Interaction of Carbon Dioxide Laser Radiation with Enamel and Dentin

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Extracted human teeth were exposed to continuous CO_2 laser radiation at 10.6μ. Ground sections showed disrupted enamel rods and incineration of odontoblastic processes in dentin. Microradiographs of enamel confirmed the changes observed, which were probably due to high temperature elevation at the site of interaction together with heat flow from this region.

Many attempts have been made to alter tooth enamel to increase its resistance to caries. If it were possible to eliminate the pits and fissures from the enamel surface by fusing or "welding" the enamel, the susceptibility of teeth to caries might be considerably decreased.

In a previous report,[1] the gross and microscopic findings of the interaction of oral hard tissues and pulsed ruby laser radiation at 0.6934μ was presented. Although the enamel surface appeared glazed, opaque, and hard, it was brittle, and true fusion of enamel was not accomplished. Other investigators[2-4] who have used ruby laser radiation have reported similar findings.

The purpose of these studies was to determine the feasibility of fusing enamel by using high-power-density, continuous-wave (CW) radiation at 10.6μ, as made available by CO_2 lasers. The gross and microscopic findings of the interaction of CW radiation on calcified tissues was compared with short-pulse-duration, high-peak-power radiation, as made available by ruby lasers at 0.6943μ. Attempts were also made to close enamel pits and fissures in vitro by fusing synthetic hydroxyapatite to native enamel by using the CO_2 laser.

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Materials and Methods

Extracted human teeth with intact enamel surfaces were exposed to continuous CO_2 laser radiation at a wave length of 10.6μ. The power output of this laser was held constant at 20 watts by adjusting the excitation voltage and gas mixture.[5] The power was measured with a thermal equilibrium thermopile. The desired spot size was achieved by reflective focusing of the beam or by use of a lens.* Radiation at 10.6μ is not visible, so a helium-neon laser was used to determine the approximate focal point. The irradiation diameter at the tooth surface was varied from 1 to 4 mm, and duration of exposure ranged from 0.1 to 5.0 seconds. This resulted in power densities of the order of 150 to 2,400 watts/sq cm; total energy density varied from 15 to 12,000 joules/ sq cm.

The undecalcified irradiated teeth were embedded in plastic, and ground sections were prepared at 100μ to 120μ thickness by using thin-sectioning machine.† After microscopic examination under the phase-contrast microscope, ground sections were used for preparation of microradiographs. Contact microradiographs were made using spectroscopic plates‡ exposed under vacuum for 15 minutes at 18 kv and 10 ma, and developed§

* Irtran II, Eastman Kodak Company, Rochester, NY

† Gillings-Hamco, Hamco Machines Inc., Rochester, NY

‡ Kodak #649-0, Eastman Kodak Co., Rochester, NY

§ Kodak Developer D-19, Eastman Kodak Co., Rochester, NY for eight minutes prior to photographic fixation. The X-ray diffraction patterns of irradiated powdered enamel were also studied by using a 114-mm diameter camera‖ and Cu Kα radiation. Films were exposed at 35 kv and 10 ma for eight hours.

Results

The enamel in the region of exposure appeared fused, chalky white, and opaque. It was hard and brittle and fractured easily. There was no evidence of closure of the fissures, and the margins of the white, opaque material could be penetrated with an explorer. Both the region of irradiation and the surrounding region of the crown were hot to touch. The most representative observation of the gross findings is shown (Fig 1*A*). In this example, exit energy of the CO_2 laser beam was 20 watts, the estimated irradiation diameter was 1 mm, and the exposure time was of the order of 0.1 second. Multiple overlapping exposures to CO_2 laser beam irradiation, 0.1-second durations, were used over the length of the fissure.

Results of attempts to fuse synthetic hydroxyapatite to enamel fissures are shown (Fig 1*B*). The hydroxyapatite was dusted into the fissure to form a thin layer prior to laser radiation exposure. This was repeated several times between laser exposures. On completion of irradiation, this region appeared glazed, opaque and chalky white. The synthetic hydroxyapatite, however, was not completely fused to the enamel and was easily removed by scraping with an explorer. Occasionally, in isolated areas of the enamel surface, there appeared to be fusion of the hydroxyapatite to enamel.

The effect of irradiation as observed by phase-contrast microscopy of ground sections is shown (Fig 2). This section was selected from an enamel region adjacent to the fissure (Fig 1*A*) where fusion was attempted. Numerous cracks were observed extending from the enamel surface toward the dentinoenamel junction. There was generalized disruption of the enamel rod structure and incineration of the interrod substance. Occasionally, isolated areas of normal enamel were apparent (Fig 2).

In the region of the dentinoenamel junction (Fig 3), the cracks that originated at the enamel surface penetrated the dentin. Heavy dark lines represented changes in the interrod substance, and it appeared that lines of cleavage developed between groups of enamel rods. The odontoblastic process in dentinal tubules adjacent to the enamel were more prominent; large regions of dentin had changes similar to naturally occurring interglobular dentin, which suggested incineration of odontoblastic processes.

‖ Norelco-Debye Scherrer, Philips Electronic Instruments, Mt. Vernon, NY

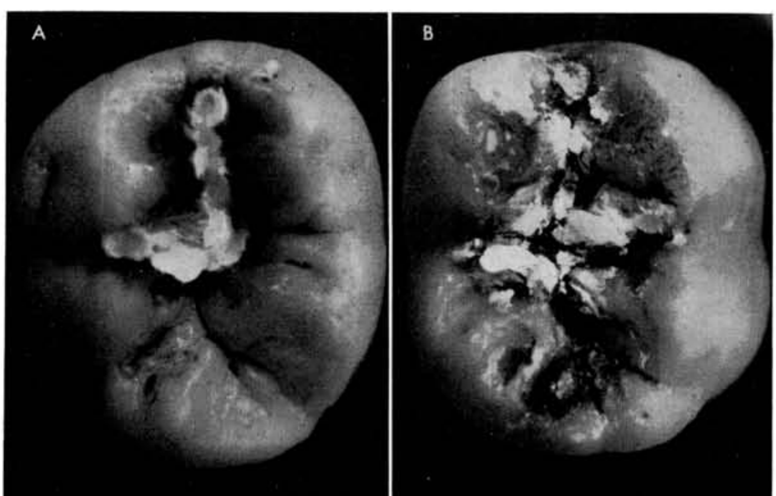

FIG 1.—*A*, Gross appearance of pits and fissure region after 0.1-second exposure to CO_2 laser beam irradiation. *B*, Gross appearance of pits and fissures dusted with hydroxyapatite prior to laser beam exposure.

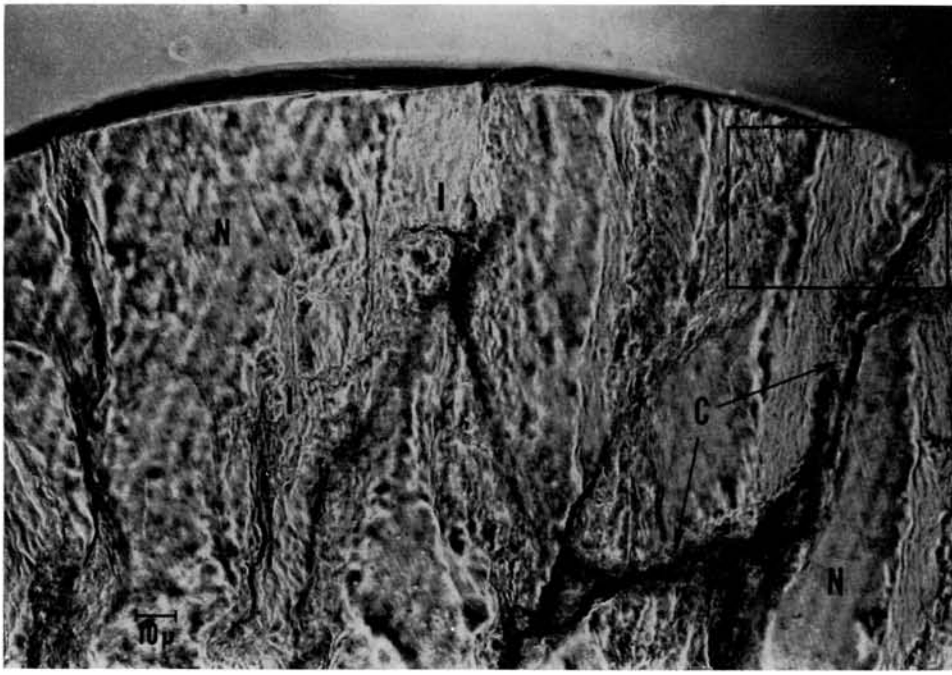

FIG 2.—Ground section of enamel region adjacent to the region of laser beam impact, examined by phase-contrast microscopy. A large number of cracks (*C*), incinerated (*I*) interrod substance, and disruption of enamel rod structure can be seen. Isolated regions of normal enamel (*N*) are visible (orig mag ×250).

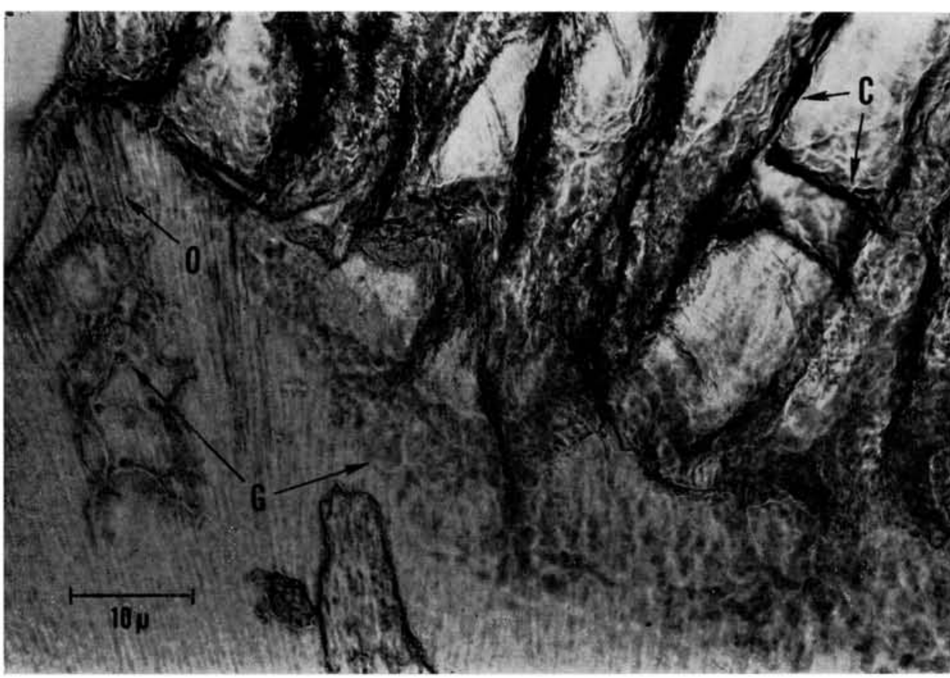

FIG 3.—Dentinoenamel junction of the ground section shown in Figure 2. There are enamel cracks (*C*) and incinerated interrod substance extending into this region. The odontoblastic process (*O*) in dentin show minor laser burns and regions similar to interglobular dentin (*G*) are apparent (orig mag ×400).

Enamel and dentin distant from the irradiation site were altered (Fig 4). Disrupted enamel rods were seen subjacent to a zone of normal enamel. Beginning as a crack, the enamel destruction terminated at the dentinoenamel junction, where the dentin structure appeared completely destroyed and burned. The dentin also had many prominent odontoblastic processes, which indicated minor laser burns.

Representative results of the attempt to fuse synthetic hydroxyapatite to enamel are shown (Fig 5) for a section of the tooth seen in Figure 1*B*. Regions of enamel showed partially disrupted rod structure and visible cross striations; adjacent enamel had been completely destroyed. At the surface, the synthetic hydroxyapatite appeared as a structureless mass. It was not possible to demonstrate fusion between enamel and the synthetic hydroxyapatite.

In a section of enamel some distance from the point of irradiation, zones of radiolucency extended from the surface of the enamel toward the dentinoenamel junction (Fig 6). It was still possible to distinguish the enamel rods structure in the altered zones. From these microradiographs, it was not possible to determine whether the radiolucency was due to disruption of the enamel rods or to loss of enamel proper. Some regions of enamel were unaffected.

The X-ray diffraction pattern of enamel exposed to CO_2 laser radiation (Fig 7*B*) was compared with that of normal enamel (Fig 7*A*) to determine if any changes in the hydroxyapatite structure of enamel had occurred after laser irradiation. The X-ray diffraction pattern of the powdered enamel sample after the CO_2 laser irradiation was essentially that of hydroxyapatite. However, weak foreign lines were seen at 7.26 angstroms, 6.32A, 5.74A, and 3.66A. These lines would be consistent with the presence of a small amount of α calcium orthophosphate in the irradiated enamel.

Discussion

The gross and microscopic findings of the changes resulting from the interaction of CW 10.6μ radiation with enamel and dentin were different from those occurring with pulsed

FIG 4.—Phase-contrast photomicrograph of a ground section of a region distant from the irradiation site. Disrupted and incinerated (*I*) enamel rods are underneath the zone of normal enamel (*N*). The odontoblastic processes (*O*) are affected, and dentin burn (*D*) is obvious (orig mag $\times 250$).

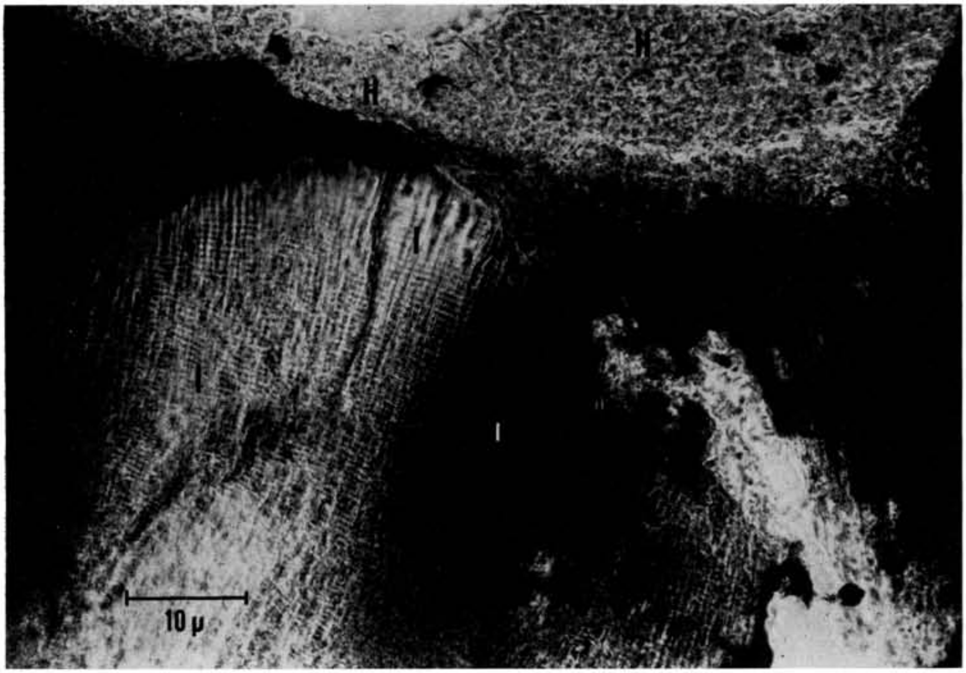

FIG 5.—Phase-contrast photomicrograph of the ground section of enamel pit and fissure region (same as Figure 1*B*), where fusion of synthetic hydroxyapatite (*H*) was attempted. Observe the disrupted enamel (*I*) and cross striations. No fusion between the enamel and hydroxyapatite can be seen (orig mag ×400).

FIG 6.—Contact microradiograph of a portion of the region shown in Figure 2. There is X-ray radiolucency in regions of enamel disruption and incineration of interrod substance (orig mag ×400).

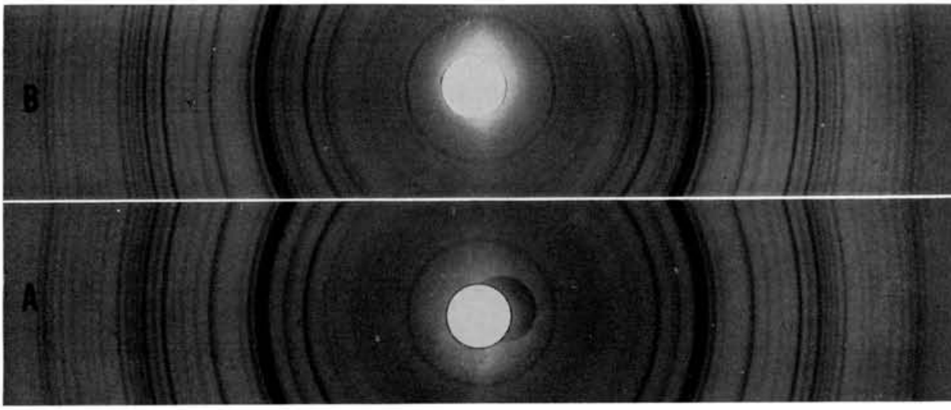

FIG 7.—*A*, The X-ray diffraction pattern of normal human enamel is that of hydroxyapatite. *B*, The X-ray diffraction pattern of human enamel after CO_2 laser irradiation shows lines compatable with the presence of α calcium orthophosphate.

radiation at 0.6943μ.[1-3] Cavitation was not produced by CW radiation, although the irradiation site and adjacent regions showed glazed, opaque, enamel surfaces similar to those produced by pulsed radiation. The absence of gross cavitation after CO_2 irradiation, under the conditions described, may be due to heat flow during irradiation. Other factors that must be considered, however, are the relative differences in absorption and scattering of radiation by these tissues at 10.6μ (CO_2 laser*) and 0.6943μ (ruby laser†).

The most distinct changes seen in the undecalcified ground sections were the disruption of enamel rod structure and the destruction of the interrod substance. Not only were there changes at the site of irradiation but, in contrast to the findings previously reported with pulsed ruby laser radiation,[1] these changes also occurred in enamel at numerous points distant to the irradiation site. The dentin also had severely damaged odontoblastic processes, which was not a finding in dentin of teeth exposed to pulsed ruby radiation. The interpretation of these findings must be considered relative to the possible mechanisms of laser interactions in biological systems. The mechanisms of interaction, as previously reported by Fine and Klein,[7] are summarized as: (1) Degradation of energy with the production of temperatures sufficient to cause thermal change. (2) Degradation of energy within a closed, filled cavity, resulting in transmission of pressure and possibly shock waves. (3) The production of sonic, ultrasonic, and hypersonic frequencies. (4) Effects due to alteration of wavelength and scattering of primary radiation. (5) Induction of photochemical reactions. (6) Formation of free radicals and light or heavy particles, charged or uncharged. (7) Formation of high electrical field gradients at high-peak-power densities.

The most likely mode of interaction of CW radiation with enamel and dentin is by heating and by the consequent production of high temperature.

The finding of charred regions of dentin in ground sections of the teeth would indicate temperatures sufficiently high to carbonize the organic matter in dentin. This was probably due to heat flow. In some instances (Fig 4), the charring was not continuous, but occurred below the dentinoenamel junction. This may have been due to direct irradiation of this region after microscopic fracture or disruption of the enamel rods.

The presence of α calcium orthophosphate in the irradiated enamel also is indicative of high transient temperatures at the irradiation site. It has been reported[6] that hydroxyapatite can be converted to α calcium orthophosphate if heated to temperatures approximating 1,400C.

These findings tend to support the conclusion that the changes observed were due to high temperature elevation at the site of interaction, together with heat flow from

* Designed and constructed by the Department of Bioengineering, Northeastern University, Boston, Mass.

† Maser Optics, Boston, Mass.

this region. Attempts to fuse synthetic hydroxyapatite to native enamel were not successful.

Conclusions

Teeth are markedly heterogeneous structures. The thermal properties of the components in each tissue will differ. To better understand the effects observed, studies of the thermal properties of the components of oral tissues are required. These studies should include investigation of the thermal capacity, thermal diffusivity, and thermal expansion coefficients of the various tissues.

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