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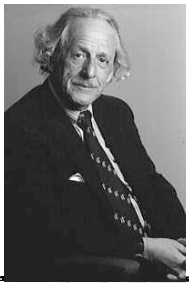

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EUGENE GARFIELD
INSTITUTE FOR SCIENTIFIC INFORMATION®
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Noninvasive Medicine. Part 3. Newer Therapeutic Procedures

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This essay (the last of three parts) discusses noninvasive therapeutic (as opposed to diagnostic) medicine. By selecting examples from modern medical practice, it will illustrate how conventional surgery is being replaced by procedures that are less traumatic but equally or more effective. Examples include lithotripsy and angioplasty, as well as several clinical applications of lasers.

Diagnostic techniques have become less invasive with the help of sophisticated computing and imaging machines. However, such systems, discussed in Part 2,[1] are only for diagnosis: no intervention or change occurs in the patient's condition through their use. The real challenge comes in devising less invasive *therapeutic* procedures. Before discussing some instances of how this challenge is being met, we must grant that medical treatment—if it is to produce results (quackery and faith healing aside)—*must* enter the human body.

The question then becomes, To what extent can modern medicine be noninvasive yet effective? The examples below, selected from the medical literature (papers that prominently feature such phrases as "semi-invasive," "more noninvasive," "truly noninvasive," and so on), will begin to show where we stand in terms of the noninvasive treatment of disease. Examples are drawn primarily from two specialties, urology and cardiology—specifically, techniques for the removal of renal stones and the widening of obstructed heart valves. Laser therapy is also discussed, as a less traumatic form of surgery.

Lithotripsy

As with many medical specialties, the treatment of renal stones has gradually progressed from invasive surgical procedures to less invasive techniques. Conventional treatment involves a traumatic surgical incision below the rib cage, one to three weeks in the hospital, and up to three months of convalescence. This has mostly been replaced by two other techniques: percutaneous nephrostolithotomy (PCNL) and extracorporeal shock-wave lithotripsy (ESWL).

PCNL still involves a small incision for inserting instruments into the kidney. As Ron Miller, Institute of Urology, University of London, UK, states, stone disintegration can be achieved chemically, ultrasonically, or electrohydraulically.[2] Stephen P. Dretler and colleagues, Massachusetts General Hospital, Boston, reported their early investigations with newly developed, larger catheters and better stone irrigation systems in the late 1970s. They noted, however, that percutaneous access and irrigation is complementary to, rather than competitive with, surgical therapy. For recurrent stones, the percutaneous method was considered the treatment of choice.[3]

Less invasive still is ESWL. This technique uses shock waves that are produced by an electrical discharge across an underwater spark gap, causing an explosive vaporization of the water. With the patient submerged in a tub of water, these shock waves (translated into pressure waves) are focused to shatter renal stones without affecting other parts of the body. The procedure was described and evaluated for safety and efficacy by Daniel M. Newman *et al.*, Institute of Kidney Stone Disease, Methodist Hospital of Indiana, Indianapolis.[4] Incidentally, ESWL is also being used in the fragmentation of gallstones. The technique may eventually complement the traditional (and atraumatic) method of treating gallstones with bile acids. The dissolution of cholesterol gallstones with bile acids, initiated in the early 1970s, has not been as effective as first hoped.[5] Some physicians still believe that this noninvasive and inexpensive approach can be improved by controlling the concentrations of bile acids.

The first clinical experience with the use of underwater shock waves to destroy kidney stones was reported in 1982 by Christian Chaussy *et al.*, Department of Urology, Institute for Surgical Research, Ludwig-Maximilians University, Munich, Federal Republic of Germany (FRG). The authors' conclusion, that "noninvasive treatment of patients with kidney stones by high energy shock waves is efficient,"[6] seems to be borne out in more recent assessments of this technique. Kostantinos E. Psihramis, currently of Mount Sinai Hospital, Toronto, Ontario, Canada, and Dretler, mentioned earlier, review the effectiveness of this method on stones in the kidney and in other regions of the urinary tract, such as the caliceal diverticula.[7] A comprehensive report by urologist George W. Drach *et al.*, Department of Surgery, University of Arizona, Tucson, presents results of a large 1984 cooperative study with the third model of the Dornier ESWL. The technique was found to effectively fragment smaller (about 1 cm in size) urinary calculi, with minimal postoperative pain, a hospital stay of one to two days, and no adjunctive or repeated procedures.[8]

J.E. Lingeman, Institute of Kidney Stone Disease, Methodist Hospital of Indiana, reviews the pros and cons of PCNL and ESWL.[9] While ESWL generally takes less time (an average of 37 minutes as opposed to 155 minutes) and entails lower morbidity than PCNL, it may not produce as high a rate of prolonged stone-free status and, thus, may need to be repeated. This ultimately makes ESWL more expensive. Additionally, ESWL can only be used successfully on stones that are less than 2 cm in size. General anesthesia is less common with ESWL than with PCNL, and less skill is required to perform ESWL. As D.R. Webb and colleagues, Institute of Urology and Devonshire Hospital Lithotriptor Centre, London, conclude, "For optimal removal of nearly all renal stones by minimal or noninvasive techniques, PCNL and ESWL are required either separately or as combined procedures."[10] However, according to Keith N. Van Arsdalen, director, Lithotriptor Unit, Division of Radiology/Urology, Hospital of the University of Pennsylvania, Philadelphia, ESWL is currently the treatment of choice.[11]

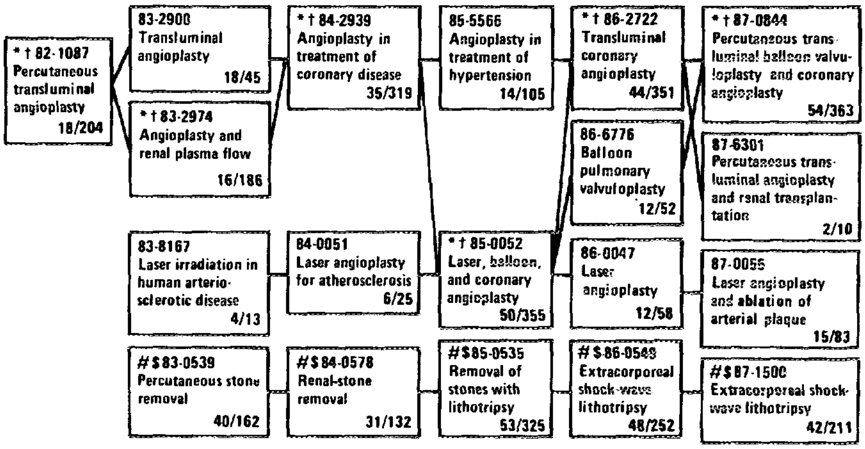
A more recent technique, initiated by Dretler, is that of laser lithotripsy. He has used the pulse-dye laser to fragment urinary stones successfully. Dretler sees laser therapy as potentially less expensive and more available than ESWL and also as less traumatic than ureteral ultrasonic lithotripsy.[12]

Research-Front Data on Lithotripsy

Figure 1 is a historiograph of the research on both lithotripsy and angioplasty from 1983 and 1982 (respectively) to 1987. By looking at research fronts from different years, including core papers, we get a historical perspective on research in both fields. Two papers, for example, that are core to every annual research front on lithotripsy are those by I. Fernström and B. Johansson, Department of Diagnostic Radiology and Urology, Karolinska Hospital, Stockholm, Sweden,[13] and by Chaussy, mentioned earlier.[6] Fernström's 1976 paper, cited in over 100 publications, describes the technique now commonly known as PCNL as "a new and useful alternative method for the removal of stones...from the renal pelvis" and asserts that "preliminary trials have been promising and free from complications."[13] Chaussy's 1982 paper has also been cited in about 100 publications. As noted above, it describes the first successful performance

Figure 1: Historiograph of research fronts relating to angioplasty and lithotripsy. Numbers of core/citing papers are indicated at the bottom of each box. Core literature includes:

* A.R. Grüntzig's 1974, 1978, and 1979 papers
† C.T. Dotter's 1964 paper
# I. Fernström's 1976 paper
$ C. Chaussy's 1982 paper



of extracorporeal destruction of kidney stones using high-energy shock waves. Significantly, even in this first trial, open surgery was not required for any of the 72 patients.[6]

Angioplasty

The traditional treatment for coronary atherosclerosis has been open-heart or bypass surgery. This procedure is palliative and aims only to achieve maximum cardiac function for as long as possible. Progression of atherosclerosis after bypass surgery is common. A less drastic and more repeatable technique to alleviate atherosclerotic conditions is percutaneous transluminal coronary angioplasty (PTCA).

This technique, as described by E.B. Ringelstein *et al.*, Departments of Neurology and Neuropathology, Aachen Technical University, FRG, is "a semiinvasive, non-operative transvascular technique for dilatation of stenosed vessel segments by help of balloon catheters."[14] A slender balloon is inserted percutaneously into the affected blood vessel via a series of catheters and guiding devices. At the site of the obstruction, the balloon is inflated, flattening (or fracturing) the atherosclerotic plaque against the walls of the blood vessel, thereby reestablishing the flow of blood. As noted in a review by Saurabh K. Chokshi and colleagues, Northwestern University Medical School, Chicago, Illinois, approximately 120,000 such procedures were performed in 1986, double the number performed in 1984. The authors further point out that this technique, less than a decade old, "has emerged as an effective, nonsurgical, palliative modality in the treatment of stenotic coronary artery disease."[15]

Additionally, PTCA "is recommended for an entire spectrum of patients, beginning with asymptomatic patients with silent ischemia and abnormal exercise stress test results and including the patient with acute myocardial infarction."[9] M. Kaltenbach, University of Frankfurt Clinic, FRG, notes that, as of 1987, about one-third of revascularizations were done by angioplasty and that, "in patients with single-vessel stenosis, angioplasty can replace surgery in the majority of cases."[16]

While PTCA is the only well-established and widely accepted modality of revascularization besides surgery, laser angioplasty is a promising technique. A review article by Stephen N. Joffe and Tom Schröder, University of Cincinnati Medical Center, Ohio, describes the status of transluminal laser angioplasty (performed so far as open procedures) as follows:

> Future trends are moving toward percutaneous transluminal angioplasty and use of fiberoptic "angioscopes" for direct visualization of atherosclerotic plaque and the Nd:YAG laser with the new contact delivery systems to vaporize the obstruction and restore patency.[17]

The concept of laser angioplasty, according to Jeffrey M. Isner, Tufts University Medical School, New England Medical Center, Boston, and Richard H. Clarke, Department of Chemistry, Boston University, owes its existence to the development of PTCA. Indeed, the authors remark, it is the logical extension of all earlier (balloon) catheter-based interventions. Instead of using a balloon, which only remodels atherosclerotic lesions (with recurrence of lesions in 20 to 35 percent of cases), laser angioplasty uses laser-generated light that completely eliminates atherosclerotic plaque, converting plaque from solid-phase matter (with its attendant risk of blood clots) to a water-soluble gas.[18]

Whether laser surgery is noninvasive is subject to debate, but laser treatment is far less traumatic than surgery, since optical fibers transmit laser light through a percutaneously inserted and guided catheter. It may also prove to be more effective than balloon angioplasty, since it destroys obstructing plaque rather than merely flattening it out. Other characteristics of lasers that make them good tools for cardiovascular plaque removal are listed by George S. Abela *et al.*, University of Florida College of Medicine, Gainesville.[19] The laser's capacity to photocoagulate tissues, its precise control of beam direction and output, and its preferential absorption by certain tissues qualify laser light as less traumatic than bypass surgery and more effective than balloon angioplasty. Subsequent work by Abela *et al.* also indicates that laser angioplasty might entail a better healing process. A canine study resulted in smoother vessel surfaces, and no accelerated atherosclerosis at lased sites was noted.[20]

Research-Front Data on Angioplasty

The six-year (1982-1987) historiograph in Figure 1 contains a string of annual research fronts on transluminal angioplasty. However, the origins of the field are much earlier. For example, a 1964 paper by Charles T. Dotter and Melvin P. Judkins, Minthorn Memorial Laboratory for Cardiovascular Research through Radiology, University of Oregon, Eugene, discussing a then-new transcutaneous technique, recurs every year. This core paper has been cited over 525 times in subsequent publications. Published as a preliminary report in *Circulation*, it describes a technique to recanalize arteriosclerotic blocks in the lower extremities transcutaneously, with a spring guide. The authors call for the "development of a device suitable for percutaneous insertion...[and] capable of externally controlled concentric expansion."[21]

What Dotter and Judkins were proposing, in effect, was the development of a balloon catheter to replace the spring guide. In use since 1974, the balloon catheter was perfected by Andreas R. Grüntzig and coworkers, Department of Medicine, University Hospital, Zurich, Switzerland. Their papers are also core to (yearly) fronts in the three top strings of boxes. Perhaps the most important of Grüntzig's publications, cited over 650 times, is a 1979 paper that describes the technique now widely known as PTCA, where "a catheter system is introduced through the systemic artery under local anesthesia to dilate a stenotic artery by controlled inflation of a distensible balloon."[22] According to Abela, using a guide wire under standard fluoroscopy, however, is still the most practical approach to guidance—for both balloon and laser angioplasty. Other guidance and/or diagnostic methods, such as ultrasound and endoscopic fluorescence, are under investigation.[23] As can be seen in the historiograph, the string of research fronts on laser angioplasty is linked at different places to research fronts on percutaneous balloon angioplasty. Indeed, as far back as 1983, there has been a simultaneous development of the even less invasive laser approach to atherosclerosis. This line of research is discussed later, in the section on laser-therapy research fronts.

In both lithotripsy and angioplasty, the most recent treatment modalities have involved laser technology. While this subject arguably deserves a full essay, a few general observations will be made here about the laser and its medical applications.

Laser Surgery and Therapy

Laser—an acronym for *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation—is

> a device that produces an intense, small, nondiverging beam of coherent electromagnetic radiation in the ultraviolet, visible, or infrared regions of the spectrum. It is used in retinal welding, microsurgery, cauterization, tumor therapy, and diagnosis of deep pathologic lesions.[24]

The first working laser was produced by Theodore H. Maiman, Hughes Aircraft Research Laboratories, Malibu, California, in 1960.[25] Since then, laser technology and its applications in medicine have made great progress. There are now literally hundreds of different lasers in use, although the three most common types in surgical practice are the carbon dioxide, argon, and Nd:YAG lasers. (Nd is the rare-earth transitional element neodymium; YAG stands for yttrium-aluminum-garnet.) This brief discussion of lasers in medicine will first determine what makes laser therapy noninvasive; it will then touch upon a few of the medical specialties that use lasers. Laser surgery is most commonly associated with ophthalmology, where the pioneering work was done. However, more recent applications—in gynecology, dermatology, and oncology—will be discussed.

Is Laser Surgery Noninvasive?

Some may argue that laser surgery is not so different from conventional surgery. In both types of surgery, a cutting tool is used to excise or otherwise repair diseased tissue. However, there are some important differences that firmly qualify laser surgery as much less invasive than conventional surgery. Two major differences are the *type of "knife"* the laser beam produces and the *endoscopic method* in surgery (that is, the visual inspection of the body's internal cavities using a small instrument called an endoscope).

While often referred to as a laser knife, it is a mistake to associate the laser beam too closely with the surgical scalpel. Indeed, both its physical and its functional features put it in a separate compartment of the medical tool chest. Through entirely different means, it produces better results than conventional surgery. The main advantages of the laser knife are the following: first, it cuts more precisely than the scalpel, causing less trauma to surrounding tissue; second, lasers cut tissue and coagulate blood simultaneously, reducing blood loss; finally, the laser knife works without actually touching targeted tissue. Due to this latter feature, an unimpeded view of the surgical site is permitted, and there is considerably less risk of infection.

Laser surgery has been greatly advanced by the development of fiber optics and endoscopes. With the help of fiber optics, lasers can deliver light virtually anywhere in the body through a small incision. Not only do endoscopic applications decrease the need for general anesthesia (with its attendant risks and morbidity), but they also obviate lengthy postoperative hospitalization and recovery. This translates into a drastic reduction of cost and pain. For all the above reasons, then, laser surgery holds the promise for less invasive treatments of disease, as illustrated below.

Lasers in Gynecology

According to a 1986 American Medical Association report, gynecology is the specialty involving the highest number of surgical laser cases in the US.[26] In a review article by Michael S. Baggish, College of Medicine and Health Sciences Center, State University of New York, Syracuse, various surgical categories are discussed. Especially pertinent is the author's coverage of laser endoscopy. This technique lends itself both to the treatment of endometriosis (effectively halving the necessity for the more intrusive laparotomy) and to the management of uncontrolled uterine bleeding via a hysteroscope (eliminating in many cases the necessity for the more traumatic hysterectomy).[27]

While the CO_2, argon, and Nd:YAG are the common lasers used in gynecological (and indeed all) surgery, under development is an even more versatile free electron laser (FEL), first built in 1976. As William R. Keye, Division of Reproductive Endocrinology, University of Utah Health Sciences Center, Salt Lake City, describes, FELs "have the capability of operating as powerful sources of continuously tunable coherent radiation in wavelengths ranging from the far infrared to the far ultraviolet."[28] No matter which laser source is used, gynecological procedures using this technology are almost always performed in the doctor's office or on an outpatient basis. Indeed, as the above-mentioned review by Baggish concludes, "gynecologists will continue to enter the field of laser surgery because as a specialty we are attuned to out-patient methodology."[27]

Lasers in Dermatology

Dermatology is another specialty that is making extensive use of lasers. For example, lasers have recently been reported to aid in the closing or healing of cutaneous wounds.[29,30] Joseph G. Morelli and John A. Parrish, Wellman Laboratories, Harvard Medical School, Boston, and Massachusetts General Hospital, describe the successful treatment of vascular lesions, such as port wine stains, with the argon laser. They also report on the use of the excimer (short for excited dimer) laser in the treatment of malignant tumors. This laser's range of ultraviolet wavelengths makes it possible to control the depth of penetration, thus treating the lesions without damaging normal tissue.[31] In this, as indeed in all laser applications, there are potential hazards to both users and patients. These include eye damage from scattered radiation (in exposed laser procedures), burn hazards, as well as the dangers of fire and electric shock.[23]

Lasers in Oncology

The use of lasers in tumor removal or management is becoming more versatile. A report by neurosurgeon Raymond N. Kjellberg *et al.*, Massachusetts General Hospital, illustrates the effective use of both diagnostic and therapeutic noninvasive methods. His treatment of brain tumors involves first mapping the tumor with a CT scanner, then destroying it with a particle beam from the Harvard cyclotron. The procedure is much safer than conventional brain surgery: it takes one-and-a-half hours, and patients go home a day later. It is also safer in that, unlike the X rays normally used in radiation therapy, proton beams can be controlled to penetrate no further than the tumor. Kjellberg reports that over 85 percent of patients in his study had no complications after the procedure and that proton-beam therapy appears to carry a lower risk of hemorrhage than does craniotomy.[32]

Another successful use of lasers is in endoscopic surgery for the treatment of laryngeal and upper-airway disorders. According to Walter G. Wolfe and Peter Van Trigt, Department of Surgery, Duke University Medical Center, Durham, North Carolina, endoscopic laser therapy is particularly effective in the management of carcinoma of the esophagus. There is no need for general anesthesia, and the systemic side effects of radiation therapy are avoided. The technique can thus be repeated without concern for dose thresholds. Additionally, laser therapy reduces both the malignant obstruction and blood loss.[33] Another report, on endoscopic surgery in the treatment of laryngeal cancer, by W. Frederick McGuirt and James

A. Koufman, Bowman Gray School of Medicine, Wake Forest University Medical Center, Winston-Salem, North Carolina, confirms the laser's success.[34] The debulking of tumors is done transorally, using a triad of tools: CO_2 laser, operating microscope, and Venturi jet ventilation (for anesthesia). This procedure is useful both to obtain a frozen section biopsy of the tumor and to destroy or reduce it at the same time. No postoperative pain is reported, and oral feeding begins on the same day. Because the laser does not damage surrounding tissue, vocal characteristics are not impaired. Finally, it leaves open other treatment options if the cancer recurs, and results are as good as those from more traumatic forms of treatment.

Perhaps the widest and most promising use of lasers, in the treatment of all types of cancer, is in the multidisciplinary area of phototherapy. A description of this technique and its uses in various oncological specialties follows.

Photodynamic Therapy

Results of the first clinical trials of photodynamic (or photoradiation) therapy (PDT) were reported by Thomas J. Dougherty *et al.*, Roswell Park Memorial Institute, Buffalo, New York, in 1978.[35] As noted by Maisie S.L. Liu *et al.*, University of Southern California School of Medicine, Los Angeles, and Huntington Medical Research Institutes, Pasadena,

> This approach is based on the fact that hematoporphyrin derivative (HPD), a nontoxic, naturally occurring compound, can accumulate in higher concentrations in tumor tissue than in surrounding skin or muscle tissue, resulting in a preferential photosensitivity of the tumor when exposed to an appropriate wavelength of laser energy.[36]

This approach has proven effective in the eradication of a wide range of tumors. It has been deemed "especially useful in the treatment of early-stage cancer because of its selectivity, its localized effect and its compatibility with most other forms of cancer therapy."[17] This type of therapy is used in the treatment of endometriosis,[28] skin cancer,[31] and early lung and bladder cancer.[17] PDT obviates conventional radiation therapy and requires fewer and shorter treatment sessions.

Research-Front Data on Laser Therapy

Table 1 lists a selection of 1987 research fronts on lasers in medicine. A brief examination of core and citing (currently published) papers making up the various research fronts underscores the importance and cumulative nature of clinical research in laser surgery.

A good example of how the research literature essentially defines and shapes itself into research clusters can be seen in research front #87-0055, "Laser angioplasty and ablation of arterial plaque." (This recent research front also figures prominently in the historiograph in Figure 1.) A sampling of both current citing and core cited papers shows distinct phases in the development of this technique. Among the core articles are two by Abela. The earlier paper reports experimentation in the use of various lasers on artery segments *in vitro*;[19] and the second, on animal arteries both *in vivo* and *in vitro*.[37] Both these feasibility papers conclude that guiding the laser tip and understanding laser-tissue interaction are two areas requiring more investigation. Two other core papers, by Daniel S.J. Choy *et al.*, St. Luke's-Roosevelt Hospital Center, New York, published in 1982 and 1984, received about 180 and 65 cites, respectively.[38,39] Like Abela's 1982 paper, mentioned above, Choy's 1982 paper describes the use of a laser catheter to recanalize arteries in cadaver hearts.[38] Choy's later paper reports the first human intraoperative laser recanalization trial. This pilot study generated very much the same questions that the earlier papers did—regarding energy source, power parameters, and catheter modifications.[39] Also worth noting is a core paper by Garrett Lee *et al.*, Western Heart Institute, St. Mary's Hospital and

Table 1: Lasers in medicine. A = number of core papers and B = number of published papers in 1987 *SCI*® /*SSCI*® research fronts.

Number	Name	A	B
87-0055	Laser angioplasty and ablation of arterial plaque	15	83
87-0075	Vessel sealing using laser energy	7	26
87-0905	Laser treatment of port wine stains	11	88
87-0950	Excimer laser ablation of the cornea	11	66
87-1049	Argon laser trabeculoplasty	53	269
87-2441	Laser photodynamic therapy for carcinoma	27	245
87-4646	CO_2 laser surgery in gynecology	10	44
87-5126	Endoscopic laser therapy for tracheobronchial tumors	7	42
87-5779	CO_2 laser in laryngeal microsurgery	5	26

Medical Center, San Francisco, California. A state-of-the-art paper, it discusses the limitations and complications of laser recanalization, "an innovative approach that is less invasive than bypass surgery."[40] Incidentally, Lee, who is a core author in the 1987 research front on laser heart surgery, is also a core author (with three earlier papers) in the first research front we identified on this topic, back in 1983. The earlier research front, also shown on the historiograph in Figure 1, is entitled "Laser irradiation in human arteriosclerotic disease" (#83-8167).

While core (previously published) papers serve to mark significant past research events in a field of study, current review papers provide a perspective on the present state of research. A 1987 paper by Isner and colleagues evaluates laser cardiology. It discusses various aspects of this technique, such as laser-tissue interaction and fiber-optic transmission, which have come under close scrutiny. Isner asserts that "percutaneous laser angioplasty has now become a clinical reality."[41] In another current review, B. Thomas Kjellström and colleagues, Research Institute, Cleveland Clinic Foundation, Ohio, conclude that the "future use of lasers in cardiac and vascular surgery seems promising, especially as an alternative to balloon angioplasty."[42] Abela adds that laser angioplasty is still considered an experimental system. For this specialty, the ideal laser—one that gets absorbed into plaques selectively, generates the least amount of heat, easily fits into a fiber, and is user friendly—does not yet exist. On the horizon, too, are other mechanical devices—catheters with little blades on the end that will cut and remove plaque material by rotation and guillotine motion.[23]

An extremely active area is "Laser photodynamic therapy for carcinoma" (#87-2441). This research front (with 245 published papers in 1987) deals with photosensitive agents (namely, HPDs) and their role in photoradiation of malignant tumors. Two of its 27 core papers, by David Kessel and coauthors, Wayne State University School of Medicine and Harper-Grace Hospitals, Detroit, Michigan, discuss the biophysical aspects of the tumor-localizing component and its importance to the success of PDT as a method of treating malignancies.[43,44] A 1987 paper, again by Dougherty (mentioned earlier as a pioneer in this line of cancer treatment), focuses on the most recent clinical trials using potentially useful new photosensitizers.[45]

A smaller front on lasers in medicine, concerned with laparoscopic surgery in the treatment of endometriosis, tubal anastomosis, and other gynecological complications, is called "CO_2 laser surgery in gynecology" (#87-4646). Of the 10 core papers, 3 are by James F. Daniell and coworkers, Vanderbilt University Medical Center, Nashville, Tennessee. The authors report on various surgical procedures using lasers, including a new technique to perform tubal surgery with the CO_2 laser, and conclude that it "may provide an acceptable alternative to laparotomy in selected patients."[46]

Conclusion

As this selective review of noninvasive therapeutic techniques shows, less painful ways of healing are fast emerging. All the procedures discussed require only a small abdominal incision or none at all. If this trend continues, it is not unreasonable to anticipate a medical setting like that of the sick bay in *Star Trek*—devoid of all medical instruments and machines—except for devices like Dr. McCoy's innocuous handheld saltshaker, which seems to diagnose and treat instantly all the exotic illnesses that strike the ship's crew.

This three-part, multidisciplinary essay has offered a glimpse of the current research—in pain management, electronics, bioengineering, and clinical medicine. As the research-front data indicate, there is real progress in all these areas in the search for less invasive and less painful medical care.

* * * * *

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