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The Future of Lasers in Clinical Dentistry

Laser and electro-optic technology has a great potential for application in the clinical dental practice of the next decade and the 21st century. The future of general practice and all specialties will be markedly influenced by the results of worldwide laser research presently in the investigative stage. Some of these potential applications include surgical laser treatment of oral malignancies and periodontal disease, caries detection and control, laser endodontics, biostimulation, and optical storage of radiologic material. This paper stresses the proposition that the timing and extent of these innovations that will impact on the dental practice of the future are intimately dependent on the degree to which research activity and funding are developed and expanded in the near future. Stimulation of greater research interest among the dental research community, favorable consideration by grant funding agencies, and cultivation of strong cooperation between the researcher and the electro-optic industry professional are the keys to future successful implementation of lasers in the dental practice of the future.

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From Past to Present

"The Past is Prologue"
— Winston Churchill

The clinical nature of dental practice in the next decade and the 21st century will be markedly influenced by the results of worldwide laser and electro-optic research presently in the investigative stage. Dental laser research has been conducted in many diverse disciplines ranging from caries treatment and oral surgery to root canal therapy and optical imaging. A chronological review of these varied disciplines includes the following.

Dental Hard Tissue Research

Laser irradiation effects on enamel, dentine, and pulp tissue and efforts in caries prevention were the first dental areas studied shortly after the first laser, the ruby laser, became operational in 1960. Noted dental researchers, Reider F. Sognnaes and Ralph H. Stern,[1,2] were the first dental investigators to report on laser research. Using a ruby laser provided by its inventor, Theodore Maiman of Hughes Aircraft, they demonstrated that a glass-like fusion of enamel occurred when a millisecond pulse was applied to intact enamel of extracted human teeth. This team produced eight significant papers reporting on laser effects on enamel and dentine, which added substantially to the knowledge of energy level density and showed that laser irradiation appeared to decrease permeability of enamel to acidic oral fluids, which play a key role in incipient caries formation. By 1967, it became evident that the energy levels required to remove hard tissue with the ruby, which operated at a wavelength in the visible red portion of the electromagnetic spectrum at 693.4 nanometers (nm), caused severe pulpal damage and, thus, was not suited for cavity preparation.

In 1968, the carbon dioxide laser, operating at a mid-infra-red (IR) wavelength of 10.6 micron, was applied to dental hard tissue. Ralph R. Lobene[3] of the Forsyth Dental Center was the first researcher to report on carbon dioxide laser application to enamel. His work, as well as reports by Stern and Sognnaes and a large body of work by Scheinin and Kantola in Finland, indicated that the carbon dioxide laser was substantially more efficient than the ruby in irradiating enamel and dentine. Promising carbon dioxide work continues to this day in France by the Jacques Melcer[4] team and several Japanese groups.[5]

The Nd:YAG (Neodymium:Yttrium-Aluminum-Garnet) laser operating at 1060 nm in the near infra-red appears to be highly effective in removal of caries in enamel and fusing of enamel for caries prevention.[6] It has been recently suggested that the Nd:YAG might be a potentially effective instrument for removal of incipient caries from enamel pits and fissures prior to sealant therapy.[7]

A newer class of lasers, the excimers operating in the ultra-violet (UV) range (193–308 nm), are beginning to make an important impact on ophthalmology and cardiac surgery. To date, no excimer laser reports have been reported in dentistry, but an informal project has been performed on enamel.[8] Excimers ablate material by photodecomposition, rather than by vaporization, as do the IR lasers. As a result, there is not substrate heating, and cutting of hard tissue, such as enamel, is extremely sharp and precise. It is possible that the excimer may prove to be significant in cutting enamel while preserving the vitality of the pulp.

Laser research on hard dental tissue waned in the United States in the mid 1970s. Several significant factors influenced this decline at a time when the laser was gaining substantial research acceptance in many medical, bioengineering, communication, and industrial applications. Firstly, several national reports were published, based mainly on ruby research, which minimized the potential of future research.[9] As a result, grant funds evaporated and potential researchers turned their efforts to other fields. To this day, the opinion of many voices in dentistry, based on the observation of this author, are still guided by these outdated reports. Secondly, dental laser research in America suffered a serious blow when Ralph Stern, who was its most prolific and vocal advocate, died prematurely in an unfortunate accident. One of his colleagues personally commented to me that, had he lived, dental laser research in America would have most likely taken a more productive course.

Surgical Laser Research in Oral, Maxillofacial, and Periodontal Surgery

Carbon dioxide surgical laser therapy was introduced in the medical field in 1972. The first report of its surgical use in the dental literature appeared in 1977.[10] Since that time, significant papers, mainly in the otolaryngology field, have reported developments in oral soft tissue lesion excision, osteosurgery, malignant tumor surgery, and, most recently, periodontal laser gingivectomy. Experienced laser surgeons claim many advantages for the surgical laser, including a bloodless field, shorter and less traumatic procedures, and less postoperative pain and edema as compared with scalpel surgery. It has been noted that, by comparison, patient hospital stays are shortened and some operating room procedures can be performed in the out-patient setting.

Dr. Stephen Joffe, a laser surgeon pioneer in gastroenterology, recently stated very frankly that 44% of all conventional OR procedures performed annually in this country could be performed more quickly and more efficiently with less risk to the patient as outpatient laser procedures. This fact is gaining respect with hospital administrators concerned with shortening hospital stay days and those involved in management of DRG categories.

The Nd:YAG surgical laser, introduced to oral surgery in 1983, is assuming an important potential by virtue of its capability of use in several different modes.[11] Nd:YAG energy can be transmitted fiberoptically with ease. It can produce focused or defocused energy fields similar to the carbon dioxide laser, or fine cutting by employment of synthetic sapphire tips. Fiberoptic delivery of the laser energy by means of the hand-held "laser scalpel" permits precise bloodless cutting that compares favorably with surgical steel blades.

In periodontics, laser gingivectomy for removal of dilantin hypertrophy utilizing the carbon dioxide laser is already being studied at three dental centers in this country. Extension of laser periodontal surgery to other more routine surgical procedures is likely to develop as favorable clinical reports mount.[12,13] Research in the use of lasers for calculus removal, scaling, and prophylaxis are vigorously under way in Japan and China. Indications from the Far East are that, within several years, laser instruments will reach the dental market in the West from the Orient for these applications.

Laser tissue welding of capillary walls and connective tissue is well under way in the medical field. Although no reports have surfaced in the periodontal arena as yet, it is worth speculating whether or not it will be practical to weld free tissue grafts to existing gingiva without sutures.

Holography, Holometry, and Holodontography Research

Holography is an optical process that involves the recording, storage, and retrieval of images of real objects in three dimensions using coherent laser light as the source of illumination. Reconstructed images contain the complete three-dimensional information, including parallax, of the original object. Holometry, a contraction of the term "holographic interferometry," is a technique of using interfering wavelengths of laser light to achieve measurements of stress deformation, movement, or surface changes with sub-micron accuracy. Holodontography is the study of dental applications of these optical techniques. They have been successfully applied to orthodontic, restorative, and prosthetic studies. Some of these studies include measurement of tooth movement in three dimensions after orthodontic therapy, anisotrophic distortion of acrylic full dentures after a period of use, and holographic storage of dental study models. Rapid pulsed lasers have demonstrated clinically that holometry studies can be performed on living patients.

Recently, the use of fiberoptics has been adapted to holography. Laser light can be launched efficiently into a fiber with a core diameter of 4 microns or less. Complicated conventional holography setups requiring much preparation time and complex equipment can be replaced with simple and efficient fiber systems with far greater flexibility. Holography applications will soon be practical in laboratory and clinical situations that were previously highly impractical or impossible before the fiberoptic holography revolution. This innovation promises a whole new spectrum of research opportunities in the spatially oriented discipline of dental science.

Laser Luminescence and Reflection Research

Blue laser light in the 400–488-nm range has been shown to be effective in detecting changes in luminescence of carious enamel at a stage earlier than any clinical method in use today.[14] Healthy enamel shows a characteristic luminescence to the blue-green (488 nm) light of the argon laser and the deep blue of the He:Cd (helium/cadmium, 410 nm) when viewed through a barrier filter. As incipient caries occurs, it causes a slight demineralization of the enamel hydroxyapatite, and the luminescence takes on a more opaque, chalky appearance that is easily recognized clinically. This change can be detected definitively earlier than routine clinical inspection.

Laser reflection techniques that take advantage of the interference property of coherent laser light and laser speckle, a well known characteristic of all laser light, have been applied to studies of orthodontic tooth movement and surface roughness caused by abrasives used in toothpastes. Optical contour mapping of occlusal surfaces to determine wear of enamel and dental restorative materials with micron range accuracy, laser diffraction studies for material adaptation, and laser diffusometer work for surface smoothness have all been reported in this category.

Laser Sterilization of Instruments

Studies have shown that lasers have the potential of being used as a means of sterilizing endodontic files, reamers, and sharp surgical instruments without destroying their effectiveness.[15] Whether or not lasers will prove to be effective in the elusive goal of sterilizing handpieces and operatory instruments between patient uses remains to be seen, but past research points to the fact that this potential does lie within the realm of distinct possibility. In this age of epidemic hepititis-B and HIV virus control, it would seem logical for the dental equipment industry to devote substantial resources to this task. Much research work needs to be done in this area, but the first company to succeed would not only perform a most important service to dentistry worldwide, but would most likely be handsomely rewarded for its efforts.

Laser in Endodontics

Studies are underway in Canada and Europe that employ the carbon dioxide laser for purposes of sterilizing diseased root canals and for preparing canal walls for permanent filling.[16] Laser fusion of the apices of prepared canals in order to produce a hermetic seal against re-infection also shows future promise.

At present, all endodontic laser research has been carried out on extracted teeth. The results to date appear promising. It is suggested that laser sterilization of infected canal walls, apical fusion of foramina for a perfect hermetic seal, and canal obliteration with fuseable plastic materials are all realistic objectives.

Laser Welding

Laser welding of precious and semi-precious metals for fixed prosthodontic and orthodontic appliances have been reported since the early 1970s.[17] More recent reports appear to show laser welding to be as effective or better than conventional soldering. Micro-drilling of precision holes in metal and implant appliances has been suggested. Studies indicate that, in the future, nanosecond pulsed lasers conceivably could be used to weld appliances directly in the mouth of the living patient, thus saving considerable patient chair time and expense.

Laser Biostimulation and Therapy

Substantial literature has appeared on these subjects in the French, German, Italian, and Japanese dental literature, but, to date, this field has received little acceptance in the American dental field. Examples of this category include helium/neon laser therapy for treatment of temporomandibular joint dysfunction and muscular spasm. It is interesting to note that, in America, the profession of physical therapy is seriously embracing the use of laser biostimulation, including its use in TMJ therapy.

Laser acupuncture therapy for dental anesthesia and analgesia is being actively studied in Japan and China. One report from Sichuan, P.R.C., which was published in an American medical laser journal, documents the extraction of five thousand human teeth with the sole anesthesia being provided by low power helium/neon laser light as the acupuncture source.[18]

In Europe and Japan, at the present time, there are at least three laser instruments on commercial sale intended for the dental profession. These involve either helium/neon or solid state semi-conductor lasers proported to be effective in hemostasis and wound healing after tooth extraction or oral surgery. One of these manufactures guarantees, in its accompanying literature, the elimination of the possibility of the notorious dry socket if the alveolus is irradiated after extraction. Some of these instruments are already finding their way into this country and being introduced to patient practice. Laser therapy is a very controversial concept in the U.S.A., and much double blind study work should be done to prove or disprove it.

Laser Medicine

Many well-documented studies regarding photodynamic therapy (PDT) have appeared in the medical literature in recent years. PDT involves the intravenous administration of hematoporphyrin derivites (HpD), photosensitive pigmented dyes that concentrate in rapidly growing malignant tumor cells. Lasers, most commonly the argon, are then applied to selectively destroy the pigmented tissue without damaging the adjacent non-diseased tissue. Work in this field is beginning to appear in the dental literature with regard to oral soft tissue malignant lesions.

Current Innovative Applications

Some very interesting new technologies are finding their way into dental research. Some of these include laser Doppler flowmetry to measure gingival blood flow in periodontal disease and the use of the carbon dioxide laser for etching of enamel in bonding procedures to replace the currently used acid etch technique.

Diagnosis of gingivitis by measuring gingival blood flow or stagnation has been studied using laser Doppler flowmetry.[19] This noninvasive procedure uses the changes in frequency of helium/neon light reflected from individual red blood cells in the free gingiva capillaries. Frequency changes with speed of blood flow, and can be measured with great accuracy.

Laser optical disk storage and retrieval of intraoral and panographic radiographs has been demonstrated.[20] In one report, ten thousand individual periapical radiographs were recorded and stored on a single 5-inch optical disk. Any individual radiograph was randomly retrievable in less than 30 seconds, and diagnostic value was thought to be improved over the original, in some cases, by virtue of the ability to vary and control the density *via* the contrast control of the video system. Holographic optical storage of visual and text material in high density microfiche and three-dimensional imaging of computer tomography (CT) and magnetic resonance (MR) scans holds much promise.

A current innovative electro-optic application that is a topic of much recent interest in dental circles is that of CAD/CAM, which stands for Computer Aided Design/Computer Aided Manufacture. CAD/CAM and associated robotic techniques have made a large impact on industrial manufacturing operations, most notably in the automobile and semi-conductor industries. In 1985, a French dentist made headlines by announcing the ability to produce a ceramic crown in 1 hour from the time of completed crown preparation to final insertion without the need for an impression.[21] This technique employed a solid state laser to scan the preparation and develop a moire pattern of the preparation. This pattern is digitalized and stored in a computer that subsequently drives a milling machine, which carves the internal and external aspects of the crown out of a ceramic block. Electro-optically, the principle involved is sound, but, clinically, the results of this particular project (based on English translations of French reports) appears to be lacking in accuracy of fit, at least by standards used in the fixed prosthodontic program at my dental school. Unquestionably, the accuracy will improve with further research, and CAD/CAM systems will find their way into prosthodontic practice.

More recently, two other CAD/CAM systems employing optical systems have been described; one is Swiss and the other American.[22]

The Future

"Tis strange but true; for truth
is always strange,—
Stranger than fiction."
— Lord Byron

Using the forgoing material, which is based on a review of the dental laser literature of the past 24 years and mixing well with some insight derived from the incredibly rapid technological development of the electro-optics industry, this observer is confident enough to look into his crystal ball and suggest what dental practice might look like 24 years hence.

Dental Practice circa. 2011 A.D.

With regard to restorative dentistry, it is my firm belief that the successful general dental practice of the 21st century will be primarily a preventive dentistry oriented practice. Traditional G.V. Black cavity preparation will yield to more conservative restorative therapies, such as pit and fissure sealants, remineralization treatments, and other prophylactic measures. Electro-optics, including lasers, will have a natural and pre-eminent role in these procedures.

The dental handpiece in this practice will have several unique features. Firstly, in order to provide magnified vision of the operative field, it will contain a solid state miniature CCD television camera to deliver a high resolution picture, processed by a computer, to a TV monitor in the operator's direct line of vision. Thinking futuristically, it is not absurd to anticipate that this TV picture will be three-dimensional. Secondly, this handpiece will deliver fiberoptically a range of laser wavelengths from the very short ultraviolets to the long infrareds, tunable at the operator's touch. Energy density control will also be instantly available to the operator.

With this instrument at his or her control, the clinician will be able to perform many functions. A synopsis of operative procedure may develop as follows:

- *Visualization*: With the imaging capability of the TV camera, the clinician will view all intraoral areas of soft and hard tissue at varying appropriate magnifications, record selective views, and store this information in the form of a visual patient record for diagnosis and treatment planning purposes.
- *Luminescence*: Using a deep blue line of laser light and low energy density, the clinician will scan all enamel surfaces for signs of decalcification indicating incipient caries.
- *Incipient Enamel Caries Removal*: If incipient enamel caries is found, the clinician will be able to tune the instrument to a longer appropriate wavelength, increase the energy density, and selectively vaporize the carious material while leaving healthy enamel intact.
- *Sealant*: A synthetic hydroxyapatite material placed into the voids created be the irradiation process will be fused to enamel by another specific wavelength/energy combination to hermetically seal a permanent restoration, impervious to future attack.
- *Alteration of Enamel*: Laser irradiation of enamel, most likely in association with remineralization agents, will be employed in selected cases to photochemically alter enamel structure to make it less permeable to acidic oral fluids and, thus, more resistant to caries formation.
- *Dentinal Caries Removal*: Some dentinal caries will still exist, even in this futuristic practice. The tunable laser handpiece, operating first in the UV, will ablate the overlying unsupported enamel. Tuned next to the mid-IR, it will destroy carious dentine and sterilize the affected dentine while preserving the pulp from exposure and stimulating pulpal healing.
- *Laser Etching*: The laser will perform the function of etching enamel, replacing caustic acid etching in cases where composite resin restorations are to be placed.
- *Light Curing of Resins*: The laser provides the purest and most coherent source of light possible. This characteristic will be valuable in the curing of composite resins, most likely in a very short time, if not instantaneously.
- *Laser Fusion of Ceramics*: The time consuming process of electric furnace fusion of ceramic materials to metal substrates will be greatly reduced in the prosthodontic laboratory by means of laser fusion of the glass-like material to the framework.
- *Laser Sterilization*: Handpieces and hand instruments, as well as accessory operatory equipment, will be sterilizible in seconds. It is conceivable that this will be accomplished by placing the instruments in an ionized plasma field environment generated by a tunable dye laser. This contained environment will achieve sterilization even in hard-to-reach areas, such as the hollow bore of suction tips and hoses.

In this general practice of the year 2011 A.D., conventional impressions for study models and precision fitting appliances will be obsolete. The reason that this can be said lies in the nature of the computer. This computer will process and store data optically, rather than electronically. The same computer will have the ability to store a trillion bits of information on optical disk, or on a microfiche card in a holographic array. According to H.J. Caulfield, director of the Center of Applied Optics at the University of Alabama in Huntsville, the theory and architecture of this technology exists today.[23]

The handpiece will be used to scan a preparation, a quadrant, or an entire arch optically, with submicron resolution. This data will be presented to the computer fiberoptically and processed holographically. The clinician will have the ability to view any material visually on the monitor, and to obtain a two-dimensional hard copy at the push of a key or a three-dimensional replica by means of CAD/CAM. Crowns and bridges will be fabricated to the same accuracy without impressions, and study model information will be stored on a thin sheet of acetate in the patient's record. When a three-dimensional model is needed, it will be produced on demand by CAD/CAM, either by the clinician in the office or by sending the relevant data by telephone to a dental laboratory equipped with CAD/CAM robotics.

The mechanical adjustable articulator of today will also disappear from the office setting to be replaced by a computerized, spatially imaged representation of the patient. The relationships of the patient's arches to each other and to the temporomandibular joint, as well as all mandibular movements, will be scanned optically and recorded by the computer without the need of face bow transfer, gothic arch tracing, or registration records. Once stored, the computer will be able to manipulate the mandible in any possible range of motions and simulate the patient's dynamic occlusion with greater accuracy than any mechanical device of today. The occlusion treatment plan will be generated from this data, and indicated appliances, such as night guards, retainers, and splints, will be produced by CAD/CAM procedures.

The computer of 2011 A.D. will also have the ability to manipulate diagnostic and prognostic data. It will, for example, project treatment outcome prior to the initiation of treatment based on various input parameters. It also will have virtually unlimited capacity to optically record and store all radiologic material generated in the office. Periapical and panograph x-rays will be digitalized and input to the computer on an order of magnitude of ten thousand images per disk or microfiche. Any individual image will be randomly retrievable in milleseconds, and diagnostic ability will be enhanced by the ability to control contrast and density. Hard copy will be available on command, either on film or print. It is not out of the realm of probability to suspect that this computer will be powered not by electrical generation, but, rather, by solar means.

In oral and maxillofacial surgery, various laser wavelengths will be used extensively for atraumatic, bloodless removal of oral soft tissue malignant and benign lesions. In the future, in addition to the carbon dioxide and Nd:YAG lasers, it is probable that other instruments, such as excimers, tunable dye lasers, and semi-conductor lasers, as well as others now considered exotic to surgery, will find acceptance in the surgical suite.

The trend of reducing operating room time or shifting former OR procedures to out-patient setting because of laser surgery advantages will continue. In the future, as more oral surgeons become familiar with laser surgery techniques, this trend will flourish.

Expanded use of photodynamic therapy (PDT) and applications of tissue and osteo-surgery, particularly in implantology surgery, are natural logical extensions of lasers into the oral surgery field.

Periodontal applications of calculus removal, scaling, and prophylaxis, as well as laser gingivectomy, will be firmly established in the dental operatory of 2011 A.D.

Endodontically, instrumentation of canals and obturation will be considerably shortened. Most root canal procedures will be completed in one appointment.

Conclusion

> "The future belongs to those who have the wisdom and courage to prepare for it in the present."
> — J.A. Barnes

The above projections are in no way exhaustive. At the present time, this reporter's crystal ball is not equipped with time reversed, optical phase conjugation technology. As a result, these prognostications of the year 2011 lack precise resolution, and should be considered in the light in which they are presented; namely, the realm of the highly possible and probable.

But, there is ONE most important and intangible factor in the probability equation of future laser application to dentistry—you, the dental researcher and clinician of today.

Compared with the entire scope of dental research over the past 24 years, electro-optic and laser research in dentistry accounts for less than one-half of 1% of the total. This statistic contrasts with the development of lasers in medical applications over the same period to a one billion dollars-a-year industry by 1990, and over 600 billion dollars for the electro-optics industry overall.

This essay does not presume to answer the logical question of why this is so. It does suggest, however, that the future will be determined by the interest, desires, and determination of today's practioners, researchers, and students.

It remains now for more dental researchers to become interested and involved in electro-optic research, for more favorable consideration by federal, commercial, and private grant funding agencies, for more collaboration between the dental researcher and the electro-optics engineer, and a more informed dental practioner. The future for lasers in dentistry is in your hands, and, from my perspective, it looks promising indeed.

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