

DOUBLE TEETH

family history of this dental anomaly. The immediate family members of Case 1 were examined and no dental anomalies were found.

The reported prevalence of double teeth is varied with little data available on their prevalence in the primary dentition (Brook and Winter, 1970; Hagman, 1988). Of the 5,230 referrals examined only five patients presented with double teeth suggesting a prevalence within this orthodontic population of 0.1%, which is similar to reported data on general population groups in studies by Grahnen and Granath (1961) and Boyne (1955). The premolar location of the anomaly was an unexpected finding. Little data could be found on premolar double teeth. In Duncan and Helpin's (1987) review of double teeth no reference was made to premolar teeth. The most common location for double teeth was in the incisor and canine region (Brook and Winter, 1970; Duncan and Helpin, 1987). Instances of premolar double teeth are unusual. Brook and Winter (1970) cited Boucher (1948), who reported a patient with double teeth involving a mandibular canine and premolar. Bennett (1931) reported a second premolar union with a supernumerary tooth while Colyer and Sprawson (1942) reported a premolar double tooth, which was similar to the type of double teeth found in this study. While all three cases in this study were female, no trend was found in relation to premolar tooth or location. First and second premolars presented with this anomaly, in addition to both a mandibular and maxillary location.

SUMMARY AND CONCLUSION

In conclusion, the number of premolar double teeth in patients referred to the Eastern Health Board Regional Orthodontic Department, Ireland, was low. The gemination type double teeth were of little aesthetic or functional significance. This study suggests that the predominance of premolar geminated teeth over incisor geminated teeth may have been due to the concerns of the referring dentist about occlusion rather than aesthetics. Thus, the referrals were made to an orthodontic service. Further study of the Eastern Health Board's general population is necessary to ascertain the exact prevalence of this dental anomaly, in addition to the factors influencing referral by general dental practitioners.

LITERATURE CITED

- Bennett N (1931) *The Science and Practice of Dental Surgery*, 2nd edit Vol. 1, London: Oxford University Press, pp.115-121.
Boucher SP (1948) Fusion of lower incisors and lower canine and first premolar. *Brit. Dent. J.* 85:103.
Boyne PJ (1955) Gemination report of two cases. *J. Am. Dent. Assoc.* 50:194.
Brook A H, and Winter GB (1970) Double Teeth; A retrospective study of 'geminated' and 'fused' teeth in children. *Brit. Dent. J.* 129: 123-131.
Colyer JF, and Sprawson E (1942) *Dental Surgery and Pathology*, 8th edit. London: Longmans, Green & Co.
Curzon HA, and Curzon MEJ (1967) Congenital dental anomalies in a group of British Columbian children. *Canad. Dent. Assoc.* 33:554-558.
Duncan WK, and Helpin ML (1987) Bilateral fusion and gemination: a literature analysis and case report. *Oral Surg. Oral Med. Oral Path.* 64:82-87.
Gellin ME (1984) The distribution of anomalies of the primary anterior teeth and their effect on the permanent successors. *Dent. Clin. North Am.* 28(1):69-80.
Grahnen H, and Granath LE (1961) Numerical variations in primary dentition and their correlation with the permanent dentition. *Odont. Revy.* 12:341-357.
Hagman FT (1985) Fused primary teeth: a documented familial report of case. *J. Dent. Child.* 52:459-460.
Hagman FT (1988) Anomalies of form and number, fused primary teeth, a correlation of the dentitions. *J. Dent. Child.* 55:359-61.
Levitas TC (1965) Gemination, fusion, twinning and concrescence. *J. Dent. Child.* 32:93-100.
Moody E, and Montgomery LB (1934) Hereditary tendencies in tooth formation. *J. Am. Dent. Assoc.* 21:1774-1776.
Morris DO (1992) Fusion of mandibular third and supernumerary fourth molars. *Dent. Update* 19:177-178.
Niswander JD, and Sujaku C (1963) Congenital anomalies of teeth in Japanese Children. *Am. J. Phys. Anthropol.* 21:569-574.
Smith GA (1980) Double teeth. *Brit. Dent. J.* 148:163-164.

ANALYSIS OF THE OPTICAL PROPERTIES OF MEDIEVAL ENAMEL

LJILJANA TIHAČEK-ŠOJIĆ¹ AND MARJA DJURIĆ-SREJIĆ²

Faculty of Stomatology, Clinic of Prosthetic Dentistry, Rankeova 4, 11000 Belgrade, Yugoslavia,¹ and Faculty of Medicine, Department of Anatomy, Laboratory of Anthropology, Dr Subotića 4/2, 11000 Belgrade, Yugoslavia.²

ABSTRACT The purpose of the study was to investigate the differences in the optical properties of samples of intact, abraded, and reduced enamel. The optical properties of medieval enamel were compared to the results obtained from studies of enamel of contemporary populations in order to investigate the structural changes of enamel due to the effect of diagenesis (destructive changes, which affect interred bone). Reduced enamel (artificially removed superficial layer of the enamel) was used as a comparative sample for the study of abraded enamel.

The dental material was obtained from the medieval cemetery site of Stara Torina located in northern Serbia. Micro-morphological analysis was conducted using a polarized light microscope. Based on the results, we can demonstrate that 1) the birefringence value of the mature medieval enamel sample ranges from 0.3 to 0.4, which means that medieval enamel has retained its optical properties, although some changes in the inorganic components were found; 2) the mature intact enamel and abraded enamel have a negative optical sign, which is the same as that found in immature enamel; and 3) the mature reduced enamel changes its optical sign due to the phenomena of bending of the surface enamel prisms from 0.7 mm to 0.9 mm. This change of the optical sign results from a rise in temperature during the reduction process and from a diffusion of "non-oriented" molecules. The increased pressure on the enamel during the reduction process causes the bending of the surface part of the enamel prisms. The presence of pigmentation and carious changes in the abraded enamel and ground enamel also indicated the process of diffusion of different molecules, which occurred while the enamel was buried in the soil, as well as during the lifetime of the individual.



Fig. 1. Intact enamel under the polarization microscope. Well-formed clear enamel prisms of different position and of negative optical sign can be perceived (with an analyzer and a gypsum plate at 37X magnification).

The presence of pigmentation and carious changes in the abraded enamel and ground enamel also indicated the process of diffusion of different molecules, which occurred while the enamel was buried in the soil, as well as during the lifetime of the individual.

INTRODUCTION

Micro-morphological analysis of enamel can be done by using the polarizing light microscope (PLM) and by observing changes in its optic properties. Information can be obtained on its structure, such as the position and direction of the enamel prisms, as well as the maturity of enamel. During maturation enamel loses its inorganic components. This leaves no evidence in the structure, but causes changes in the optical properties of the enamel.

The optical properties of teeth have been studied since the nineteenth century. Valentin (1861) first noticed birefringence (double refraction, which is the difference between the maximal refractive index and the minimal refractive index) of the enamel. He argued that birefringence of the enamel is considerably stronger than that found in dentin or cementum. Valentin (1961) also found negative elongation of the enamel prisms in the direction of its long axis. Hoppe (1962) observed that prisms of mature enamel show a negative optical sign in man and other mammals, while developing enamel varies in optical sign from positive to negative. The phenomenon of the change of the optical sign can be seen following the direction of the prisms. Hoppe (1962) concluded that enamel prisms are uniaxial with the optical axis of the negative beam parallel with the long axis of the prism; more exactly, to the elongation of the prism. Schmidt (1925) also noted the change of the optical sign in developing dental enamel. Cape and Kitschin (1930) showed the values of the common beam (n_o), the uncommon beam (n_e), and the birefringence ($n_o - n_e$) of the natural minerals, apatites, and dental enamel (Table 1). On the basis of radiographic study, the authors concluded that changes of the optical sign of enamel represent a consequence of two different inorganic components persisting within its structure. These are hydroxyl apatite ($\text{Ca}_5(\text{PO}_4)_3\text{OH}$) and carbonate apatite ($\text{Ca}_5(\text{PO}_4)_3\text{CO}_3$). They display the same X-ray diagram, but an opposite optical character and birefringence of differing strengths. The positive of these is dominant in the first stages of development; the negative one gradually becomes predominant as the enamel matures.

Allan (1959a,b) found that the intrinsic birefringence of hydroxyl apatite may be modified by heating due to the thermal movement of the molecules and the changing of its orientation. Non-oriented liquids would only change their refractive index, which falls as the temperature rises. Calstrom (1962) has analyzed birefringence of mineralogous apatite and found that it is higher (-0.007) (approximately double) than the observed birefringence of enamel (-0.003 to -0.004). Results of later investigations deal with changes of the optical properties of the enamel caused by microabrasion (Waggoner *et al.*, 1989; Segura, 1991; Willis and Arbuckle, 1992; Segura, *et al.*, 1993; Stampe, *et al.*, 1993; Chan *et al.*, 1995).



Fig. 2. Abraded enamel under the polarization microscope. The occurrence of pigmentation in the enamel: top) on the surface of abraded enamel (without the analyzer at 42X magnification), center) on the surface and in the enamel itself (with the analyzer at 42X magnification), bottom) on the surface and in the enamel without any change of optical sign (with the analyzer and the gypsum plate at 42X magnification).

AIM OF THE STUDY

In the present study the differences in the optical characteristics of samples of intact, abraded, and reduced enamel were analyzed. Intact enamel was obtained from archaeological material in order to investigate the influence of the diagenesis (changes in composition of inorganic components) of enamel and its structure. We believed that evidence of diagenesis could be seen only in the optical properties of enamel. Mechanically (artificially) reduced enamel was used to compare its optical properties with the properties of naturally abraded (worn) enamel resulting from the process of mastication.

MATERIALS

Twenty-one teeth from adult individuals, unearthed at the late medieval cemetery of Stara Torina located in the North of Serbia were examined in this study. Archaeological investigations of the necropolis indicate that the period of burial interment probably took place between the twelfth and the seventeenth centuries. Anthropological analysis of the skeletal remains of nearly 800 individuals is being done at the Laboratory for Anthropology. The material used in the study was divided into three categories: 1) samples of intact enamel (N=7) (Group A); 2) samples of abraded (horizontal, vertical and mixed cuts) enamel (N=7) (Group B); and 3) samples of intact reduced enamel (artificially removed superficial layer) (N=7) (Group C).

METHODS

Non-decalcified teeth were vertically cut using a low speed saw with a rotating circular disk impregnated with diamond dust. Enamel sections were mounted in Canadian balsam, which has a refractive index of 1.537, and placed on glass slides measuring 25mm x 50mm x 0.17mm.

To study the optical properties of enamel a polarizing light microscope (Reichert, Neovar, Pol) fitted with the following equipment was used: 1) a polarizer without an analyzer, which allows the light to pass through in one direction only, thus limiting the oscillation of the light to one plane; 2) a polarizer with an analyzer (Nikoli+), which allows only the light oscillating perpendicular to the first one to pass through, because the orientation of the oscillation planes of the polarizer and the analyzer is opposite to each other (The anisotropic crystals can only be seen with the crossed Nicol's.); 3) a cast tile or a gypsum plate which is

OPTICAL PROPERTIES OF MEDIEVAL ENAMEL

placed in the tube-slot of the microscope and orientated in the -45° position, which establishes a sign of optical elongation. Examination of the material was accomplished in three steps: 1) examination with a polarizer; 2) examination with a polarizer and an analyzer; and 3) examination with a gypsum plate. The three groups of specimens were analyzed at a magnification ratio of 40:1.

The strength of birefringence of the objects is obtained indirectly by determining the path difference (Δ) measured with a Berek's compensator. The experimental strength of the birefringence obtained can be obtained using the equation $(\epsilon - \omega) = \Delta/d$, where ϵ is the refractive index of the common beam; ω is the refractive index of the uncommon beam (anomalous dispersion); Δ is the path difference; and d is the thickness of the section of the object (from which the path difference is calculated). The difference between the maximum and minimum refractive index ($n_o - n_e$) gives the strength of birefringence (n_o is the common beam; n_e is the uncommon beam).

RESULTS

Significant differences in the optical properties of dentin, enamel, and cementum have been reported. Considerably stronger birefringence of the enamel in comparison with dentin was observed. Analysis of each group is given separately.

Group A - Samples of Intact Enamel

Examination with a polarizer (without an analyzer) demonstrated the presence of non-homogenous stained enamel with regions of bright and dark yellow color. The mature enamel is composed of prisms consisting of bundles of apatite crystals (from 0.3333 mm to 0.8325 mm in length and about 30 nm to 40 nm in diameter) oriented at right angles to the surface.

Examination with an analyzer (Nikoli+) revealed significant birefringence of enamel. Measured with a Berek's compensator, the birefringence value ranged from 0.0037 to 0.0400. Crystals of hydroxylapatite are elongated and oriented parallel with the relatively longer axis of the prisms. These prisms become somewhat bent toward the enamel surface. In addition, the optical axis of the crystal was incongruent from those of the prism's relatively longer axis, and differences from 0 to 20 were found, mostly in the peripheral zone of enamel.

Examination with a gypsum plate showed the optical sign of crystal elongation within the prisms to have mostly negative values. This is particularly in the peripheral zone of the enamel, as well as in the contact zone toward the dentin. The interference colors of those prisms appear bluish-white. An area of comparatively lower birefractance is commonly observed in the middle zone of the enamel. Intermittently crossed prisms of diazone and parazone with optically positive and negative birefractance occur in the middle zone of the enamel. Because of the tangential intersection of the parazone, which is cut toward the relatively longer axis of the tangential plane, its birefractance has a higher value than those of the diazone, which is cut transversely. Interference colors in this area are mostly abnormal: yellowish-brown and indigo-blue; that is, the manifest of dispersion of birefractance for different wavelengths in the visible part of the spectra (Fig. 1).

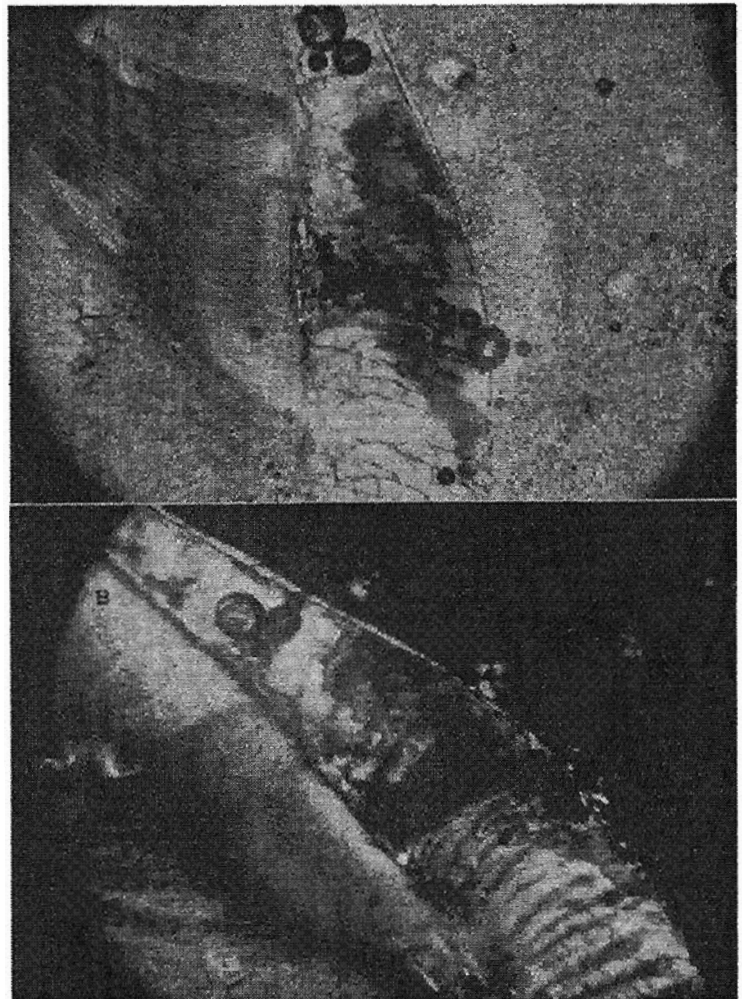


Fig. 3. The abraded enamel under the polarization microscope: top) distinct polychromy on the surface due to changes in the structure and chemical composition of the enamel (without the analyzer at 28X magnification); bottom) visible anomalous interferential colors on the surface of the changed enamel (with the analyzer at 28X magnification).

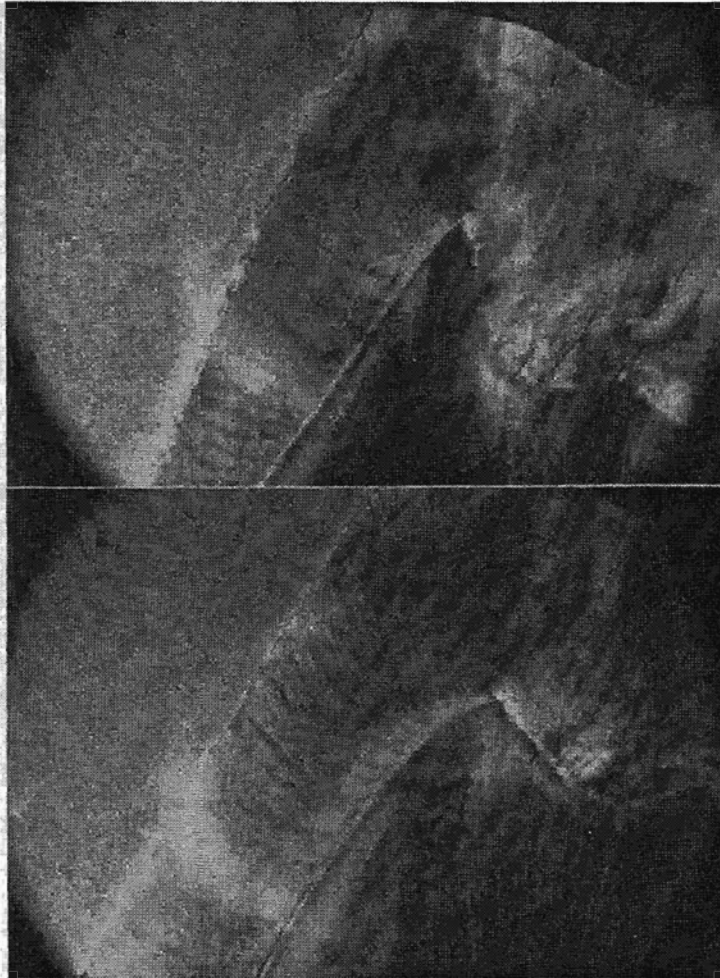


Fig. 4. The reduced enamel under the polarization microscope. On the surface of the reduced enamel tissue the following can be perceived: top) an intensive bending of enamel prisms and a change of the optical sign (with an analyzer and a gypsum plate at 25X magnification); and bottom) an intensive change of the optical sign that can be noticed through the occurrence of the blue interferential color on the enamel tissue (with an analyzer and a gypsum plate at 25X magnification).

Examination of the zones of carious lesions with an analyzer (Nikoli+) show these areas to be anomalies with the interference of colors evidenced, as well as brown-colored areas with intermittent positive and negative birefringence. In addition, anomalous yellowish-brown colors were observed in some dark zones of enamel (Fig. 3 bottom).

Group C - Samples of Ground Enamel

Examination of ground enamel with a polarizer and an analyzer (Nikoli+) indicated similarities with the observations obtained from the samples of intact enamel from Group A. Enamel prisms of those samples are sharp and clear.

Examination with a gypsum plate revealed that the optical sign of ground enamel is changed from that of intact enamel. The change in the optical sign is seen in a blue interferant color at the surface of the enamel. We believe that this change is due to the grinding of the enamel surface. Ends of prisms are bent or break during the grinding process (0.0730 mm to 0.0999 mm) (Fig. 4 top and bottom). In addition, negative elongated prisms were observed.

Group B - Samples of Abraded Enamel

Examination of abraded enamel with a polarizer without an analyzer revealed the presence of pigmentation in one areas of the surface, as well as beneath it (Fig. 2 top). Examination with a polarizer and an analyzer (Nikoli+) revealed oval-bordered grayish areas in regions of pigmented enamel. Prisms located under the abraded surfaces are orthogonally cut, which is also characteristic of corroded enamel (Fig. 2 center).

Examination with a gypsum plate revealed areas of pigmentations, as well as prisms cut orthogonally. However, the most important observation was the optical sign of abraded enamel. The abrasion process removes the surface layer of enamel, but the value of the optical sign and the optical elongation remains unchanged (negative) as the result of inner dual refraction of hydroxylapatite (Fig. 2 bottom).

In several cases carious lesions were found at the abraded surfaces. These cases were analyzed separately. Examination of the carious lesions with a polarizer (without an analyzer) showed that the polychromatic nature of the sample's surfaces resulted from the structural and chemical changes of the abraded enamel.

A brown color was observed in the area of a carious lesion indicating the existence of turbid media, which consists of at least two components with different indices of refraction (hydroxylapatite and gasses or liquids). Dichromatism and coloration of these zones indicate the high concentration of some element (iron in this case) which directly influences the absorption of some wavelengths in the visible part of the spectra. The zones of caries lesions are clearly visible in Fig. 3 top and bottom.

DISCUSSION

The enamel of the contemporary sample and the mature enamel of the medieval sample shows inner dual refraction of hydroxylapatite (a negative optical sign), which is interpreted to mean that the samples of enamel studied kept their optical properties during the long-term interment in the soil. Comparisons of the range of birefringence obtained in the study with the values of birefringence from Table 1 suggest that some changes in the composition of exhumed enamel occurred. The enamel that we examined consists mainly of fluorapatite ($\text{Ca}_5(\text{PO}_4)_3\text{F}$), while the range of hydroxyapatite (normally the main constituent of the inorganic component of enamel) was very low. This evidence suggests that teeth, once buried, undergo chemical reactions with the environment in which hydroxyl ions are replaced chemically by other ions such as fluoride. The process of substitution by the fluoride ion is still unclear and requires further research.



Fig. 5. Reduced enamel under the polarization microscope. Prisms are elongated in a negative way with distinct easy cutting of the reduced enamel tissue visible (with an analyzer and a gypsum plate at 63X magnification).

The loss of the surface enamel layer in abraded enamel did not change the optical sign. On the contrary, grinding of enamel resulted in the reverting of the optical sign, which was followed with bending of enamel prisms from 0.0730 mm to 0.0999 mm.

Changing of the optical sign of ground enamel is not a consequence of removal of the surface layer. This is confirmed by the absence of optical sign changes within abraded enamel, which also has undergone reduction of the surface layer. The changes in the optical sign are the result of exposure of enamel to heat by grinding. The heat induces the changes of the inner dual refraction of hydroxylapatite, causing movements of the molecules thermally and changing their orientation. Further diffusion of liquids with un-oriented molecules into the ground enamel leads to changes of the refraction index. Lowering of the index is proportional with the rising of the heat, consistent with the results of Allan (1959a,b).

Bending of the outer part of enamel prisms results from the high pressure developed by the grinding process, which allows prisms to be along their relatively longer axis. In the abraded enamel the mechanism of reduction is different, resulting from friction and pressure occurring over a comparatively longer period of time and under relatively less pressure without excessive heat. Such a mechanism results only with the possibility of cutting of prisms through their comparatively longer axis, which does not affect the optical sign. The parts of pigmented enamel discovered indicate the possibility of the diffusion of different molecules into the enamel.

CONCLUSIONS

Based on the evaluation of the results obtained from the analysis of the optical properties of intact, abraded, and ground enamel, we concluded the following:

1. Dental enamel from buried remains kept its optical properties. Birefringence of the mature enamel of medieval skeletons ranges from 0.0037 to 0.0040, which suggests some changes in the constituents of the inorganic components of the enamel.
2. Mature intact and abraded enamel shows a negative optical sign. Mature enamel, which has been artificially ground down, changes its optical sign to neutral or positive. Furthermore, bending of the outer parts of enamel prisms from 0.0730 mm to 0.0999 mm occurs. Changing of the optical sign is induced by the heat developed by grinding and the diffusion of un-oriented molecules into the ground enamel. Bending of the outer portion of enamel prisms is a consequence of the pressure produced by the grinding process.
3. Cutting of the prisms through their relatively longer axis, pigmentation, and carious lesions observed on the abraded and ground enamel indicate that processes of diffusion of various molecules are active while the enamel is buried in the soil, as well as during the lifetime of the person.

OPTICAL PROPERTIES OF MEDIEVAL ENAMEL

TABLE 1. Values of the common ray (n_o), the uncommon ray (n_e), and the birefringence ($n_o - n_e$) of natural minerals, apatites, and enamel as modified from Cape and Kitchin (1930).

Apatite	n_o	n_e	Birefringence
Fluorapatite ($\text{Ca}_5(\text{PO}_4)_3\text{F}$)	1.633-1.650	1.629-1.646	0.003-0.005
Hydroxyl apatite $\text{Ca}_5(\text{PO}_4)_3\text{OH}$	1.643-1.658	1.637-1.654	0.007-0.004
Carbonate apatite $\text{Ca}_5(\text{PO}_4)_3\text{CO}_3$	1.633-1.655	1.630-1.651	0.004-0.0043
Enamel	1.6277	1.6234	0.0043

- Chan D, Howell M, Carraway K, and Garcia-Godoy F (1995) Polarized and transmitted light microscopic study of enamel after microabrasion. *Quintessence International* 26:57-62.
- Hoppe F (1962) Untersuchungen über die Constitution des Zahnschmelzes. *Virchows Arch.* 24:13-32.
- Schmidt W (1925) Doppelbrechung und Feinbau des Zahnschmelzes, S. B. (1923-1925) Niederrhein. Ges. Natur-u. Heilk., Bonn, Nat. Abt. 1-19.
- Segura A (1991) Acid-abrasive enamel reduction for tooth color correction. *Amer. J. Dent.* 4:107-104.
- Segura A, Donly K, and Wefel J (1993) The effects of microabrasion on demineralization inhibition of enamel surfaces. *J. Dent. Res.* 72:272-318.
- Stampe W WE, Broome JC, Murchison DF, Rutledge RE, and Snell GM (1993) Rate of enamel loss with varied enamel microabrasion techniques. *J. Dent. Res.* 72:372-384.
- Valentin G (1861) Die Untersuchung der Pflanzen und der Thiergewebe in polarisiertem Licht. Leipzig.
- Waggoner W, Johnson W, Schumann S, and Schikowski E (1989) Microabrasion of human enamel in vitro using hydrochloric acid and pumice. *Pediatr. Dent.* 11:319-323.
- Willis G, and Arbuckle G (1992) Orthodontic decalcification management with microabrasion. *J. Indiana Dent. Assoc.* 71:16-19.

LITERATURE CITED

- Allan JH (1959a) The polarized light appearances of human dental enamel. *J. Dent. Res.* 38:60-66.
- Allan JH (1959b) Investigations into the mineralization pattern of human dental enamel. *J. Dent. Res.* 38:1096-1128.
- Cape A, and Kitchin P (1930) Histologic phenomena of tooth tissues as observed under polarized light with a roentgen-ray spectra of enamel and dentin. *J. Amer. Dent. Assoc.* 17:193-227.
- Carlström D (1962) Studies of the ultrastructure of dental enamel. III The birefringence of human enamel. *J. Ultrastruct. Res.* 8:1-29.

DENTAL ANTHROPOLOGY AT THE UNIVERSITY OF OREGON

GUY L. TASA¹ AND DEBBIE GUATELLI-STEINBERG²

State Museum of Anthropology, Museum of Natural History¹ and the Department of Anthropology,² 1224 University of Oregon, Eugene, OR 97403-1224, U.S.A.

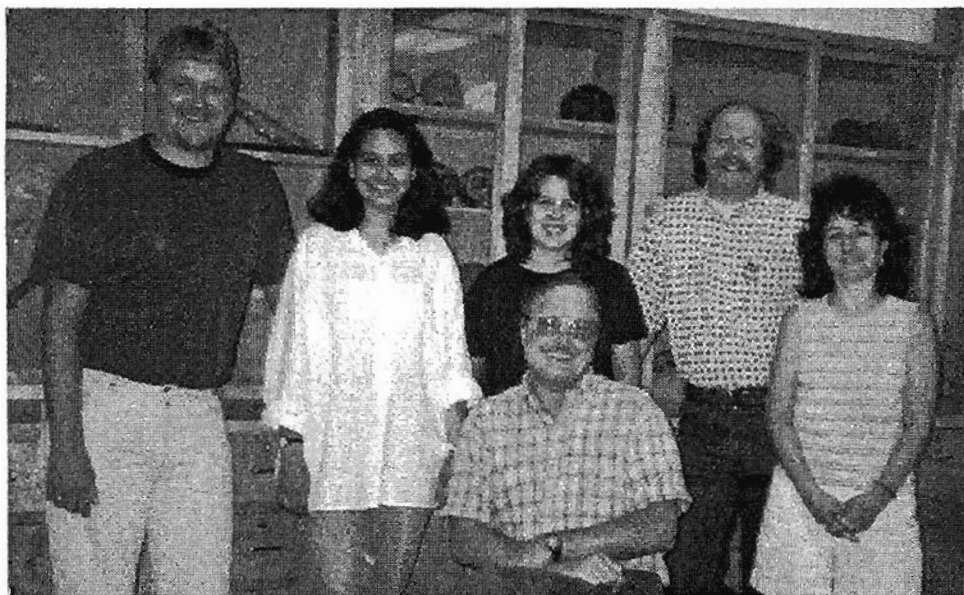


Fig. 1. Guy Tasa, Samantha Bhiladvala, Darcy Hannibal, Greg Nelson, Debbie Guatelli-Steinberg, and John Lukacs (sitting) in front of the teaching collections in the Department of Anthropology at the University of Oregon.

Dental anthropology continues to flourish at the University of Oregon (UO), with additions to skeletal collections and an increasingly diverse set of faculty and student research endeavors (Fig. 1). The UO's State Museum of Anthropology (SMA) and Department of Anthropology both house collections available for study. The SMA served as the state repository for Native American skeletal remains collected before the enactment of Oregon's Indian burial law, and, although most of the collection is slated for repatriation under NAGPRA (Native American Graves Protection Act) in the very near future, it is still available for analysis by qualified researchers. While conducting archaeological recovery projects for various agencies, the SMA also