Human Teeth With and Without Caries Studied by Laser Scattering, Fluorescence, and Absorption Spectroscopy*

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Abstract—**The visible elastic light scattering and fluorescence emission from carious and noncarious regions of teeth were measured and compared. Carious teeth regions scattered light less effectively than noncarious regions for the spectral region 480–600 nm. The spectral shape of the fluorescence excited by a coherent source was similar to emission produced by incoherent (lamp) excitation. For both modes of excitation the emission peaks at approximately 550 nm. Differences in the fluorescence and light scattering spectra from carious and noncarious regions at a given wavelength was found not to be constant across the spectrum. Laser-induced fluorescence spectra for gamma irradiated teeth (total dose of 2000 rad) showed differences from control samples; the emission was blue shifted relative to the unirradiated samples. In addition, the relative visible absorption spectra for a tooth was measured in the visible region.**

I. Introduction

OPTICAL and laser technology offers techniques for the detection and characterization of physical and chemical changes which occur in calcified tissue. The light energy lost from the incident beam upon its interaction with matter can be dissipated in a variety of radiative and nonradiative processes, such as luminescence, absorption, internal conversion, photochemical processes, and light scattering. Recently, differences in the visible luminescence spectra of carious and noncarious regions of teeth was found [1]. Here we report the first measurements of the visible elastic light scattering [2]-[5] from human teeth with and without caries. Our results demonstrate that carious teeth regions scatter more light for a wavelength greater than 560 nm compared to noncarious regions. We also report the fluorescence spectrum for gamma irradiated teeth. In the latter study, our interest was motivated by the possibility that if differences in the fluorescence response between radiated and controls samples were observed then spectral characterization of teeth could probably serve as a biological dosimeter. At the high doses investigated (2000 rad) differences in the fluorescence spectra between irradiated and control teeth were detected.

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II. Materials and Methods

For unirradiated samples three different experimental methods were employed: light scattering, fluorescence, and absorption. For gamma irradiated teeth only the fluorescence spectrum for laser excitation at 488 nm was measured. The caries regions appeared red to orange in color.

A. Light Scattering

To measure the visible elastic light-scattered spectrum from teeth, quasi-monochromatic light from a tungsten source dispersed with a grating monochromator was focused on a tooth. Excitation wavelengths ranged from 400 to 700 nm. The spectral width of the exciting source was 10 nm. The elastic-scattered nonspecularly reflected light from the front surface of a tooth was collected into a double Spex-1/2 meter scanning spectrometer blazed at 500 nm. A photomultiplier tube (PMT) RCA 7265 (S-20) located at the exit slit of the spectrometer measured the intensity at different scattered wavelengths. The output of the PMT was connected to a Princeton Applied Research lock-in amplifier recorder combination to display the scattered intensity at each wavelength. Light scattered from a scatter plate was used to calibrate the spectral response of the system.

B. Fluorescence

The samples were excited by either light from a tungsten source or a laser at 488 nm. A narrow band filter of 10 nm bandwidth was placed in front of the sources. The beam size of the lamp and laser were set approximately to 2 mm in diameter. The fluorescence spectrum was measured with the same detection system described in Section I-A.

C. Absorption

Teeth were cut with a diamond saw into thin pieces in order that light be easily transmitted. Light from a tungsten source was focused onto the thinnest part of the example, which had a thickness of about $\frac{1}{2}$ mm. Both enamel and dentine were measured. The transmitted light was detected using the system as described in Section I-A. The relative absorption spectra was calculated using Beer's Law.

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D. Irradiated Samples

Gamma irradiation was performed on freshly extracted teeth not containing caries. Each of the four teeth studied was split longitudinally into approximately two equal parts of which one served as the control. The teeth were first cleaned in distilled water, dried with tissues and then placed in test tubes containing enough water for submersion. Samples were bilaterally ^{60}Co irradiated in an ice-bath at a dose rate of 521 rad/min and dried before measurements were made. Fluorescence spectral measurements were performed at ambient temperatures on samples both before and after irradiation. The laser beam was focused on the same tooth region.

III. Results

A. Light Scattering

Typical light-scattered spectra measured from carious and noncarious regions on the same tooth for two different teeth are displayed in Figs. 1(a) and 2(a). The difference between scattered intensities from noncarious and carious regions are displayed in Figs. 1(b) and 2(b). Normalizing the peak of the scattered spectrum of the cavity equal to the peak of the noncavity at 530 nm [shown in Fig. 1(c)] and correcting for the spectral response of the detection system, we find that carious regions (relatively) scattered more light in the red region than noncarious regions with respect to the peak (at 530 nm) as is displayed in Fig. 1(d). For different teeth investigated, the scattered intensities from carious lesions were found to be smaller by 0.8 to 5 times of the intensities from the same size noncarious regions. The sizes of caries regions ranged from 0.5 to 3 mm.

B. Fluorescence

Typical fluorescence spectra of teeth excited at 488 nm by noncoherent (lamp) and coherent (laser) beams are shown in Figs. 3 and 4, respectively. It is evident that differences, at a given wavelength, in the intensities of fluorescence between noncarious and carious spectra varies across the spectrum. The spectra normalized to the peak of each spectrum at a wavelength of 550 nm are shown in Figs. 5 and 6. The normalized spectrals curves show that more light is emitted from caries in the red portion of the spectrum relative to the fluorescence peak. This result is consistent with our light scattering data described in Section III-A. The fluorescence most likely arises from traps of unknown origin. Fig. 7 illustrates more distinctly the comparison of the normalized fluorescence spectra for both laser and lamp excitation at 488 nm. Although laser-induced fluorescence is more enhanced at longer a wavelength, as compared to incoherent excitation the spectral shapes are observed to be quite similar.

C. Absorption

Typical absorption spectrum measured from a thinly sliced noncarious tooth is shown in Fig. 8. There is a sharp decrease in absorption towards the red end of the spectra with a slight increase near 750 nm. The apparent absorption by the tooth is due to absorption and light scattering. The absorption near 750 nm probably arises from traps and also from con-

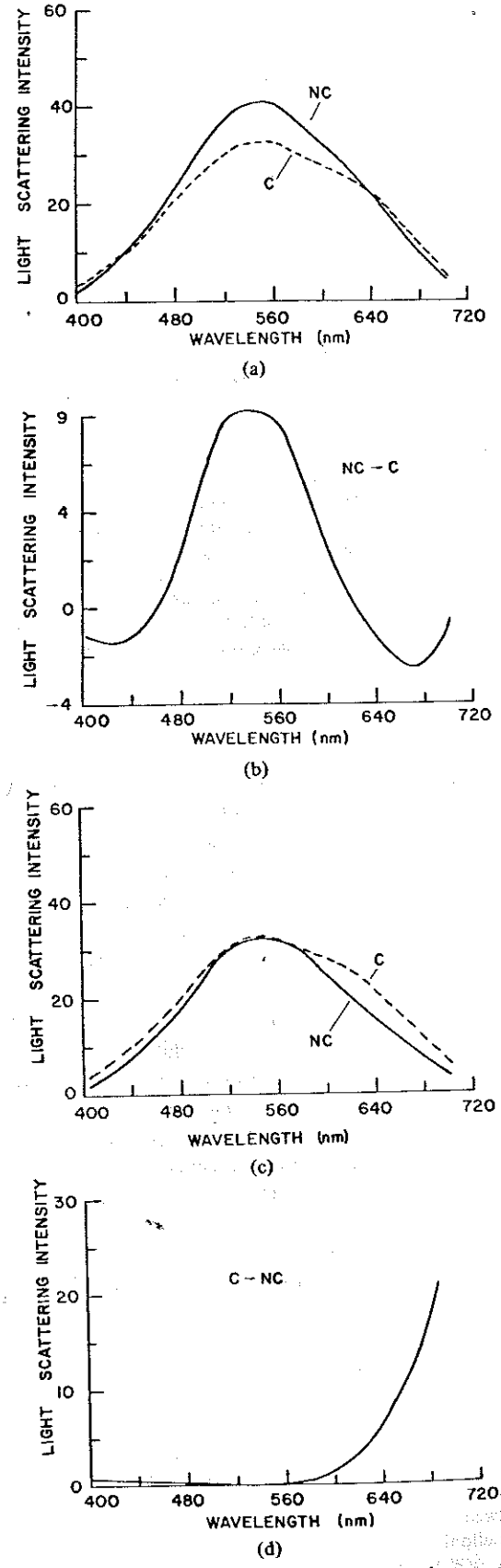

Fig. 1. (a) The light-scattered spectra from noncarious and carious regions. (b) The difference between noncarious and carious spectra. (c) Scattered spectra of caries and noncaries set equal at 530 nm to peak of each spectrum. (d) The difference between caries and noncaries spectra after correcting for detection system for (c) (tooth number 3).

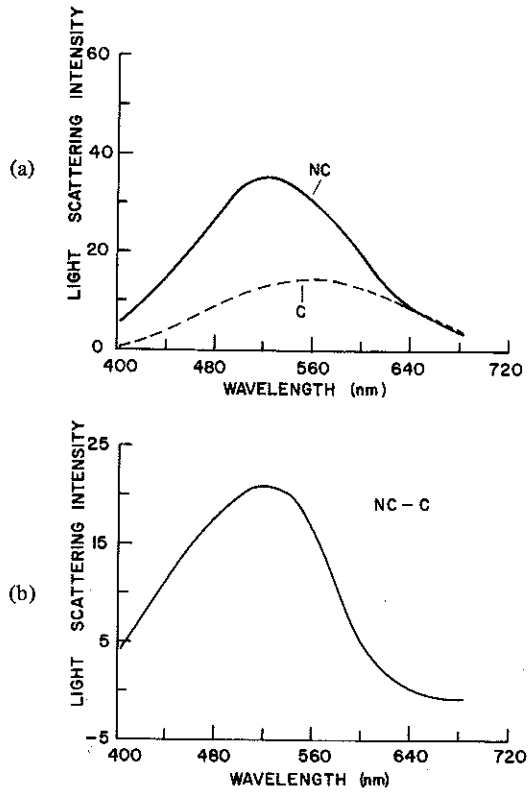

Fig. 2. (a) The light scattered spectra from noncarious and carious regions. (b) The difference between noncarious and carious spectra (tooth number 4).

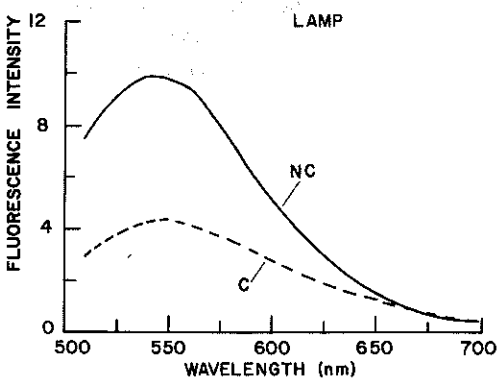

Fig. 3. The fluorescence intensity emitted from carious and noncarious regions excited by lamp radiation at 488 nm (full scale 10 mV).

tribution from the absorption tail due to the proteins. The increase at a shorter wavelength is presumably due to the amino acid constitutes of the sample.

D. Irradiation Samples

The fluorescence intensity versus emission wavelength for ^{60}Co irradiated tooth (sample B1) is shown together with its corresponding-control (sample A1) in Fig. 9. Similar spectra were obtained for all four teeth studied. Fig. 10 shows the difference spectra between the normalized spectra for an irradiated tooth minus its nonirradiation control. Observable differences in the emission are clearly evident. In particular, the peaks of the fluorescence emission from irradiated teeth are blue shifted by 10 to 70 A compared to emission from control samples of the same tooth. Presumably the number

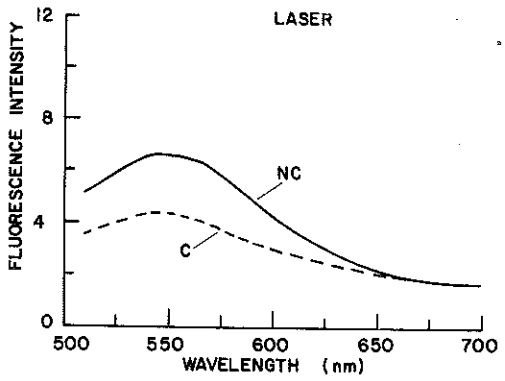

Fig. 4. The fluorescence intensity emitted from carious and noncarious regions excited by laser radiation at 488 nm (the same tooth as in Fig. 3). The fluorescence signal is approximately 20 times more intense than the lamp signal (full scale at 200 mV).

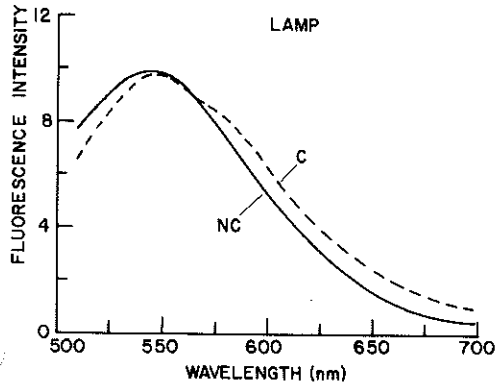

Fig. 5. The caries lesion spectrum normalized to the peak of noncarious region excited by radiation from lamp at 488 nm (full scale at 10 mV).

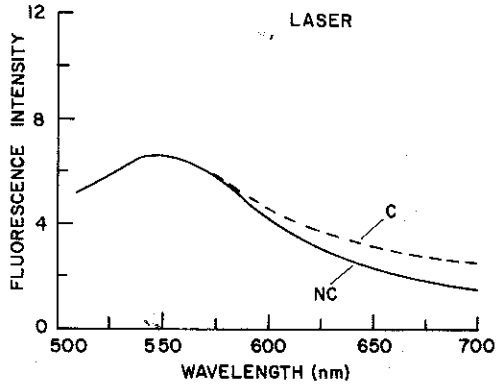

Fig. 6. The caries lesion spectrum normalized to the peak of noncarious region excited by radiation from the laser at 488 nm.

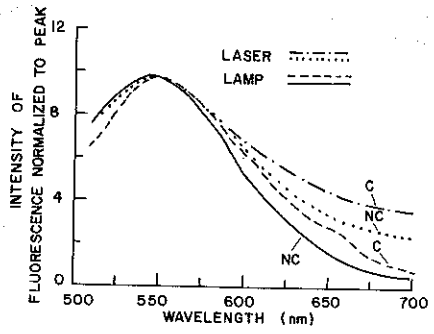

Fig. 7. Comparison between fluorescence spectra excited by lamp and laser radiation. The spectra were normalized to the peak at 550 nm.

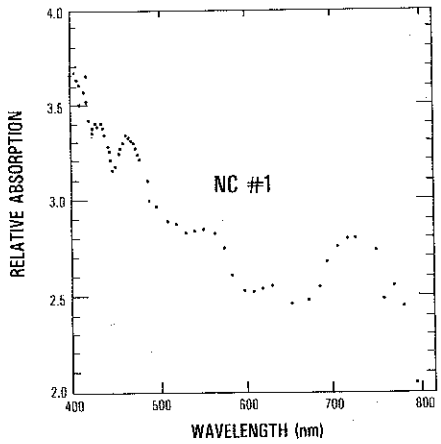

Fig. 8. Relative absorption spectrum for a noncarious tooth.

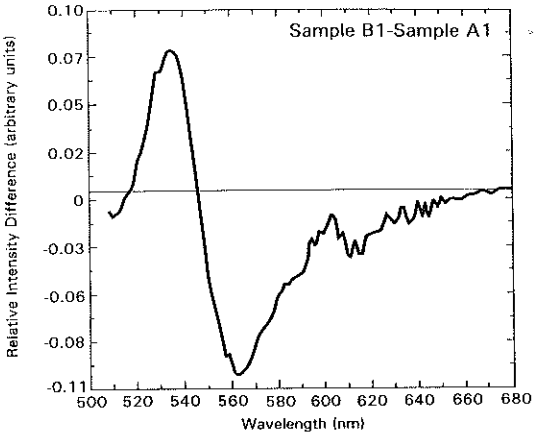

Fig. 10. Normalized difference spectra for the tooth in Fig. 9.

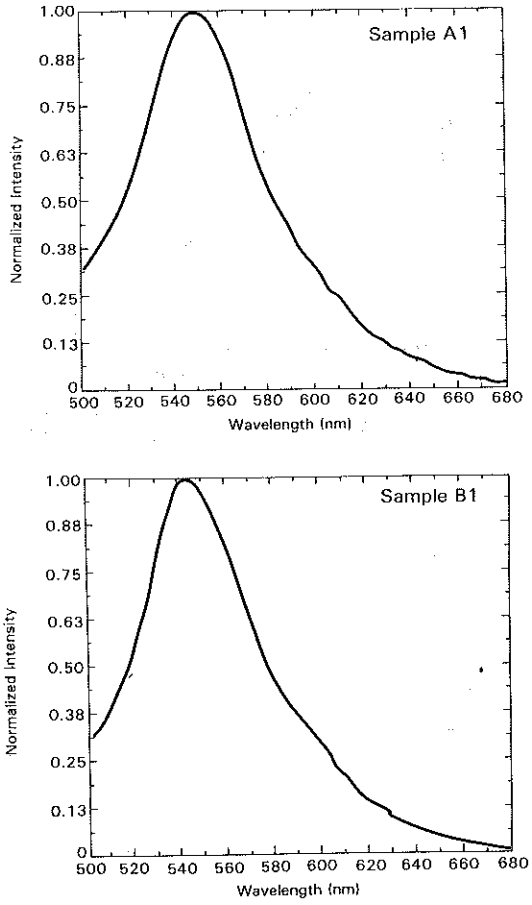

Fig. 9. Typical fluorescence spectrum of a gamma irradiated tooth at 2000 rad and a nonexposed control tooth. Sample A1 and sample B1 denote, respectively, the control tooth sample and the corresponding irradiated tooth. Laser excitation wavelength, 488 nm. Both curves were normalized at the peaks of unity.

of fluorescent color centers produced in the irradiated samples is high enough to be detected at the highest irradiation doses investigated. The microscopic nature of these traps produced in the UV region is not known. Current research is directed towards a measurement of the trap emission lifetime and their radiation dose dependence.

IV. Conclusion

The scattering and fluorescence measurements indicate that the carious region scatters and emits light differently than adjacent noncarious regions in the visible spectral region. We conclude from our light scattering and fluorescence measurements that caries emit more red light relative to its peak than adjacent noncarious regions; a result traceable to the fact that caries absorb more light than noncarious regions in the 400–600 nm spectral domain as indicated by reduction in the scattered light. Our optical techniques may offer a method to observe incipient decay by measuring changes in the fluorescence or scattering intensities and changes in the spectral shapes emitted by a carious region as compared to adjacent noncarious regions [6]. These optical techniques are quite sensitive since they are microscopic in origin and therefore may allow for early detection of decay and preventive maintenance. If the origin of the fluorescence from tooth (or bone) was understood at the molecular level perhaps a better understanding of the process of dental caries (and bone disease) would be reached. The observed difference in the emission spectra for gamma irradiated teeth is tentatively attributed to irradiation-induced color centers and traps. Future studies will focus on the measurement of the emission lifetimes of these induced center. The study of both fluorescence lifetime and emissions at different wavelengths of an irradiated tooth could serve as its own control.

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[6] R. R. Alfano, U.S. patent (pending).

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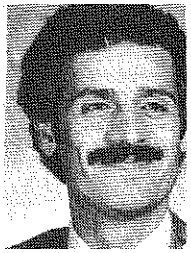

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