type of Nd-YAG laser was not as effective for incising soft tissue, but was more effective at coagulating bleeding from large vascular organs in comparison with the CO_2 laser. The use of high-power Q-switched Nd-YAG laser system may increase the cutting efficiency of this laser type in future studies, although initial studies of Q-switching showed poor cutting, but incidentally effective metal welding, for example for dentures in the mouth. A detailed review of these results will be reported at a later time.

After the animal experiments, the skin was used as a test model to evaluate the techniques of the use of this in man rather than do develop a controlled study of its value and limitations for skin lesions. Pigmented and non-pigmented lesions were selected. In some of the patients other laser systems had been used. These initial

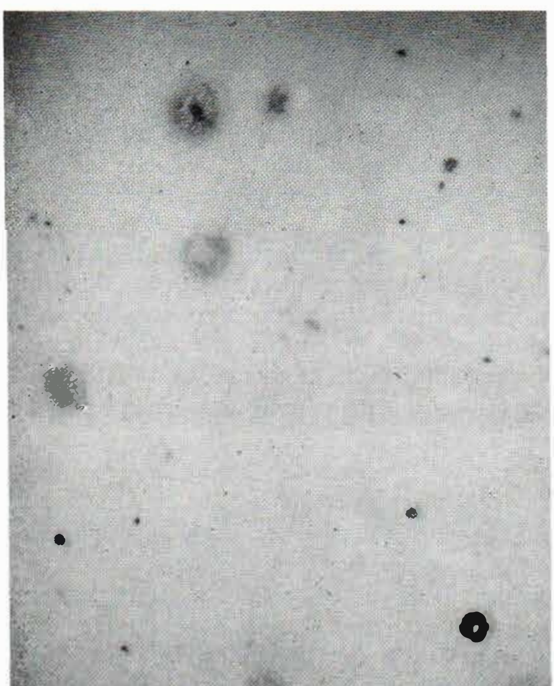

Fig. 3. Two months after laser surgery, showing healing of all lesions.

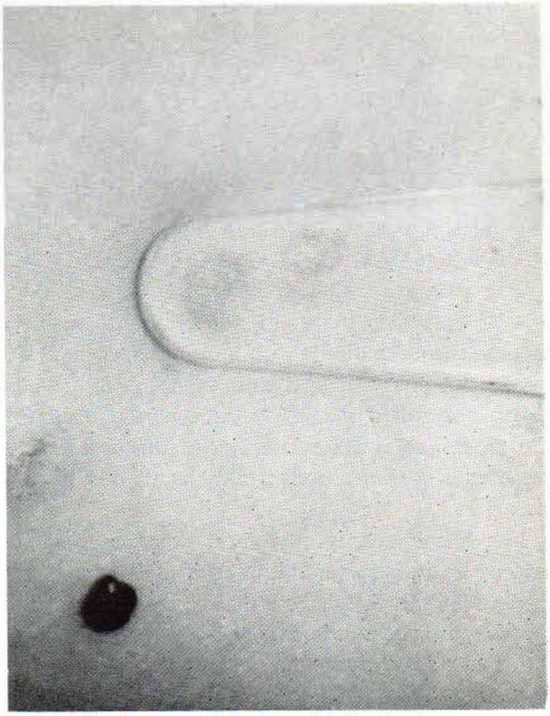

Fig. 4. Diascopy shows no evidence of recurrence after laser surgery; previously all lesions treated by excision or by high-frequency electrosurgery had recurred within several weeks of treatment.

experiments, then, would show how easily accessible tissue, such as the skin, can be used for initial studies of laser surgery on man. Thus, a critical evaluation of such factors as flexibility, precision, and safety of the laser scalpel can be combined with sterile operating-room technique. All this we were able to do in this first clinical series of investigative high-power output Neodymium-YAG laser surgery in man.

The patients included 5 patients with tattoos, 3 with port-wine marks, 1 with blue-rubber-bleb angioma and 3 patients with multiple malignancies of the skin. No attempts were made, as indicated, to do controlled studies but merely to evaluate the technique and the intensity of the usual laser reaction of nonspecific thermal coagulation necrosis.

For linear tattoos, the laser was used as an erasure technique to follow accurately along the pattern of the tattoos. In these experiments, the power output varied from 10–20 W focused to 0.4 mm. A five-month observation period, to date, has been possible for all patients treated with the Nd-YAG laser. For 5 patients with tattoos, the test treatments were limited to small areas and no local anesthesia was used. Good erasure of small linear areas was found. Redness from the treatment has persisted.

In the treatment of port-wine marks (2, 3), the laser was used in an attempt to remove the reticulated pattern which had resulted in some patients following ruby-laser irradiation of areas 2.1 cm^2. Three patients were treated; 1 patient has had a thickened persistent scar. In the other 2 patients, there was effective removal of the linear port-wine markings.

In three pigmented basal malignancies with the lesions rimmed by local anesthesia, the laser was found to produce intensive thermal necrosis deep in tissue with 75–100 W. These have healed, so far, without recurrence. To induce a more pronounced color-selective reaction in two non-pigmented basal cell malignancies, the surface was painted with 1% aqueous gentian violet dye. This procedure helped to enhance the absorption selectiveness and produce a localized deeper thermal necrosis only in the basal cell epithelioma area.

One patient had an inoperable squamous cell malignancy from a chronic paronychial infection about the big toe. Large vegetative lesions were on the big toe, and linear metastases were found upon the leg and in the involved inguinal lymph glands. Although the patient was receiving Cobalt-60 radiation, certain areas were selected and, following nerve-block anesthesia, treatments were given with the Nd-YAG laser. For the initial treatments in this patient, surface thermal coagulation necrosis was produced with 75–100 W. No bleeding was associated with this highly vascular and friable tissue. These treated lesions have healed so far without any recurrence. The control lesions, Cobalt-60 radiation alone, healed more slowly.

Nd-YAG laser was used on blue-rubber-bleb angioma syndrome in a 17-year-old boy. Multiple angiomas were present in the viscera as well as in the skin. Extensive removal of the angiomas had been necessary in this patient because of the severe hemorrhages. This included amputation of one leg and colectomy. Furthermore, most of the lesions in the skin which had been previously removed by deep excisional surgery, or even by high-frequency electrosurgery, had recurred, usually within weeks after surgery. Secondary hemorrhage and consequent anemia were the most significant features of his current state. Eight different types of cutaneous lesions were done on the back under local anesthesia. These included thin-walled vegetative lesions as well as scarred lesions with recurrences deep in the scar. There was no hemorrhage, immediate or secondary, in any of the lesions treated. To date, after 9 months, there have been no local recurrences.

DISCUSSION

These preliminary results indicate that this laser can be used in a sterile operating room procedure with complete ease and flexibility and precision for specific areas. The intensity of the induced thermal coagulation necrosis varied with the power output, character of the target area as regards color, vascularity, fibrosis and the duration of the impact of the laser beam on the skin. Moreover, the high-power output Neodymium-YAG laser provides superior arrest of hemorrhage in tissue and a degree of selective reactions due to the differential color absorption characteristics of tissue at this laser frequency. These are both significant features which are different from previous investigations with high-power CW laser surgery done with the CO^2 laser.

The Neodymium-YAG laser is now being developed for incorporation into an operative laser endoscope for use in cavities in the body, for metallic dentures in the mouth, and also for laser transillumination studies for detection of masses of different densities in the skin and soft tissues. The cases now under investigation include cysts, mucinous pseudo-cysts (so-called myxoid cysts) of the finger, localized areas of scleroderma, Raynaud's syndrome, stasis dermatitis for the intensity of dermal and subcutaneous fibrosis, and tumors of the breast and oral cavity.

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