Simulated Intraoral Laser Microwelding of Orthodontic Appliances

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Since its advent in mid-1960,[1] the operational laser has been in constant transition from a laboratory phenomenon to a productive tool. Many successful modifications of this initial device have led to a totally new technology which overlaps into many diverse areas. Less than two years after its introduction, numerous articles appeared in dental literature as researchers began to probe the laser's unique capabilities.

Initial attempts concentrated on directing the laser beam at teeth and observing the effects. As the research continued, reactions to such a device were mixed. By some, it was viewed as a potential device to replace the dental handpiece in cavity preparations.[2] But, with time, it became apparent that direct exposure of dental hard tissues to a high power laser radiation cannot be tolerated. Lack of control of the laser beam's effects on teeth took many forms, the most serious of which was damage to the pulp of vital teeth.[3] The emphasis in laser applications' research shifted not long after these discoveries.

A common task for industrial lasers is the fusion of two metals without the aid of soldering agents. It was not surprising to find such an obviously practical process the center of more recent dental research, shifting the emphasis from intraoral use to laboratory procedures. It is clearly documented that laser welding is stronger than solder joints of comparable size.[4] This factor plus the low thermal distortion which accompanies the welding process makes the routine lab welding of prostheses very attractive.[5] But, such work has the potential of being safely carried one step further: the fusion of metals intraorally.

This study has attempted to simulate intraoral laser microwelding on a realistic level. Routine oral-surgical and orthodontic materials were used to fabricate a number of appliances that were formed and welded to orthodontic bands and direct bond brackets on freshly extracted human teeth. In doing so, a number of important questions could be answered realistically.

Methods and Materials

The laser microwelder[6] used in this study was a high power industrial neodymium laser capable of delivering 20 joules/pulse for a maximum of 6 milliseconds at a wavelength of 1.06 microns. A four inch focal length lens was used throughout the study yielding an effective spot diameter of .010 to .015 inch. Optimal focus settings varied as a function of weld fusion zone penetration and consequently was dependent upon the specific appliance to be welded. Previous studies on this particular laser unit determined pulse length and power settings. Once settings were determined for an appliance, welding continued to completion without change. A 6 millisecond pulse length was used on every appliance and normal pulse energies were between 4 to 8 joules/pulse depending upon the total weld depth desired.

The extracted teeth used were not over six months old and were stored continuously in normal saline. The teeth were mounted in orthodontic plaster in a full arch configuration as illustrated in Figure 1 or simple quadrant, depending upon the welding task to be

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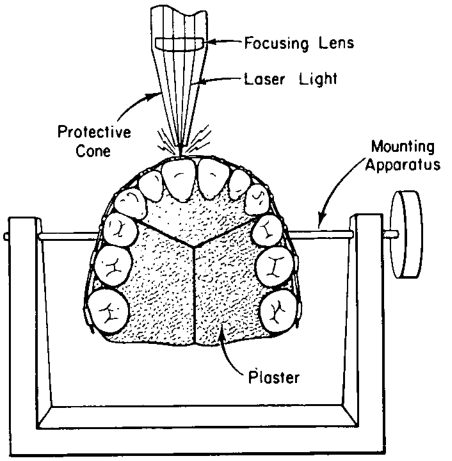

Fig. 1 This schematic of the setup illustrates how the 1.06 micron wavelength laser light is directed through a plano-convex focusing lens to a 4 inch focal point of .010 to .015 inch in diameter.

accomplished. All teeth were treated at all times in a normal clinical manner with respect to banding, direct bonding and other orthodontic procedures. Orthodontic bands were cemented in place with zinc phosphate cement, and direct bond brackets were mounted in accordance with the recommendations of the manufacturer.

Microwelding was done in four areas of simulated intraoral orthodontic procedures. These were normal archwire attachment and ortho-surgical splint simulation, space maintainers and retention devices, periodontal splint simulation, and bracket and auxiliary attachments. All appliances were formed prior to placement and welding. Actual welding, once laser settings were selected, entailed no more than placement of the appliances in their desired location within the arch followed by activation of the laser. No solder, flux, or other soldering aids were used.

To determine maximum safe operating parameters, intentionally induced laser damage was done to both bond pads bonded, and orthodontic bands cemented in place on teeth. This was done by dealing 5 to 10 pulses directly to each appliance at an increased level of laser output followed by both topical and cross-sectional microscopic examination.

Since standards for strength are nonexistent for these types of appliances, no quantitative tests were attempted. However, all welded units were subject to approval by experienced clinicians.

Results

Favorable results were obtained in placement and attachment of the appliances in all four areas outlined.

1) Normal archwire attachment was readily accomplished and simulated ortho-surgical splints were easily fabricated. Figure 2A shows a completed .017 x .022 inch archwire welded in place on a sectioned maxillary arch simulating a three piece maxillary surgical procedure.

Figure 2B is a close-up of the welds on each bracket and Figure 2C demonstrates how the archwire was welded through the molar tubes. The welds exhibited remarkable strength with the entire procedure of welding a full arch lasting less than 10 minutes, once the necessary laser settings were determined. The archwire could not be pulled out of the molar tubes or free from the brackets when pulled by hand in a mesial-distal rotational movement thus demonstrating what appears to be a very high shear strength.

2) A cuspid-to-cuspid lingual retainer and several space maintainers were easily made and welded to bands with minimal difficulty. Figure 3A shows the left half of a cuspid-to-cuspid lingual retainer with a premolar space maintainer formed from a .017 x .022 inch archwire. Only four welds were used on the canine and five on the premolar to produce a very strong joint. In another case, simple loops of arch-

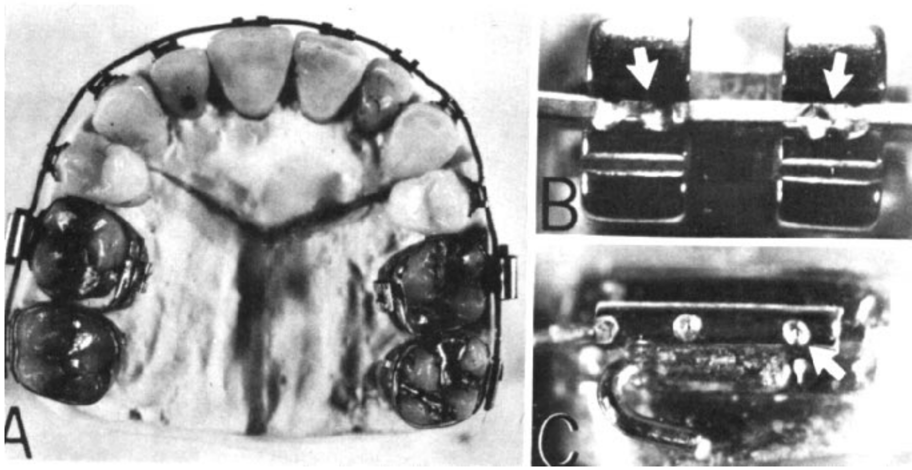

Fig. 2 A. Simulated 3-piece maxillary surgical procedure. The formed archwire was welded directly to the brackets to serve as a splinting mechanism. B. Close-up of anterior archwire from A. Note the four round welds (10X). C. Close-up of archwire from A welded into molar tube with 3 welds (5X).

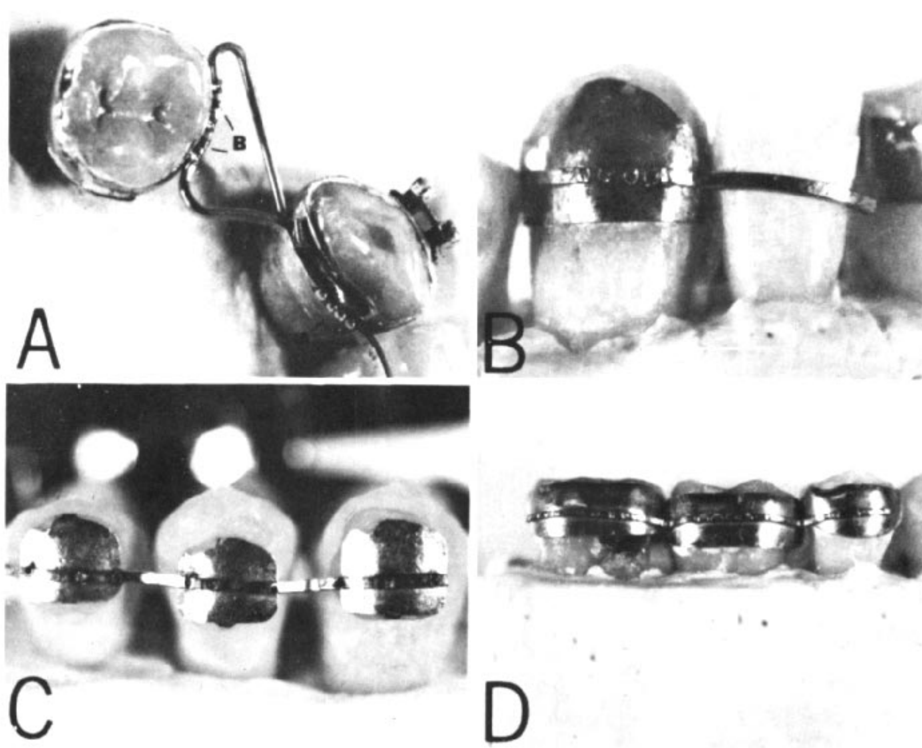

Fig. 3 A. Cuspid-to-cuspid lingual retainer/premolar space maintainer combination. Four welds on mesial-lingual of canine (A) and five on mesial of premolar (B) were used. B. Incisor band and spur type retention device formed by welding an archwire directly to a canine orthodontic band with six welds. C. Simulated periodontal splint formed by direct welding of a passive wire to direct bond pads. D. Splint formed by direct welding of a passively formed archwire to cemented orthodontic bands.

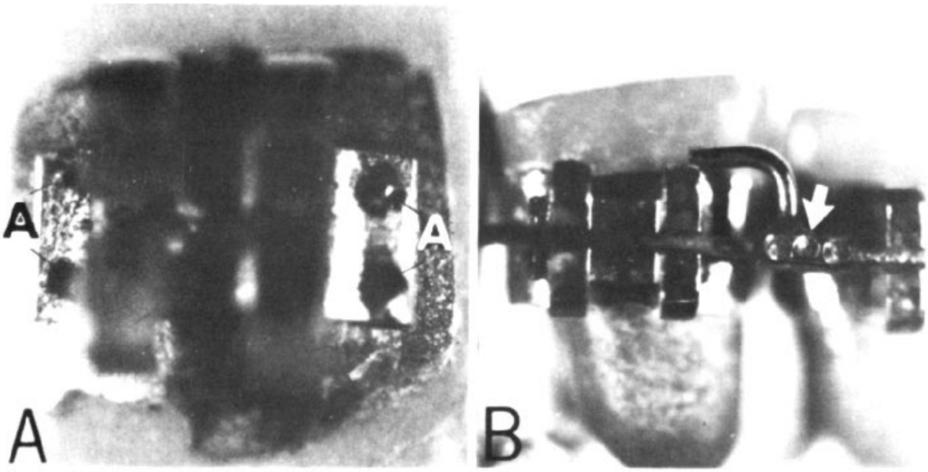

Fig. 4 A. Close-up of a bracket attached to a direct bond pad by four welds (labeled A). B. Auxiliary hook fastened to archwire by three welds.

wire were formed to produce a simple space maintainer independent of a cuspid-to-cuspid lingual retainer. These were welded to the interproximal surface of bands cemented on a canine and premolar with comparable results. A simple incisor band and spur type retention device (Fig. 3B) was also rapidly fabricated and welded to a mandibular canine band with five welds.

3) Very simple but effective periodontal splints were formed by direct welding of a formed archwire to direct bond pads and orthodontic bands. In the case of the direct bond pads (Fig. 3C) the center tooth was not allowed to set firmly in the lab plaster simulating a traumatized or periodontally involved tooth. The tooth could be moved 2 to 3 mm in any direction, but upon attachment to the neighboring teeth via the archwire, substantial pressure could be placed upon the tooth with only minimal flex in the wire. The direct welding of a formed archwire to an orthodontic band (Fig. 3D) worked equally well.

4) The attachment of auxiliaries and additional archwire brackets proved to be a simple task. Figure 4A illustrates a close-up of the four welds used to attach an archwire bracket to a direct bond pad. In Figure 4B a hook was fastened to an archwire with three welds. Although firmly in place, the bracket could be detached with moderate pressure indicating that four welds were not enough for adequate retention. The hook retainer, however, could not be removed with finger pressure and exceeded necessary clinical strength requirements.

The band from the second molar in Figure 3D was removed to inspect for any damage to cement or tooth structure, but none could be found using microscopic techniques. The welds from this band were examined microscopically. Figure 5 schematically illustrates the relationship of the laser to the archwire, band, and tooth. The enclosed portion of the diagram represents the plane used in making cross sections of the laser welds. Figure 6A illustrates a typical cross section of the laser welds found on this band. Penetration from the archwire into the band metal was found to be .002 to .003 inch with little variation. In cases where a direct con-

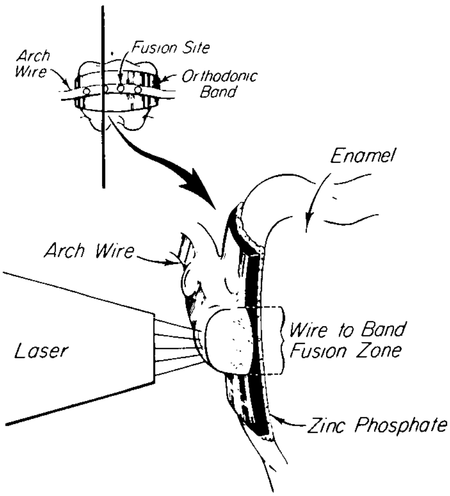

Fig. 5 The welds from Fig. 3D were cross-sectioned in the plane demonstrated above. Note the relationship of the laser beam to archwire, fusion, zone, band, and tooth.

tact between band and archwire did not occur, welding was still accomplished provided the gap did not exceed .005 inch with a lesser degree of penetration in the band as the gap widened.

Figure 6B shows an enlarged buccal view of the above band after removal from the second molar, and Figure 6C reveals the internal band surface. No vaporized or discolored zinc phosphate cement was observed upon removal, nor could any damage be found on the enamel surface of the molar after microscopic inspection at 100X indicating that weld penetration to the inside surface of the band never occurred. Close inspection of the inside surface of the band did indicate that two slightly discolored spots could be seen to the left center in Figure 6C, but discoloration is not an indication that penetration of the weld fusion zone to the surface had occurred. Oxidation of stainless steel does occur at an elevated temperature, but at a considerably lower temperature than the melting point.

When intentionally induced laser damage was done to direct bond pads and orthodontic bands, several changes were immediately apparent. During

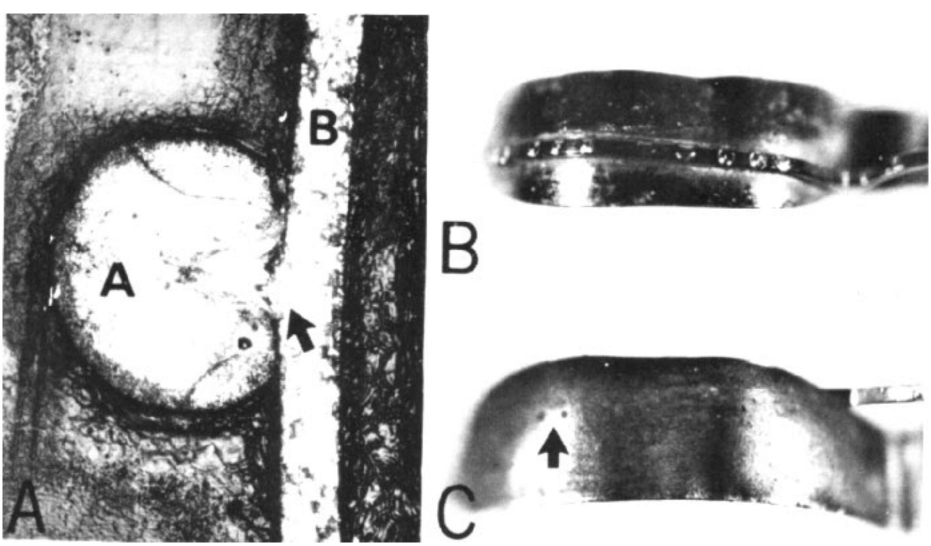

Fig. 6 Cross section of weld from mandibular second molar in Fig. 3D. A = archwire, B = orthodontic band. Note the depth of the fusion zone as indicated by the arrow (100X). B. Orthodontic band from Fig. 3D before cross-sectioning. C. Internal surface of band indicating no penetration of fusion zone to surface. Two discolored spots (by arrow) indicate some surface oxidation.

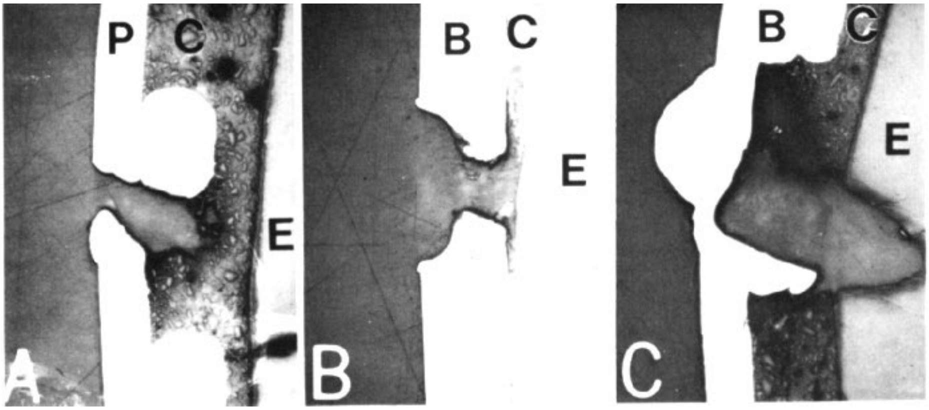

Fig. 7 Intentional damage. A. Cross section of a direct bond pad mounted on tooth (10 joules/pulse). P = direct bond pad, C = cementing medium, E = tooth enamel. B. Cross section of an orthodontic band (10 joules/pulse). B = band, C = cement, E = enamel. C. Cross section of bonded direct bond pad with enamel destruction (12 joules/pulse). B = direct bond pad, C = cement, E = enamel.

welding a brighter flash of light occurred, being accompanied by a very subdued but noticeable "popping" sound. This appeared to occur as the weld penetrated the metal base and reacted with the cement and enamel.

Figures 7A and 7B illustrate intentional damage done to direct bond pads and cemented bands, respectively. Externally, both band and direct bond pad appeared quite similar, as cratering formed with pit diameters of .010 to .015 inch. The metal originally present in the base appeared to actually have been forced out under pressure, since no evidence of metal buildup is indicated around the hole. Figure 7A shows a cross section of a direct bond pad at 100X clearly showing the bonding cement and enamel surface. As with Figure 7B, which is a cross section of a cemented orthodontic band, this kind of damage is typical at a power setting of approximately 10 joules/pulse. This is almost double the power required for normal welding. One should observe that no damage appears to have been done to the enamel surfaces, even when viewed at much higher magnification. The cement has been vaporized, expelling the momentarily molten metal outward, protecting the enamel surface. At more extreme power settings, penetration into the enamel does occur. Figure 7C illustrates the type of damage produced at an output of 12 joules/pulse. The cement from the direct bond pad was vaporized as was approximately .010 inch of the enamel surface. In one case a penetration into the enamel to a depth of .030 inch was observed.

Discussion

Previous experiences with this particular type of laser microwelding unit suggested there would be no problem for certain types of appliances to accept laser welding. For all practical purposes the laser beam may be considered to be a surface phenomenon during actual welding of a metal unit. For welding to occur at a point beneath the irradiated surface, it is necessary for sufficient heat to penetrate to that depth and cause fusion to occur. Consequently, when one layer of metal overlies another, as is the case with most orthodontic components and auxiliaries, heat must be transferred to the second piece via the first. A gap or space between the two pieces of metal, although tolerable to as much as .005 inch, will cut back substantially upon the total heat transferred and obviously weaken the weld.

The laser has limitations on the total depth of penetration it can attain while still yielding a smooth weld. In normal circumstances the laser unit works predictably to a depth of approximately .030 inch; but variations in gap size between the two pieces to be joined will reduce this depth appreciably. Differing physical properties of the metals being joined such as increased thermal conductivity or unusual surface conditions will also affect the efficiency of the welding process.

No damage to tooth structures was observable after welding of archwires directly to orthodontic bands, as illustrated in Figure 7. The maximum band/cement interface temperature calculated, using a heat transfer model developed for laser heating, was 1100 to 1150°F (590 to 620°C).[7] This appears alarmingly high when initially considered, but other factors must be considered as the welding process takes place. The zinc phosphate cement used to attach the bands to the tooth has been widely recognized for its ability to thermally insulate. Combine this with its minimum film thickness of 35 micrometers[8] and such rapid temperature changes may be of minor consequence when experienced for less than 6 milliseconds.

Numerous studies have been carried out to document the effects of rapid temperature changes on teeth, but none are directly applicable to laser microwelding. The potentially destructive heat zone formed on the inside surface of the bands would not be expected to exceed a radius of .005 to .010 inch. Furthermore, time is a critical factor. The maximum length of time when the band/cement interface experiences such extreme temperatures could never be expected to exceed 10 milliseconds.[7] A maximum laser beam pulse duration of 6 milliseconds was used throughout this study. Other studies, such as those performed by Brown,[9] Braden,[10] Craig and Peyton[11] and others all dealt with time factors up to 30 seconds in length, a 3000X increase. A computer simulation of the welding process is presently under development to further refine the laser heat transfer model which will aid in further defining the welding process and safe operating parameters.

In the placement of routine appliances, substitution of laser welding for several common fastening techniques is accomplished. Soldering, which normally cannot be done intraorally because of dangerous heat buildup, is bypassed. Laser welding is also stronger than soldering because of the higher strength of the parent metals[4] and is more accurate due to less thermal expansion.[5] Tying with ligature wires is readily replaced by laser welding for securing of archwires, as in the orthosurgical splint and normal archwire placement. Ligature tying is time consuming and, moreover, no practical comparison need be made as to the strength of the ligature wires to that of the microwelds produced. The replacement of crimping and clamping or the use of laser welding as an adjunct to this has definite strength advantages also. Hooks, springs and other auxiliaries may be more firmly secured leaving less chance of damage or breakage.

The replacement of the above fastening techniques with laser microwelds does infer a certain degree of permanence and may prove to be a detriment in many instances. The attachment of archwires may ultimately be impractical with the microwelding technique if minor adjustments are required at a future time. Ligature wires do allow for easy readjustment of the archwire without disruption of the bracket mechanism. The new Nitinol wires used in conjunction with microwelding might be much more suitable for long-term placement in the routine treatment of arch irregularities. The elastic "memory" of this special type of wire may prove that fewer future adjustments will be necessary when compared with that of a normal stainless steel wire, thus allowing for more permanence in its initial fixation. It is apparent that laser microwelding becomes most advantageous for one time applications in which a high degree of retention is desired (i.e., periodontal or ortho-surgical splints) or for long term intraoral devices (archwires, auxiliaries, retainers and so forth) which must withstand the forces of prolonged use without adjustment.

The advent of a clinical intraoral laser microwelder system will undoubtedly stimulate new appliance designs. Metallurgical and heat transfer considerations would facilitate a design which would more readily accept laser welding. Not only could more efficient use of the laser's output be accomplished, but also heat transfer into the tooth structures would be minimized evenmore. Redesigning auxiliaries to allow simple additions to the archwire without removal of the archwire would be a simple task and allow for more efficient use of clinic time.

This tiny weld, only .015 to .020 inch in diameter, when properly controlled and judiciously placed, opens the doors to a myriad of intraoral and laboratory aids for the dental operator. But how does the welding technique used and its potential as an important tool in dentistry fit with present day laser technology?

Introduction of an operational laser came in mid-1960 with studies performed in the field of dentistry shortly thereafter. Initial studies concentrated primarily on pointing the laser beam directly at tooth structures and observing the effects which followed. Vaporization of enamel, hole drilling, laser cavity preparations, and caries and calculus removal all seemed to point toward the hope of replacing the high speed dental handpiece.

In the late 1960's it became apparent that control of the laser and the response of pulpal tissue to direct laser irradiation of hard tooth structures was to make such hopes an improbability.[3] Wolbarsht[12] seems to have realistically dispelled the early misconceptions of the laser's capabilities and put the laser in better perspective by stating:

> "Gross misunderstanding of laser application has been disseminated at all levels—from Dick Tracy cartoons and the nefarious activities of Goldfinger to the overly optimistic as well as pessimistic early reports in the scientific literature. The laser has some very specific limitations as a clinical tool in dentistry. It will not replace the dental drill . . . will not be used to remove carious tooth material . . . will also probably not be used to remove calcific deposits from the tooth crown. It will not be used for these tasks simply because of potential hazards to the dental pulp."

The past few years have witnessed a shift of hope to more realistic goals undoubtedly following a more thorough understanding of such a device. Use of lasers as a valuable lab tool to replace soldering of castings and prosthesis because of increased accuracy and effective cost reductions is now a major concern. Hints of various attempts to fuse restoration materials directly to tooth structures[13] and laser aided fluoride treatments[14] are to be found also. The emphasis is toward using the laser as a potential addition to the operators' armamentarium and not a miracle device to replace existing instruments.

The lasers used to perform these experiments are far from becoming a practicality when the requirements of routine intraoral laser welding are understood. However, size, cost and safety of current lasers in a fast expanding, competitive market, when compared with those of only several years ago, do seem to point to a time in the future when such devices can evolve to meet the stringent requirements of clinical use. Further studies are now under way to define the requirements of such an instrument for clinical intraoral use. Can such a cumbersome, costly tool be refined sufficiently to meet these needs? One has only to look back upon the development of the current $10 pocket calculator to realize it was only several years ago that they were an expensive novelty.

Summary

The rapid and repeatable actions of the pulsed neodymium laser microwelder used in simulating intraoral welding strongly suggests that safe intraoral welding can be done with proper controls on a routine basis with no damage to hard dental tissues.

A vast number of "off the shelf" orthodontic items are readily available which can be easily used with little or no modification under such welding conditions provided one has a basic understanding of the welding process and its limitations. The construction, placement, and intraoral welding of space maintainers, retention devices, periodontal splints, ortho-surgical splints, archwire brackets to existing bands, and auxiliaries can be readily accomplished. The process of placing the appliances by laser microwelding effectively eliminates time consuming procedures such as tying of ligature wires, sometimes impossible and potentially painful intraoral soldering, and aids or eliminates crimping or clamping. In virtually all cases the microweld is of superior strength and consistency.

With almost two decades of development the laser is still far from becoming anything but a common tool in laboratory, clinical and industrial settings. The past several years have seen rapid advances in laser technology especially in size reduction, cost effectiveness, simplicity of operation and safety. However, a large gap will exist for sometime before the device can evolve to meet some of the demanding requirements of safe, routine intraoral laser microwelding.

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