From:
The Institute of Dentistry,
University of Turku, Finland

LASER-INDUCED EFFECTS ON TOOTH STRUCTURE
II. MICRORADIOGRAPHY AND POLARIZED LIGHT MICROSCOPY OF DENTAL ENAMEL AND DENTINE

by

ARJE SCHEININ
SIRKKA KANTOLA

INTRODUCTION

Previous reports have indicated that the physical and chemical properties of dental enamel and dentine might be altered due to the effects of a laser beam. *Stern et al.* (1966) found no significant differences in solubility between laser-exposed and laser-unexposed enamel surfaces. Laser beam exposures imparted, however, a degree of impermeability that reduced subsurface demineralization. These authors thus concluded that the observed resistance of laser-exposed enamel to subsurface demineralization seemed to result from alteration to permeability rather than in solubility.

Gordon (1967) observed fused tooth structure, cracking of dentine, plume condensation, and burning of enamel and dentine following application of energy densities up to 50.000 joules/cm^2. Further reports have included laser-induced glazing (*Varner et al.*, 1967) which may explain the similar x-ray diffraction pattern of laser-glazed enamel and unlased enamel (*Lobene & Fine*, 1966). Examination in polarized light has shown, however, definite changes in the refractive properties of the lased enamel bordering the enamel crater (*Peck & Peck*, 1967). These findings have suggested the presence of laser-induced crystallographic changes.

In spite of the previous studies on the laser-induced alterations in the dental hard tissues, as reported above, the effects are not yet fully under-

Received for publication, September 23, 1968.

stood. The present study was thus carried out in order to investigate, by means of microradiography and polarized light microscopy, the structure of dental enamel and dentine following intense lasing.

MATERIAL AND METHOD

The laser equipment and the tooth material were described in the first part of this study (*Scheinin & Kantola*, 1968). The lased teeth were embedded in methylmetacrylate, and ground sections of a thickness between 30 and 250 μm prepared. The microradiography was carried out by using a x-ray diffraction unit, model Philips 1008 (Philips, Eindhoven, Holland). All exposures were made by using Ni-filtered Cu-radiation on Kodak High

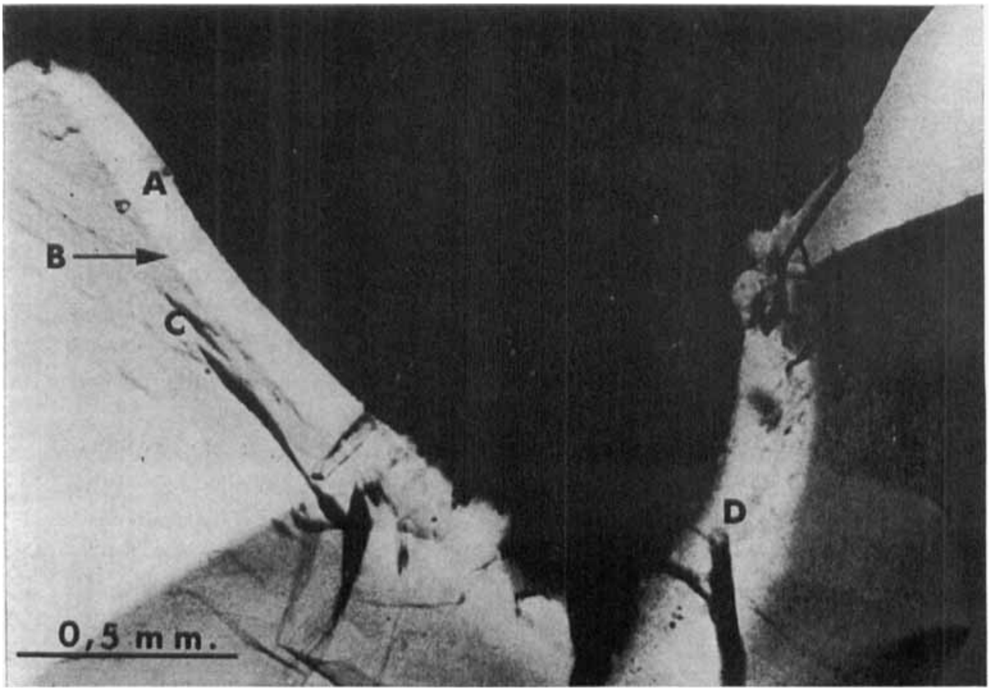


Fig. 1. Microradiograph of crater produced by application of focused infrared CO_2-laser radiation for 3 seconds.
A. Radiopaque surface enamel
B. Radiolucent zone
C. Subsurface enamel
D. Radiopaque dentine
Note the numerous fractures in enamel and dentine.

Resolution Plates, exposure time 5 hrs., at 25 KV, 18mA. The microscopic observations, including the microphotography of the microradiographs and the polarized light microscopy, were carried out by using a Reichert Zetopan-Pol microscope (Reichert, Vienna, Austria). The ground sections, embedded in water and subsequently in Canada balsam, were thus examined between crossed polarizing filters, and by using a gypsum compensator, first order. In addition, ordinary transmitted light microscopy was carried out.

RESULTS

The microradiographs and the corresponding ground sections were examined particularly in the laser-induced crater region. The results are shown in Figs. 1—5. Typical and persistant findings were:

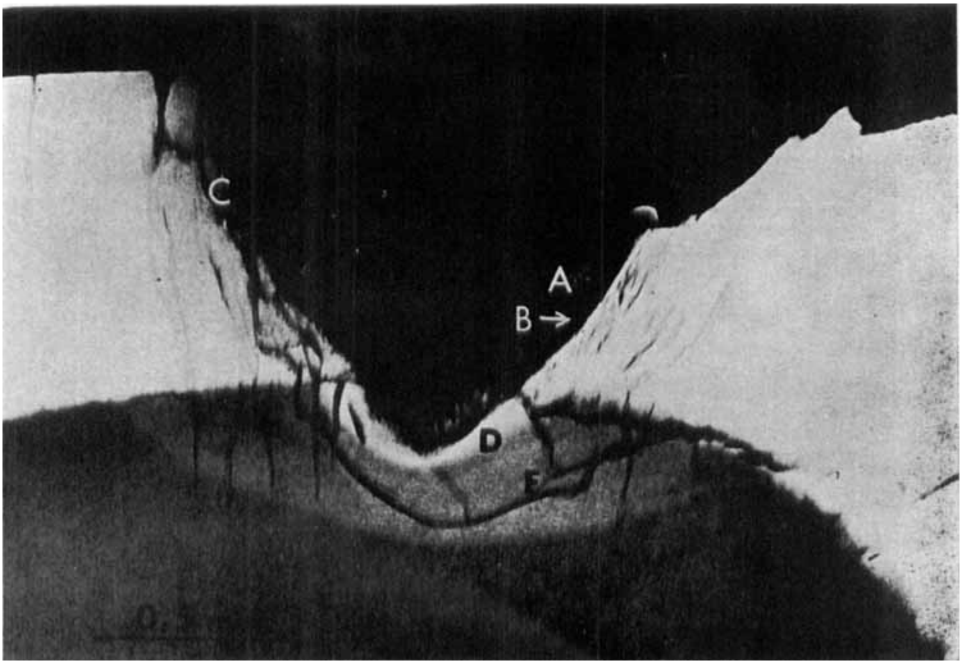


Fig. 2. Microradiograph of laser-induced crater. Lasing time 1 second.
A. Radiopaque surface enamel
B. Radiolucent zone
C. Radiolucent subsurface enamel
D. Outer radiopaque zone in dentine
E. Inner radiopaque zone in dentine

—A markedly increased radiopacity of lased, crater surface enamel (Fig. 1). This surface layer, forming also the elevated rim of the crater, was separated from the rest of the enamel by a narrow radiolucent zone. A different type of a less radiopaque enamel surface structure was also observed within the crater (Fig. 2).

—A decreased radiopacity of subsurface enamel (Fig. 1, 2, 3 A, B). In this region the x-ray absorption was even below that of the dentine (Fig. 3 A, B) and the structure displayed considerable irregularity.

—A markedly increased radiopacity of lased, crater surface dentine (Figs. 1, 2, 3 A, B, 4 A). In certain areas the radiopacity of lased dentine approached that of the enamel (Figs. 1, 2, 3 A, B) and was defined into two zones, the area bordering the enamel displaying high x-ray absorption (Figs. 2, 3 A, B, 4 A), and the adjacent inner zone being more radiopaque than normal, unlased dentine.

—A considerable number of fractures, both in the enamel and the dentine adjoining the craters (Figs. 1, 2 A, B, 3 A, B, 4 A, B, C).

—A severe carbonization of the organic constituents of enamel and dentine (Figs. 4 B—E, 5). The carbonized area corresponded roughly to those regions

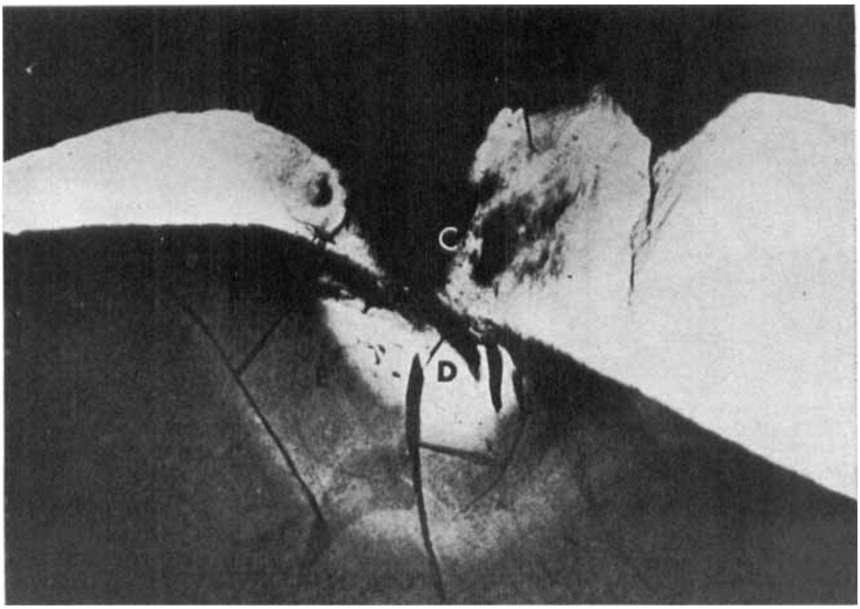


Fig. 3 A. Microradiograph of laser-induced crater. Lasing time 1 second. Abbreviations as in Fig. 2.

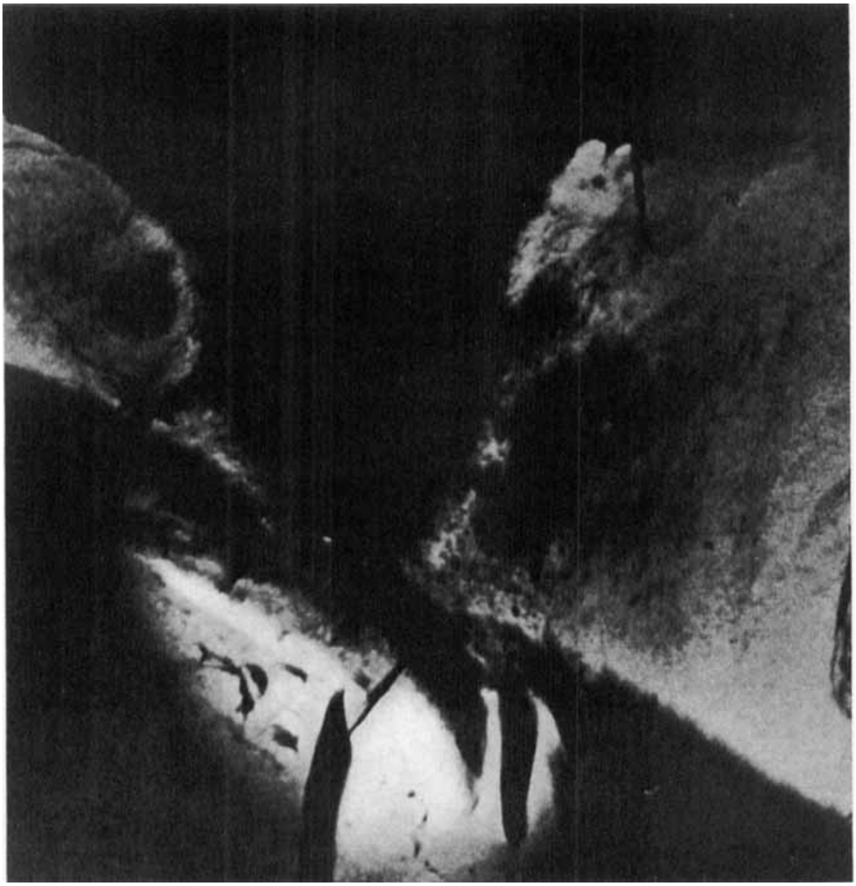


Fig. 3 B. Higher magnification of Fig. 3 A. Note the irregular structure of subsurface enamel.

of enamel and dentine exhibiting increased x-ray absorption, as seen by comparing the micrographs (Fig. 4 B—E) to the corresponding microradiograph (Fig. 4 A). The surface structure of the craters contained, however, less carbonized material than the subsurface layers (Fig. 4 C—D).

—An alteration in the birefringence of lased enamel and dentine. Unfortunately, due to the fracturing, the enamel part of the crater surface was not preserved for polarized light microscopy. The remaining parts of the crater surface enamel proved to be heavily carbonized, thus preventing the evaluation of the birefringence in this area. The subsurface enamel was characterized by a broad, positively birefringent zone followed by a narrow

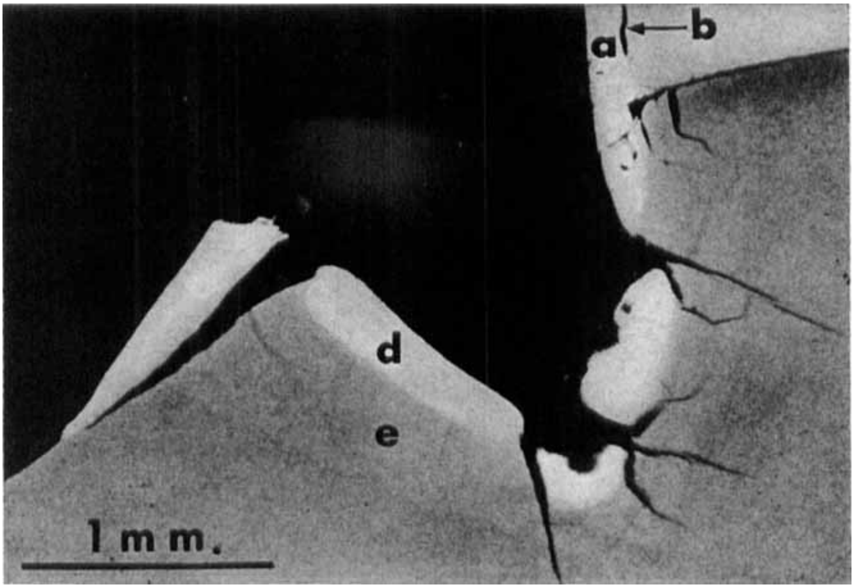
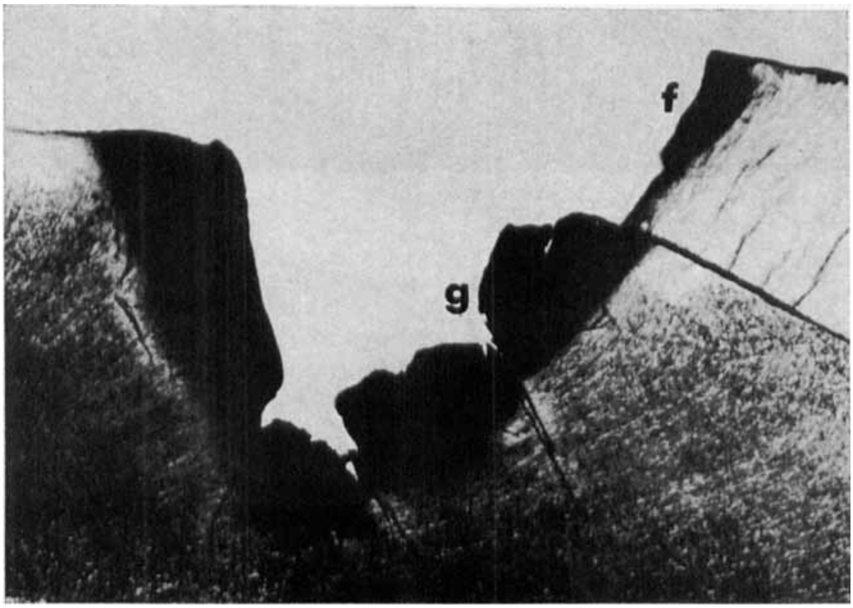
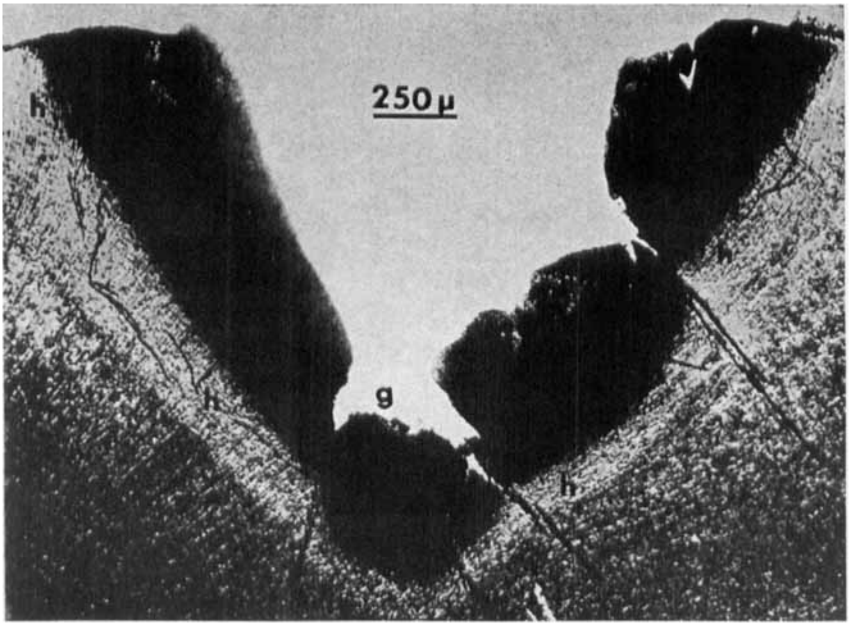


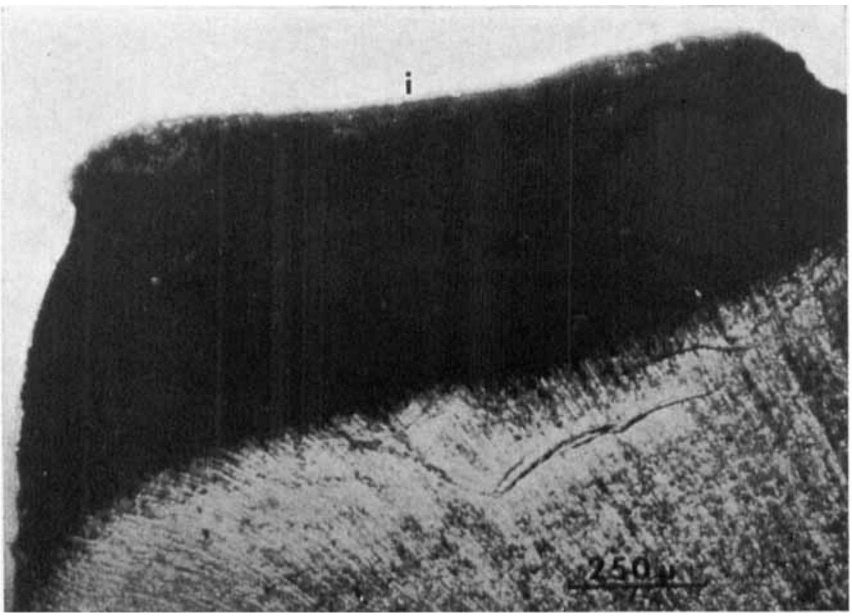
Fig. 4 —E.A Micrographs of laser-induced crater. Lasing time 2 seconds.
A. Microradiograph of lesion. Note radiopaque surface enamel (a), radiolucent zone (b), outer (d), and inner (e) radiopaque zones in dentine.



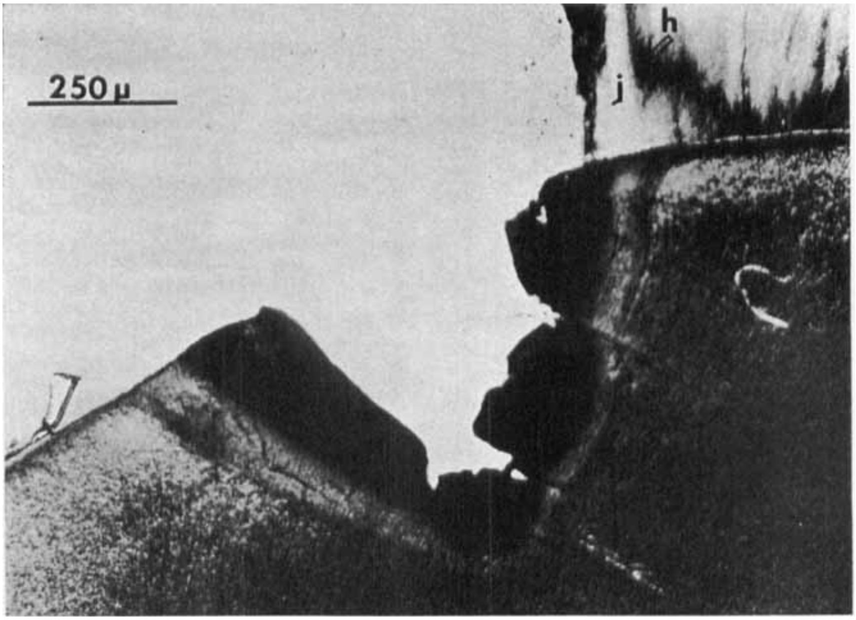
B. Microphotograph in ordinary transmitted light. Note carbonization of enamel (f) and dentine (g). Part of the enamel was lost when mounting the section.



C. Microphotograph in polarized light. Note carbonization of dentine (g) and pseudoisotropic zone (h).



D. Microphotograph in polarized light. Note the negative birefringence (i) and the homogeneous structure in the vicinity of the crater surface.



E. Microphotograph in polarized light. Note the pseudoisotropic zone (h) and the positively birefringent zone (j) in the enamel.

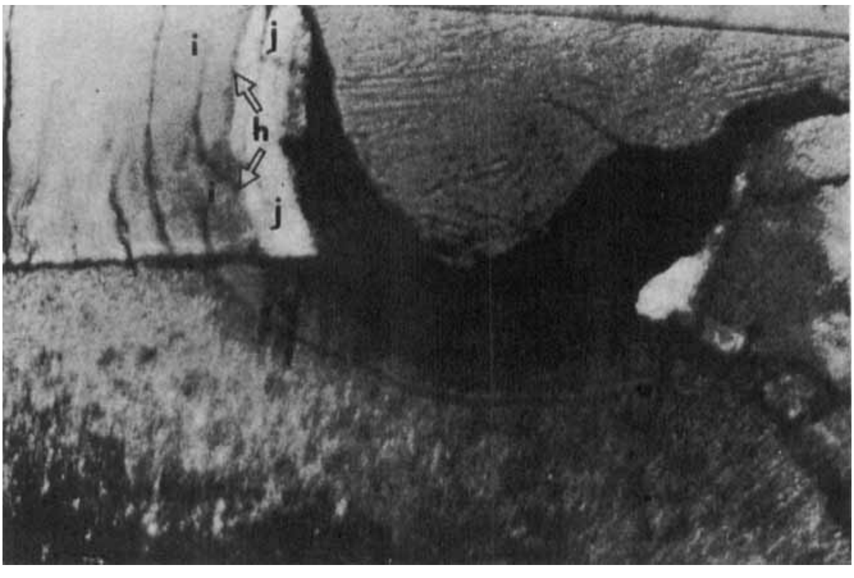


Fig. 5. Microphotograph in polarized light. Note the pseudoisotropic zone (h) separating the negatively birefringent (i) and positively birefringent (j) areas in the enamel. Compare to corresponding microradiograph (Fig. 2).

pseudoisotropic zone adjacent to the normal, negatively birefringent enamel (Figs. 4 E, 5).

In the dentine, normal unaltered structure was bordered by a pseudo-isotropic zone, followed by an area of carbonization in which the degree of birefringence could not be established. In the outermost layer of the carbonized area, however, strong negative birefringence was observed (Figs. 4 C, D). This was indicated by a dark-blue interference color in a rather homogeneous structure showing no signs of prisms or dentinal canals (Fig. 4 C, D).

DISCUSSION

The laser-induced macroscopic effects on enamel and dentine were reported in a separate paper (*Scheinin & Kantola*, 1968). The present communication deals thus with the corresponding microscopic effects, as estimated by means of microradiography and polarized light microscopy.

The assessment of changes in the microstructure of dental enamel was rendered difficult especially in the crater surface region. This was due to extensive fracturing as a consequence of the lasing. The preservation of the actual laser-induced crater surface was thus not insured in the enamel, except when the external rim of the crater was preserved. For this reason, the alterations in the surface structure of the enamel were evaluated only in restricted regions of the sections. The highly radiopaque surface including the rim of the crater, as seen in Fig. 1, was thus thought to be representative of the laser-induced effects in this region. On the other hand, a different type of a less radiopaque enamel surface structure was also observed (Fig. 2). Both aforementioned crater surfaces were considered to be the result of plume condensation and recrystallization, the variations in the mineral distribution being attributed to differences in the energy density in the target area. The distinct radiolucency of the lased subsurface enamel indicates the location where a considerable proportion of the hydroxyapatite was vaporized and/or melted.

No conclusions can be drawn on the surface structure alterations in the enamel by means of polarized light microscopy. This was partly due to the heavy carbonization of the enamel, and partly to the loss of these areas when preparing the specimens. On the other hand, polarized light microscopy revealed definite changes in the birefringence of dental enamel. The positively birefringent and pseudoisotropic areas thus found in the subsurface enamel indicates the regions with a reduced amount of ordinarily negatively birefringent crystallites. It should be noted, however, that the estimation of the degree of mineralization by means of polarized light microscopy was rendered uncertain, due to the carbonization of the organic stroma, and also due to the unknown crystallographic properties of recondensed and recrystallized hydroxyapatite. Further studies, by means of x-ray diffraction, will be carried out in order to reveal the structure of lased dental enamel.

The present findings show, however, that subsurface demineralization of the enamel was demonstrated both by microradiography and polarized light microscopy. An increase in the mineral content of surface enamel was verified by means of microradiography.

The laser-induced effects in the dentine were comprehensive, although in the first place, the natural outer surface of the enamel was subjected to the lasing. The most noticeable change was the remarkably high x-ray absorption in the peripheral dentine, indicating a high degree of mineralization in this zone. The hydroxyapatite of the enamel is considered to be the likely source of origin of this mineral, which due to the energy density of the laser beam was vaporized and/or melted and then forced into the dentine.

The formation of a second radiopaque zone in the dentine might be explained in a similar way. It is thus thought that the minerals in this case originated from the peripheral dentine, thus accounting for the difference in the degree of mineral content in these two zones. The development of an outer and inner hypermineralized zone in the dentine is thus readily explained by the transposition of minerals from the enamel and the dentine, respectively.

There was a good agreement between the findings by means of microradiography and polarized light microscopy, although the carbonization prevented the establishment of the degree of birefringence in the inner part of the outer, hypermineralized zone. The peripheral part of this area, forming the crater surface in the dentine, showed a strong negative birefringence and a lack of structural detail associated with enamel and dentine. This area was thus considered to consist of truly fused hydroxyapatite.

It might be argued whether the alterations in the microstructure of enamel and dentine, as caused by a continuously operating CO_2-laser, are comparable to the effects induced by focused ruby or neodymium laser pulses at microsecond speed. It was postulated, however, that the application of very high energy density would produce the most clear-cut effects, irrespectively of differences in wavelength and application time. The characteristic results, as obtained in the present study, will thus serve as a standard, especially when striving in future work to produce microstructural alterations without causing actual cratering.

Acknowledgment. The first author (A. S.) has received financial support from Finska Läkaresällskapet (The Linda Gadd Prize) and from the National Research Council for Medical Sciences of Finland. The authors are indebted to Mr. Jarmo Koskinen for the microphotography.

SUMMARY

The structural alterations, produced by a CO_2-laser in dental enamel and dentine, were investigated by means of microradiography and polarized light microscopy. An increase in the mineral content of surface enamel was verified through microradiography. In addition, considerable subsurface demineralization was demonstrated both by microradiography and polarized light microscopy.

The laser induced effects in the dentine involved the formation of two, hypermineralized zones. Fused tooth structure was observed at the site of the laser impact in the dentine.

RÉSUMÉ

EFFETS PRODUITS PAR LES LASERS SUR LES TISSUS DENTAIRES. II. ÉTUDE DE L'ÉMAIL DENTAIRE ET DE LA DENTINE PAR MICRORADIOGRAPHIE ET PAR MICROSCOPIE EN LUMIÈRE POLARISÉE

Les modifications de structure produites par un laser à CO_2 dans l'émail dentaire et dans la dentine ont été étudiées en utilisant la microradiographie et la microscopie en lumière polarisée. Une augmentation de la teneur en substances minérales à la surface de l'émail a été confirmée par microradiographie. De plus, une déminéralisation considérable au-dessous de la surface a été mise en évidence par microradiographie et par microscopie en lumière polarisée.

Les effets produits par le laser dans la dentine comprenaient la formation de deux zones hyperminéralisées. Des tissus dentaires fondus étaient observés à l'endroit ou le faisceau du laser frappait la dentine.

ZUSAMMENFASSUNG

EINWIRKUNGEN DER LASER-BESTRAHLUNG AUF DIE ZAHNSTRUKTUR. II. MIKRORADIOGRAPHIE UND POLARISIERTE LICHTMIKROSKOPIE DES SCHMELZES UND DENTINS

Die durch CO_2-Laser bedingten Strukturveränderungen im Schmelz und im Dentin wurden mit Mikroradiographie und polarisierter Lichtmikroskopie untersucht. Mit der Mikroradiographie wurde eine Zunahme des Mineralgehaltes in Schmelzoberfläche festgelegt. Ausserdem wurde eine deutliche Demineralisation der tieferen Schicht sowohl durch Mikroradiographie als durch polarisierte Lichtmikroskopie demonstriert.

Als Folgeerscheinung der Laser-Bestrahlung entstanden im Dentin zwei hypermineralisierte Zonen. Eine verschmelzte Zahnstruktur wurde im Dentin an der von Laserstrahlen getroffenen Stelle festgestellt.

REFERENCES

Gordon, Jr. T. E., 1967: Single-surface cutting of normal tooth with ruby laser. J. Amer. Dent. Ass. *74*:601—606.

Lobene, R. R. & S. Fine, 1966: Interaction of laser radiation with oral hard tissues. J. Prosth. Dent. *16*:589—597.

Peck, S. & H. Peck, 1967: Laser radiation: Some specific dental effects and an evaluation of its potential in dentistry. J. Prosth. Dent. *17*:195—203.

Scheinin, A. & S. Kantola, 1968: Laser-induced effects on tooth structure. I. Crater production with a CO_2-laser. Acta odont. scand. *27*: 173—179

Stern, R. H., R. F. Sognnaes & F. Goodman, 1966: Laser effect on in vitro enamel permeability and solubility. J. Amer. Dent. Ass. *73*:838—843.

Varner, R. E., J. P. Jarabak, N. M. Phatak & T. Kinersly, 1967: Effect of different colored stains on laser microbeam impact sites on tooth enamel. J. Dent. Res. *46*:756.

Address:

Institute of Dentistry,
University of Turku,
Turku 3, Finland